(200)
QA
.U4.18, pt.4
1896-97

# EIGHTEENTH ANNUAL REPORT

OF THE

# UNITED STATES GEOLOGICAL SURVEY

TO THE

## SECRETARY OF THE INTERIOR

## 1896-97

---

CHARLES D. WALCOTT
DIRECTOR

---

IN FIVE PARTS

---

PART IV—HYDROGRAPHY

U.S. GEOLOGICAL SURVEY
140764
LIBRARY
MAY 6 1952

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

# EIGHTEENTH ANNUAL REPORT

OF THE

# UNITED STATES GEOLOGICAL SURVEY.

PART IV.—HYDROGRAPHY.

# CONTENTS.


Page.

DAVIS, A. P. Report of progress of stream measurements for the calendar year 1896 (Plates I-XXXII) ..... 13

LEVERETT, FRANK. The water resources of Indiana and Ohio (Plates XXXIII-XXXVII) ..... 419

DARTON, N. H. New developments in well boring and irrigation in South Dakota (Plates XXXVIII-XLVII) ..... 561

SCHUYLER, J. D. Water storage and construction of dams (Plates XLVIII-CII). 617

# LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
*Washington, June 1, 1897.*

SIR: I have the honor to transmit herewith the manuscript for a volume on hydrography, prepared for publication as one of the parts of the Eighteenth Annual Report of the Survey. This material consists of a report of the progress of stream measurements and related investigations carried on by the Division of Hydrography during the calendar year 1896, prepared by Mr. Arthur P. Davis, hydrographer in charge of river work, and three other papers whose character renders it desirable that they be printed in the Annual Report. The first of these is by Mr. Frank Leverett, assistant geologist, and relates to the water supply of Indiana and of the greater portion of Ohio. The observations upon which this paper is based were obtained during several years of field work pertaining to the study of glacial phenomena, carried on under the direction of Prof. T. C. Chamberlin. The information regarding the water resources is of such value that it seemed desirable to arrange and digest this for publication independently of the discussion of glacial phenomena. This was accordingly done by Mr. Leverett during the past year. The next paper has been prepared by Mr. N. H. Darton, assistant geologist, from the results of investigations carried on in Dakota during the season of 1896. This is essentially a continuation of his paper in the Seventeenth Annual Report, entitled "Preliminary report on artesian waters of a portion of the Dakotas." This later paper adds to the data previously presented and shows the results obtained by utilization in irrigation of the flowing wells. In this work Mr. Darton was assisted by Maj. Fred F. B. Coffin, formerly State engineer of irrigation of South Dakota.

With these papers has been included one by Mr. James D. Schuyler, of Los Angeles, California, whose name is identified with the planning and construction of some of the greatest irrigation works of the country. In 1896, as opportunity offered, he prepared this paper upon the

subject of storage reservoirs of the western part of the country. The demand for information of this character is so great and the paper is so notable, illustrating to the public the extent of development and the success attained in water conservation, that it is desirable to include it in the Annual Report.

Very respectfully,

F. H. NEWELL,
*Hydrographer in Charge.*

Hon. CHARLES D. WALCOTT,
*Director, United States Geological Survey.*

# INTRODUCTION.

The completion of this volume marks the revival of extended systematic investigation of the hydrography of the United States. This book is, in effect, the ninth annual report of what has been known as the Irrigation Survey. Its preparation and publication has been made possible by the act of June 11, 1896 (Stat. L., vol. 29, p. 436), which enlarged the scope of the work and authorized the preparation of reports upon the best methods of utilizing the water resources of arid and semiarid sections. For some years before this date the sums available for hydrographic work were so small that it was practicable merely to continue observations at previously established stations, compute discharges, and compile for publication the data accumulated in the office.

The act above referred to not only enabled the investigations to be carried on more thoroughly, but in a later paragraph (Stat. L., vol. 29, p. 453) gave authority for printing a new series of publications, limited in size to 100 pages and to an edition of 5,000 copies. This series, entitled, for distinction from the ordinary bulletins of this Survey, "Water-Supply and Irrigation Papers," affords an opportunity for the Division of Hydrography to put before the public, in a series of pamphlets published at short intervals, the results of investigations in various lines.

The hydrographic data obtained during past years are scattered through a number of publications. In order to facilitate reference to these, the following brief review is given of the progress of the investigation, showing in chronologic order the development of the work.

*First year, 1888–89.*—The Irrigation Survey was organized in accordance with the provisions of the act of October 2, 1888. The results of the first year's work are given in the Tenth Annual Report of the Geological Survey, Part II, Irrigation. This volume is devoted mainly to the details of organization and of the plans adopted and partly executed.

*Second year, 1889–90.*—The results of the operations outlined in the report just named are given in the Eleventh Annual Report, Part II, Irrigation. This contains a discussion of the hydrography and of the engineering surveys for canals and reservoirs, the statement of the Director of the Geological Survey to the House Committee on Irrigation, a report upon the topography, and a list of irrigation literature.

*Third year, 1890–91.*—The results of operations are given in the Twelfth Annual Report, Part II, Irrigation. This contains a statement of the location and survey of reservoir sites, by A. H. Thompson; a paper on the hydrography of the arid region, by F. H. Newell, and a discussion of irrigation in India, by Herbert M. Wilson.

*Fourth year, 1891–92.*—The discussion of results obtained is continued in the Thirteenth Annual Report, Part III, Irrigation. This consists of a paper upon water supply for irrigation, by F. H. Newell; two papers by Herbert M. Wilson, the first upon American irrigation engineering and the second upon the engineering results of the Irrigation Survey; and a report by A. H. Thompson upon the location and survey of reservoir sites during the fiscal year.

*Fifth year, 1892–93.*—The Fourteenth Annual Report, Part II, contains a paper entitled, "The Results of Stream Measurements," by F. H. Newell. With this are two others bearing upon hydrography, the first entitled "Potable Waters of Eastern United States," by W. J. McGee; the second, "Natural Mineral Waters of the United States," by A. C. Peale.

*Sixth year, 1893–94.*—The results of field work during this year are shown in Bulletin No. 131.

*Seventh year, 1894–95.*—The operations of this year are also shown in Bulletin No. 131. The Sixteenth Annual Report, Part II, contains a paper entitled "The Public Lands and Their Water Supply," by F. H. Newell. This gives in condensed form the results of hydrographic work in preceding years. There is also in the same volume a report on the "Water Resources of a Portion of the Great Plains," by Robert Hay.

*Eighth year, 1895–96.*—Bulletin No. 140, entitled "Report of Progress of the Division of Hydrography," gives the results of field work during the greater part of this year. The Seventeenth Annual Report contains a paper by G. K. Gilbert on the "Underground Waters of the Arkansas Valley in Eastern Colorado," one by Frank Leverett on the "Water Resources of Illinois," and another, by N. H. Darton, on "Artesian Waters of a Portion of the Dakotas."

*Ninth year, 1896–97.*—The report of progress of stream measurements is given in the present volume.

The general results of investigations of artesian and underground waters and of methods of utilizing the water resources are shown in the new series of Water-Supply and Irrigation Papers. Of these, 25 have been prepared, and a number have already been issued. The operations of the division are set forth in greater detail in the report of the Director, Part I of this Annual Report, pages 70–82.

F. H. N.

# REPORT OF PROGRESS OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1896.

BY

ARTHUR POWELL DAVIS.

# CONTENTS.


| | Page. |
|---|---|
| Introduction | 13 |
| Chesapeake watershed | 16 |
| Rowlandville station on Octoraro Creek | 16 |
| Woodstock station on Patapsco River | 16 |
| Laurel station on Patuxent River | 18 |
| Potomac Basin | 18 |
| Potomac River above Shenandoah River | 19 |
| Springfield station on South Branch | 19 |
| Cumberland station on Potomac River | 22 |
| Great Cacapon station on Potomac River | 25 |
| Shenandoah River | 25 |
| Port Republic station on North and South rivers | 25 |
| Millville station on Shenandoah River | 26 |
| Potomac River below Shenandoah River | 29 |
| Point of Rocks station on Potomac River | 29 |
| Frederick station on Monocacy River | 34 |
| Chain Bridge station on Potomac River | 35 |
| James River Basin | 36 |
| James River | 36 |
| Glasgow station on North River | 36 |
| Buchanan station on James River | 39 |
| South Atlantic watershed | 42 |
| Roanoke River | 42 |
| Roanoke station on Roanoke River | 42 |
| Clarksville station on Dan and Staunton rivers | 42 |
| Neal station on Roanoke River | 47 |
| Tar, Neuse, and Cape Fear rivers | 50 |
| Tarboro station on Tar River | 50 |
| Selma station on Neuse River | 52 |
| Fayetteville station on Cape Fear River | 54 |
| Yadkin River | 57 |
| Salisbury station on Yadkin River | 57 |
| Norwood station on Yadkin River | 60 |
| Catawba River | 61 |
| Rockhill station on Catawba River | 61 |
| Catawba station on Catawba River | 64 |
| Broad River | 65 |
| Gaffney station on Broad River | 65 |
| Alston station on Broad River | 67 |
| Saluda River | 68 |
| Waterloo station on Saluda River | 68 |
| General discussion of Georgia streams | 68 |
| Waterpower streams | 69 |

South Atlantic watershed—Continued. Page.
Okefenokee Swamp ... 71
Savannah Basin ... 72
Calhoun Falls station on Savannah River ... 73
Savannah River at Augusta, Georgia ... 75
Ogeechee Basin ... 77
Altamaha Basin ... 77
Carey station on Oconee River ... 78
Macon station on Ocmulgee River ... 79
Gulf of Mexico watershed ... 84
Apalachicola Basin ... 84
Oakdale station on Chattahoochee River ... 85
West Point station on Chattahoochee River ... 90
Miscellaneous discharge measurements ... 92
Mobile Basin ... 93
Canton station on Etowah River ... 94
Carters station on Coosawattee River ... 96
Resaca station on Oostanaula River ... 98
Riverside station on Coosa River ... 99
Lock No. 5 on Coosa River ... 101
Tuscaloosa station on Black Warrior River ... 103
Miscellaneous measurements ... 108
Texas streams ... 110
Ohio River tributaries ... 111
Kanawha Basin ... 111
Alderson station on Greenbrier River ... 111
Fayette station on New River ... 113
Tennessee Basin ... 116
Asheville station on French Broad River ... 116
Bryson station on Tuckaseegee River ... 116
Judson station on Little Tennessee River ... 117
Murphy station on Hiwassee River ... 118
Chattanooga station on Tennessee River ... 119
Miscellaneous measurements ... 123
Upper Missouri Basin ... 123
Townsend station on Missouri River ... 123
Gallatin River ... 124
Salesville station on West Gallatin River ... 124
Bozeman station on Middle Creek ... 127
Logan station on Gallatin River ... 128
Madison River ... 131
Three Forks station on Madison River ... 131
Jefferson River ... 135
Sappington station on Jefferson River ... 135
Yellowstone River ... 136
Sheridan station on Little Goose Creek ... 136
Sheridan station on Big Goose Creek ... 137
Buffalo station on Clear Creek ... 138
Platte Basin ... 141
North Platte River ... 141
Laramie River ... 142
Woods Landing station on Laramie River ... 145
Uva station on Laramie River ... 148
Orin Junction station on North Platte River ... 150
Camp Clarke station on North Platte River ... 153
North Platte station on North Platte River ... 156

Platte Basin—Continued. Page.
South Platte River ... 159
Deansbury station on South Platte River ... 159
Denver station on South Platte River ... 162
Orchard station on South Platte River ... 166
Morrison station on Bear Creek ... 167
Marshall station on South Boulder Creek ... 169
Boulder station on Boulder Creek ... 171
Lyons station on St. Vrain Creek ... 172
Arkins station on Big Thompson Creek ... 174
Loup River ... 176
St. Paul station on North Loup River ... 176
St. Paul station on Middle Loup River ... 179
Miscellaneous measurements ... 181
Columbus station on Loup River ... 182
Platte River ... 188
Columbus station on Platte River ... 188
Norfolk station on Elkhorn River ... 190
Miscellaneous measurements ... 193
Kansas Basin ... 194
Republican River ... 194
Haigler station on North Fork of Republican River ... 194
Wauneta station on Frenchman River ... 196
Palisade station on Frenchman River ... 197
Superior station on Republican River ... 199
Junction City station on Republican River ... 203
Measurements at points other than gaging stations ... 206
Smoky Hill River ... 207
Beloit station on Solomon River ... 207
Beverly station on Saline River ... 210
Ellsworth station on Smoky Hill River ... 212
Kansas River ... 215
Manhattan station on Blue River ... 215
Lecompton station on Kansas River ... 218
Lawrence station on Kansas River ... 219
Arkansas Basin ... 223
Arkansas River ... 223
Salida station on Arkansas River ... 224
Canyon station on Arkansas River ... 225
Pueblo station on Arkansas River ... 227
Little Fountain Creek ... 231
Trinidad station on Purgatoire River ... 231
Hutchinson station on Arkansas River ... 232
Verdigris and Neosho rivers ... 234
Liberty station on Verdigris River ... 235
Iola station on Neosho River ... 238
Medicine and Cimarron rivers ... 240
Kiowa station on Medicine River ... 240
Arkalon station on Cimarron River ... 243
Canadian River ... 245
Watrous station on Mora River ... 245
Rio Grande Basin ... 245
Del Norte station on Rio Grande ... 246
Embudo station on Rio Grande ... 248
Abiquiu station on Chama River ... 252
Rio Grande station on Rio Grande ... 252

Rio Grande Basin—Continued. Page.
San Marcial station on Rio Grande ..... 254
El Paso station on Rio Grande ..... 257
Colorado Basin ..... 260
Grand River ..... 260
Grand Junction station on Grand River ..... 260
Dolores station on Dolores River ..... 261
Fall Creek station on San Miguel River ..... 264
Fort Crawford station on Uncompahgre River ..... 265
Green River ..... 268
Granger station on Blacks Fork ..... 268
Greenriver City station on Green River ..... 272
Blake station on Green River ..... 275
San Juan River ..... 278
Arboles station on San Juan River ..... 279
Arboles station on Piedras River ..... 281
Durango station on Animas River ..... 283
Gila River ..... 286
Buttes station on Gila River ..... 286
Buttes reservoir on Gila River ..... 291
Whitlow station on Queen Creek ..... 292
Whitlow reservoir on Queen Creek ..... 295
Salt and Verde rivers ..... 297
Lower Colorado River ..... 298
Yuma station on Colorado River ..... 298
Interior Basin in Nevada ..... 299
Humboldt River ..... 299
Elko station on Humboldt River ..... 299
Battle Mountain station on Humboldt River ..... 302
Golconda station on Humboldt River ..... 303
Oreana station on Humboldt River ..... 306
Battle Mountain station on Rock Creek ..... 308
Mason's ranch station on South Fork of Humboldt River ..... 311
Interior Basin in Utah and Idaho ..... 311
Bear River ..... 311
Soda Springs station on Bear River ..... 312
Battle Creek station on Bear River ..... 313
South Fork of Little Bear River ..... 313
East Canyon Creek ..... 313
Blacksmith Fork ..... 313
Logan station on Logan River ..... 316
Measurements of Cub River ..... 318
Collinston station on Bear River ..... 319
Ogden, Weber, and Provo rivers ..... 321
Eden station on Ogden River ..... 321
Uinta station on Weber River ..... 323
Provo station on Provo River ..... 325
Utah Lake ..... 327
Columbia Basin ..... 330
Snake River ..... 330
Blackfoot River ..... 330
McCammon station on Portneuf River ..... 333
Montgomery station on Snake River ..... 334
Camas station on Little Camas Creek ..... 336
Taponis station on Malad and Little Wood rivers ..... 336

Columbia Basin—Continued.
Snake River—Continued. Page.
Grand View station on Bruneau River ... 339
Boise station on Boise River ... 340
Caldwell station on Boise River ... 344
Nyssa station on Owyhee River ... 346
Vale station on Malheur River ... 348
Payette station on Payette River ... 350
Weiser station on Weiser River ... 352
Yakima River ... 355
North Yakima station on Naches River ... 355
Yakima station on Yakima River ... 356
Kiona station on Yakima River ... 358
Spokane and Umatilla rivers ... 359
Spokane station on Spokane River ... 359
Gibbon station on Umatilla River ... 361
San Francisco Bay drainage ... 361
Sacramento River ... 361
Redbluff station on Sacramento River ... 362
Jellys Ferry station on Sacramento River ... 365
San Mateo Creek ... 370
Upper Crystal Springs and Pilarcitos-San Andreas reservoirs ... 370
San Joaquin River ... 371
Oakdale station on Stanislaus River ... 371
Salt Springs Valley Reservoir ... 375
Lagrange station on Tuolumne River ... 378
Modesto station on Tuolumne River ... 384
Herndon station on San Joaquin River ... 385
Red Mountain station on Kings River ... 390
Kingsburg station on Kings River ... 393
Kern River ... 395
Small lost creeks in southern California ... 397
San Emidio ranch house station on San Emidio Creek ... 397
Tejon ranch house station on Tejon House Creek ... 400
Palmdale station on Little Rock Creek ... 402
South Pacific Coast watershed ... 405
Azusa station on San Gabriel River ... 405
Warm Springs station on Santa Ana River ... 411
Los Angeles River ... 413
Sweetwater River ... 415
Sweetwater dam on Sweetwater River ... 415
Miscellaneous measurements ... 416
California rainfall data ... 418

# ILLUSTRATIONS.


| | | Page. |
|---|---|---|
| PLATE I. | Virginia drainage map | 36 |
| II. | Carolina drainage map | 48 |
| III. | Georgia drainage map | 70 |
| IV. | Discharge of Etowah River at Canton, Georgia, 1892–96 | 96 |
| V. | Discharge of Black Warrior River at Tuscaloosa, Alabama, 1889–1896 | 108 |
| VI. | Discharge of North Loup River at St. Paul, Nebraska, 1895–96 | 178 |
| VII. | Discharge of Middle Loup River at St. Paul, Nebraska, 1895–96 | 180 |
| VIII. | Gaging station on Middle Loup River at St. Paul, Nebraska | 182 |
| IX. | Discharge of Loup River at Columbus, Nebraska, 1895–96 | 184 |
| X. | Discharge of Platte River at Columbus, Nebraska, 1895–96 | 190 |
| XI. | Discharge of Republican River at Junction City, Kansas, 1895–96 | 204 |
| XII. | Discharge of Solomon River at Beloit, Kansas, 1895–96 | 210 |
| XIII. | Discharge of Saline River at Beverly, Kansas, 1895–96 | 212 |
| XIV. | Discharge of Arkansas River at Hutchinson, Kansas, 1895–96 | 234 |
| XV. | Discharge of Medicine River at Kiowa, Kansas, 1895–96 | 242 |
| XVI. | Embudo gaging station on the Rio Grande, New Mexico | 250 |
| XVII. | Rio Grande gaging station on the Rio Grande, New Mexico | 252 |
| XVIII. | San Marcial gaging station on the Rio Grande, New Mexico | 254 |
| XIX. | El Paso gaging station on the Rio Grande, Texas | 258 |
| XX. | Buttes reservoir site on Gila River, Arizona | 292 |
| XXI. | Whitlow reservoir site on Queen Creek, Arizona | 294 |
| XXII. | Reservoir dam site on Salt River from entrance of canyon | 296 |
| XXIII. | Discharge of Rio Verde above Salt River, 1895–96 | 298 |
| XXIV. | Discharge of Salt River above junction with Rio Verde, 1895–96 | 298 |
| XXV. | Head gates of Consolidated Canal on Salt River | 300 |
| XXVI. | Discharge of Bear River at Collinston, Utah, 1893–96 | 320 |
| XXVII. | Devil's Gate on Weber River, Utah, one-half mile below gaging station | 324 |
| XXVIII. | Provo station on Provo River, Utah | 326 |
| XXIX. | Reservoir site on Blackfoot River, Idaho | 332 |
| XXX. | Flumes and pressure pipe on Yakima Valley Canal | 356 |
| XXXI. | Jellys Ferry station on Sacramento River, California | 366 |
| XXXII. | Red Mountain station on Kings River, California, looking southeast | 392 |
| FIG. 1. | Discharge of Potomac River at Cumberland, Maryland, 1895–96 | 24 |
| 2. | Discharge of Shenandoah River at Millville, West Virginia, 1895–96 | 29 |
| 3. | Discharge of Potomac River at Point of Rocks, Maryland, 1895–96 | 33 |
| 4. | Discharge of North Fork of James River, Glasgow, Virginia, 1896 | 38 |
| 5. | Discharge of James River at Buchanan, Virginia, 1896 | 41 |
| 6. | Discharge of Cape Fear River at Fayetteville, North Carolina, 1896 | 57 |
| 7. | Discharge of Yadkin River at Salisbury, North Carolina, 1896 | 59 |
| 8. | Discharge of Catawba River at Rock Hill, South Carolina, 1896 | 63 |
| 9. | Gaging station near Calhoun Falls, South Carolina | 73 |
| 10. | Discharge of Ocmulgee River at Macon, Georgia, 1896 | 84 |

Page.

FIG. 11. Oakdale station on Chattahoochee River ..... 86
12. Discharge of Chattahoochee River at Oakdale, Georgia, 1895–96 ..... 89
13. Curves of current velocity and discharge of Coosa River at Lock No. 5, Georgia ..... 104
14. Discharge of New River at Fayette, West Virginia, 1896 ..... 115
15. Discharge of West Gallatin River near Salesville, Montana, 1896 ..... 126
16. Discharge of Gallatin River at Logan, Montana, 1895–96 ..... 130
17. Discharge of Madison River at Three Forks, Montana, 1896 ..... 134
18. Discharge of Clear Creek near Buffalo, Wyoming, 1896 ..... 141
19. Bridge across Laramie at Woods, Wyoming ..... 145
20. Looking up Laramie from bridge at Woods, Wyoming ..... 146
21. Discharge of Laramie River at Uva and Woods, Wyoming, 1896 ..... 148
22. Laramie River at Uva, Wyoming, above railroad bridge ..... 148
23. Laramie River wagon bridge at Uva, Wyoming ..... 150
24. Discharge of North Platte River at Orin, Wyoming, 1896 ..... 153
25. Discharge of South Platte River at Deansbury and Denver, Colorado, 1896 ..... 166
26. North Loup River near Burwell, Nebraska ..... 177
27. Gaging station on Loup River at Columbus, Nebraska, showing location of gage rod ..... 185
28. Looking north across south channel of Platte River near Columbus, Nebraska ..... 188
29. Discharge of Frenchman River at Palisade, Nebraska, 1896 ..... 200
30. Discharge of Smoky Hill River at Ellsworth, Kansas, 1895–96 ..... 215
31. Discharge of Blue River at Manhattan, Kansas, 1895–96 ..... 219
32. Discharge of Kansas River at Lawrence, Kansas, 1895–96 ..... 223
33. Discharge of Arkansas River at Pueblo, Colorado, 1895–96 ..... 231
34. Discharge of Rio Grande at Del Norte, Colorado, 1895–96 ..... 249
35. Discharge of Rio Grande at Embudo, New Mexico, 1895–96 ..... 251
36. Discharge of Rio Grande at Rio Grande, New Mexico, 1895–96 ..... 255
37. Cross section of Rio Grande at San Marcial, New Mexico ..... 257
38. Cross section of Rio Rrande at El Paso, Texas ..... 258
39. Discharge of Dolores River at Dolores, Colorado, 1895–96 ..... 264
40. Discharge of San Miguel River at Fall Creek, Colorado, 1895–96 ..... 266
41. Discharge of Uncompahgre River at Fort Crawford, Colorado, 1895–96. 268
42. Gaging station on Blacks Fork near Granger, Wyoming ..... 270
43. Discharge of Blacks Fork near Granger, Wyoming, 1896 ..... 272
44. Ferry on Green River at Greenriver City, Wyoming ..... 273
45. Discharge of Green River at Greenriver City, Wyoming, 1896 ..... 275
46. Discharge of Green River at Blake, Utah, 1895–96 ..... 279
47. Discharge of San Juan River at Arboles, Colorado, 1895–96 ..... 281
48. Discharge of Piedras River at Arboles, Colorado, 1895–96 ..... 283
49. Discharge of Animas River at Durango, Colorado, 1895–96 ..... 285
50. Discharge of Gila River at Buttes, Arizona, 1895–96 ..... 291
51. Discharge of Queen Creek at Whitlow's ranch, Arizona, 1896–97 ..... 295
52. Discharge of Humboldt River at Elko, Battle Mountain, Golconda, and Oreana, Nevada, 1896 ..... 309
53. Discharge of Bear River at Battle Creek, Idaho, 1893–1896 ..... 316
54. Discharge of Weber River at Devils Gate above Uinta, Utah, 1895–96 .. 325
55. Discharge of Provo River in Provo Canyon near Provo, Utah, 1893–1896 ..... 328
56. Discharge of Bruneau River near Grand View, Idaho, 1895–96 ..... 341
57. Discharge of Boise River above Boise, Idaho, 1895–96 ..... 344
58. Discharge of Sacramento River at Redbluff, California, 1895–96 ..... 366
59. Cross sections of Sacramento River at Jelly's Ferry, California ..... 367

Page.
FIG. 60. Rating curve for station at Jellys Ferry, California ..... 368
61. Discharge of Sacramento River at Jellys Ferry above Iron Canyon, California, 1895–96 ..... 369
62. Discharge of Stanislaus River at Oakdale, California, 1895–96 ..... 376
63. Lagrange dam ..... 378
64. Lagrange bridge, looking downstream ..... 379
65. Cross section of Tuolumne River at Lagrange bridge, California ..... 380
66. Rating curve for station at Lagrange bridge on Tuolumne River ..... 382
67. Discharge of Tuolumne River at Lagrange bridge, California, 1895–96 ..... 383
68. Discharge of Tuolumne River at Modesto, California, 1895–96 ..... 386
69. Sections of San Joaquin River at Herndon, California, showing changes in the bed ..... 387
70. Rating curve for Herndon station on San Joaquin River, California ..... 388
71. Gaging station on San Joaquin River at Herndon, California ..... 389
72. Discharge of San Joaquin River at Herndon, California, 1895–96 ..... 390
73. Railroad and wagon bridges across the San Joaquin River at the Herndon gaging station ..... 391
74. Discharge of Kings River at Red Mountain, California, 1896 ..... 393
75. Discharge of Kern River, California, at "first point of measurement" of Kern County Land Company, 1894–95 ..... 398

# REPORT OF PROGRESS OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1896.

By ARTHUR POWELL DAVIS.

## INTRODUCTION.

The measurement of streams by the Division of Hydrography during 1896 has been on a more extended scale and in the main of a somewhat higher degree of accuracy than before attempted. A few stations at which measurements were made in 1895 have been abandoned for sundry reasons, the chief of which is the ascertained impracticability of obtaining accurate results, due to the rapidly shifting character of the river bed or other causes. A larger number of new stations have been established, chiefly in the eastern States of Maryland, Georgia, Alabama, and the Carolinas.

There still remain in the list of stations maintained a few upon which success has not yet been attained in securing results of a sufficiently high grade of accuracy to give more than a general idea of the fluctuation of the stream flow. This is due to the changes of the stream beds, which are so rapid and erratic as to leave no ascertainable relation between the discharge of the river and either the cross section of the stream bed or the height of water on the gage rod. Instances of stations with these difficulties are found on the Great Plains and on the lower Rio Grande, Gila, and Colorado rivers. There appears to be no solution of this difficulty except by largely increasing the number and frequency of actual measurements of discharge. The policy has been, therefore, to abandon a few of the less important of such stations and to concentrate effort upon the rest. It is believed that this procedure will add greatly to the value of the results.

In most cases the hydrographic work has been under the immediate supervision of skilled hydrographers, engaged either in engineering instruction or in general practice, who have been employed by the day for only such time as actually engaged in the work of this division. Following is a list of the resident hydrographers, with the territory under charge of each:

California, J. B. Lippincott, civil engineer, Los Angeles.
Colorado, Fillmore Cogswell, deputy State engineer, Denver.

Georgia and Alabama, Prof. B. M. Hall, civil engineer, Atlanta.
Idaho, L. B. Kendall, United States deputy surveyor, Boise.
Kansas, eastern, Prof. E. C. Murphy, engineering department, State University, Lawrence.
Kansas, western, W. G. Russell, civil engineer, Russell.
Montana, Prof. Frank Beach, Agricultural Experiment Station, Bozeman.
Nebraska, Prof. O. V. P. Stout, engineering department, State University, Lincoln.
Nebraska, North Platte station, Charles P. Ross, civil engineer, North Platte.
Nevada, L. H. Taylor, civil engineer, Battle Mountain.
New Mexico, P. E. Harroun, civil engineer, Santa Fe.
North Carolina and South Carolina, Prof. J. A. Holmes, State geologist, Chapel Hill.
Utah, Prof. Samuel Fortier, State Agricultural College, Logan.
Virginia and West Virginia, Prof. D. C. Humphreys, Washington and Lee University, Lexington.
Wyoming, Elwood Mead, State engineer, Cheyenne.

Mr. Cyrus C. Babb, assistant hydrographer, has been occupied for a large portion of the year in traveling through the West, inspecting and repairing old stations and establishing new ones. Most of the measurements in the State of Maryland have been made by Mr. E. G. Paul, assistant hydrographer.

The amount of work undertaken with the moderate appropriation could not have been accomplished without the assistance and cooperation of many of the States in which work is carried on and of a large number of railroad companies from which courtesies have been received, and also of many State and college officials and private citizens who have been actuated by an interest in the work and a keen appreciation of the value of its results. Important cooperation has been extended by the following railroads:

Western and Atlantic Railroad; Atlanta, Knoxville and Northern Railroad; Seaboard Air Line; Atlanta, West Point and Western Railroad of Alabama; Georgia Railroad; Southern Railroad; Chesapeake and Ohio Railway; Norfolk and Western Railway; Denver and Rio Grande Railroad; Rio Grande and Southern Railroad; Colorado Midland Railroad; Union Pacific, Denver and Gulf Railroad; Atchison, Topeka and Santa Fe Railroad; Southern Pacific Company; Union Pacific Railway.

In the State of Maryland cooperation is extended by the State Weather Service through the courtesy and interest of Prof. W. B. Clark, State geologist, the State bureau paying the observers of river height on four stations.

Cooperation is also extended by the State of North Carolina through the geological department, which defrays a part of the expense of the work in that State.

In Georgia and Alabama arrangements have been made with Prof. William S. Yeates, State geologist of Georgia, and Dr. Eugene A. Smith, State geologist of Alabama, by which they pay the river observers at the gaging stations in their respective States and receive the data obtained for publication in their reports.

A similar arrangement was made with the State board of irrigation in connection with stream measurements in Kansas.

In Colorado the State engineering department contributes a large portion of the services of the deputy State engineer. Important cooperation is also extended by some of the water commissioners in Colorado.

An appropriation of $200 was made by the commissioners of Cache County, Utah, to aid in making a hydrographic survey of Cache Valley.

Thanks are due to Mr. H. Huber, general manager of the El Paso Smelting Company, for valuable cooperation in obtaining measurements and soundings at El Paso, Texas.

Especial mention should also be made of the assistance rendered by Mr. William Hood, chief engineer Southern Pacific Railroad, who has furnished daily rod readings of river height at numerous railroad bridges on the system, and who has rendered much valuable assistance in the compilation of physical data of California; by Mr. Walter James, chief engineer Kern County Land Company, for valuable information concerning the Kern River and for use of the station for the rating of the meters; by Mr. H. N. Savage, for data in reference to the Sweetwater River; by Mr. J. D. Schuyler, for general information; and by Mr. H. F. Parkinson, for information and assistance on the San Gabriel River.

Credit is given in the body of this report to numerous individuals who have contributed important services and information which have enlarged the results of the hydrographic investigation. It is not practicable even to enumerate the names of the many individuals who have extended courtesies similar to those mentioned, having in the aggregate an important bearing upon the quantity and quality of the results obtained.

The data obtained and the results of computations based upon these are presented in the following pages in as condensed form as possible, giving such facts as will enable the student to form an opinion for himself as to the degree of accuracy of the investigation. In connection with the description of the localities at which measurements are made attention has been called to the name or designation of the adjacent quadrangle and corresponding topographic atlas sheet. Also, with the statements concerning the river basins, a list of names of these topographic sheets is presented to facilitate reference to the maps. A study of these should be made in connection with discussions of the behavior of each stream. The tables of daily gage height are not given in this paper, as they have less relative interest and would swell the report to an unwieldy size. They may be found for the most part in Water-Supply and Irrigation Paper No. 11.

## CHESAPEAKE WATERSHED.

### ROWLANDSVILLE STATION ON OCTORARO CREEK.

This creek rises in Pennsylvania and flows into the Susquehanna River about 2 miles above Port Deposit, Maryland. The station was established November 21, 1896, at the wagon bridge in the village of Rowlandsville, Maryland. The situation is not a model one for taking discharge measurements, owing to an eddy along the left bank and the proximity of the mouth of a small tributary which would cause cross currents in time of high water.

A wire gage was attached to the floor timber on the upper side of the bridge, the scale being a 14-foot board painted white and spaced to tenths of a foot with small nails, fastened to the floor timber of the bridge. The observer is Hugh W. Caldwell. The initial point for making soundings is the end of the hand rail on the lower side of the bridge on the left bank of the stream. A bench mark was established and verified with surveyor's level. The bench mark is a cross cut in top of capstone on the lower side of the bridge abutment on the left bank of the stream, and is 17.67 feet above the datum of the gage.

A measurement was made at this station on November 21, 1896, by E. G. Paul. The height of the water was 3 feet, the discharge 138 second-feet. Observations of height of water began at this point on November 22 and were continued until December 31, 1896, the height ranging from 3 to 3.20 feet, except in the case of a flood on November 29 rising to 4.30 feet.

### WOODSTOCK STATION ON PATAPSCO RIVER.

The drainage area is 251 square miles, and is partly shown on the Ellicott and Frederick sheets of the Topographic Atlas. This station was established August 6, 1896, on the county bridge on the road from Woodstock to Granite, Maryland, a mile and a half below the junction with the North Branch, seen on the Ellicott atlas sheet.

The bridge has been measured and distances from the initial point for making soundings have been stenciled on the guard plank under the hand rail on the upper side of the bridge. The pulley of the wire gage in use at this station is fastened to the floor timber of the upper side of the bridge 40 feet from an initial point established for making soundings. The scale is a board spaced to tenths of a foot with small nails and nailed to the floor timber of the bridge.

The channel is rough, with large rocks in the bed of the stream. The stream is subject to high water and sudden floods, owing to the character of its upper watershed. The bench mark is a United States Geological Survey standard copper bolt set in the face of the retaining wall of the entrance to the college grounds at the north end of the bridge. It is 22.06 feet above gage datum. The record of daily gage

heights for 1896, from August 6 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 8.

*List of discharge measurements made on Patapsco River at Woodstock, Maryland.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 6 | E. G. Paul | 68 | 3.60 | 93 | 1.33 | 123 |
| 2 | Sept. 16 | do | 68 | 3.90 | 109 | 1.83 | 200 |
| 3 | Nov. 19 | do | 68 | 3.90 | 101 | 2.03 | 204 |
| | 1897. | | | | | | |
| 4 | Feb. 10 | do | 68 | 4.20 | 143 | 2.40 | 345 |

*Rating table for Patapsco River at Woodstock, Maryland.*

[This table is applicable from August 1, 1896, to February 20, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.30 | 70 | 3.90 | 210 | 4.50 | 500 |
| 3.40 | 85 | 4.00 | 250 | 4.60 | 560 |
| 3.50 | 100 | 4.10 | 300 | 4.70 | 620 |
| 3.60 | 125 | 4.20 | 350 | 4.80 | 680 |
| 3.70 | 150 | 4.30 | 400 | 4.90 | 740 |
| 3.80 | 180 | 4.40 | 450 | 5.00 | 800 |

*Estimated monthly discharge of Patapsco River at Woodstock, Maryland.*

[Drainage area, 251 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August 16 to 31 | 150 | 77 | 120 | 3,808 | 0.28 | 0.48 |
| September | 195 | 55 | 116 | 6,902 | .52 | .46 |
| October | 230 | 100 | 151 | 9,284 | .69 | .60 |
| November | 740 | 138 | 210 | 12,496 | .93 | .84 |
| December | 275 | 92 | 161 | 6,210 | .74 | .64 |

### LAUREL STATION ON PATUXENT RIVER.

This station is in the Laurel quadrangle, in latitude 39° 5.5′, longitude 76° 50.5′. It was established August 3, 1896, on the bridge on the main cross street of the town of Laurel, Maryland. The initial point for soundings is the end of iron truss, upper side. The bridge was measured and distances from the initial point for sounding were stenciled on the floor timber of the upper side of the bridge. A wire gage with metal weight was attached to the lower side of the bridge, the scale being a 14-foot board spaced to tenths of a foot with small nails and fastened to the floor timber of the bridge.

The flow of water past this station in time of dry weather is confined to certain hours of the day, owing to a dam at the large cotton mill situated about 1 mile up the stream from the station. During August, 1896, the cotton mill ran but five hours each working day, owing to the scarcity of water. The mill would run from 7 a. m. until noon. By that time the supply of water would be exhausted and the gates of the dam be closed. In but few instances during August, 1896, did water flow over the dam by 7 a. m. the next day.

The bench mark is a copper bolt set in large capstone of the retaining wall on the lower side of the bridge abutment on the left bank of the stream. It is 21.22 feet above zero of gage height. The drainage area is 137 square miles, and is mapped on the Frederick, Laurel, and Monocacy sheets of the Topographic Atlas. The record of daily river heights for 1896, from August 3 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 8.

*List of discharge measurements made on Patuxent River at Laurel, Maryland.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Sept. 18 | E. G. Paul..... | 67 | 4.60 | 117 | 1.37 | 161 |
| 2 | Nov. 25 | .....do ..... | ..... | 4.40 | 93 | 1.32 | 123 |

## POTOMAC BASIN.

The Potomac River, as the name is commonly applied, results from the union of the North Branch with the South Branch at a point about 12 miles below Cumberland, Maryland. The main features of this basin are outlined in Bulletin 140, pages 41–43.

Following down the Potomac River, the drainage areas of the princi-

pal tributaries have been measured at their mouths and ascertained to be as follows:

*Drainage areas of tributaries of Potomac River.*

| | Sq. miles. |
|---|---|
| Little Cacapon | 117 |
| Great Cacapon. (Of this, North River has a drainage area of 205 square miles; Lost River, 189 square miles; Cacapon above North River, 404 square miles.) | 671 |
| Warm Spring Creek | 16 |
| Conoloway Creek | 125 |
| Sleepy Creek | 146 |
| Licking Creek | 195 |
| Back Creek (to Virginia and West Virginia line, 185 square miles) | 288 |
| Conococheague at Williamsport | 579 |
| Opequon | 335 |
| Antietam | 305 |
| Shenandoah | 3,009 |
| Monocacy | 941 |
| Goose Creek | 384 |
| Seneca Creek | 132 |
| Rock Creek | 81 |

The areas of the Potomac drainage at various points in succession below the union of the North and South branches are as follows:

| | Sq. miles. |
|---|---|
| Above Great Cacapon River | 3,388 |
| At Hancock | 4,099 |
| At Williamsport | 5,556 |
| At Harpers Ferry above the Shenandoah | 6,354 |
| At Harpers Ferry below the Shenandoah | 9,363 |
| At Weverton | 9,397 |
| At Point of Rocks | 9,654 |
| At Edwards Ferry below Goose Creek | 11,100 |
| At Great Falls | 11,427 |
| At Chain Bridge | 11,545 |

The principal river stations for ascertaining the fluctuation of the stream are stated below in geographic order, and the results obtained at each are shown in concise form.

## POTOMAC RIVER ABOVE SHENANDOAH.

### SPRINGFIELD STATION ON SOUTH BRANCH OF POTOMAC RIVER.

This point is at the railroad bridge at Washington station, 2 miles above Springfield, West Virginia. It is shown on the Romney sheet of the Topographic Atlas, and is in latitude 39° 25′ and longitude 78° 44′. Its drainage area is all shown on the Romney, Piedmont, Beverly, Franklin, Woodstock, Staunton, and Monterey sheets. Observations were discontinued in February, 1896, upon the exhaustion of funds, and have not been resumed. The bench mark is a cross cut in a broad capstone of the lower wall of the north abutment of the bridge, and is 24.58

feet above the surface of the water when the gage reads 3.6 feet, or 28.18 feet above datum.

The measurements of river height are made by means of a wire gage, the scale of which is marked to feet and tenths on the guard rail of the bridge on the lower side by means of brass tacks. The distance from the pulley to the zero of the gage is 1.66 feet; the length of the gage wire is 34 feet. It is placed in the first panel of the bridge at the third span from the north. Measurements of discharge are made from the same bridge. The channel, both above and below the station, is straight; the water is somewhat swift. The banks are liable to overflow at time of high water.

This station is described in Bulletin 131, page 88. Rating tables and daily gage heights for 1895 are published in Bulletin 140, pages 44 and 45. The same rating table is used in computing the table of discharges given herewith. Additional measurements of minimum flow are required for completing the record for 1895. Observations were made at this point from January 1 to February 29, 1896, the height ranging from 3.60 to 9.40, but the greater part of the time fluctuating rapidly. From January 5 to 22 the river was reported as frozen.

*List of discharge measurements made on South Branch of Potomac River, West Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | May 31 | R. H. Chapman.... | 23 h | 4.70 | 532 | 2.02 | 1,074 |
| | 1895. | | | | | | |
| 2 | Mar. 29 | C. C. Babb ..... | 29 l | 5.90 | 695 | 2.95 | 2,049 |
| 3 | Apr. 11 | .....do ..... | 29 l | 8.95 | 1,488 | 2.95 | 4,389 |
| 4 | Apr. 26 | .....do ..... | 29 l | 4.20 | 395 | 2.45 | 968 |
| 5 | May 3 | .....do ..... | 29 l | 7.40 | 974 | 3.62 | 3,539 |
| 6 | May 9 | .....do ..... | 29 l | 5.25 | 481 | 3.30 | 1,588 |
| 7 | May 22 | .....do ..... | 29 l | 8.30 | 1,238 | 3.16 | 3,886 |
| 8 | June 4 | .....do ..... | 29 h | 3.90 | 330 | 2.15 | 710 |
| 9 | June 6 | .....do ..... | 29 h | 3.90 | 357 | 2.13 | 759 |
| 10 | June 14 | .....do ..... | 29 h | 3.47 | 258 | 2.27 | 586 |
| 11 | June 19 | .....do ..... | 29 h | 3.10 | 195 | 1.79 | 349 |
| 12 | July 16 | .....do ..... | 76 | 3.10 | 219 | 1.73 | 378 |
| 13 | July 17 | .....do ..... | 76 | 3.00 | 195 | 1.82 | 355 |
| | 1896. | | | | | | |
| 14 | Aug. 6 | D. C. Humphreys .. | 1 a | 4.40 | 465 | 2.28 | 1,058 |
| 15 | Nov. 18 | A. P. Davis ..... | 68 | 3.60 | 307 | 2.06 | 634 |

*Rating table for South Branch of Potomac River.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.50 | 180 | 4.40 | 1,030 | 6.30 | 2,370 | 8.20 | 3,795 |
| 2.60 | 210 | 4.50 | 1,090 | 6.40 | 2,445 | 8.30 | 3,870 |
| 2.70 | 240 | 4.60 | 1,160 | 6.50 | 2,520 | 8.40 | 3,945 |
| 2.80 | 270 | 4.70 | 1,230 | 6.60 | 2,595 | 8.50 | 4,020 |
| 2.90 | 300 | 4.80 | 1,300 | 6.70 | 2,670 | 8.60 | 4,095 |
| 3.00 | 330 | 4.90 | 1,370 | 6.80 | 2,745 | 8.70 | 4,170 |
| 3.10 | 360 | 5.00 | 1,440 | 6.90 | 2,820 | 8.80 | 4,245 |
| 3.20 | 400 | 5.10 | 1,510 | 7.00 | 2,895 | 8.90 | 4,320 |
| 3.30 | 450 | 5.20 | 1,580 | 7.10 | 2,970 | 9.00 | 4,395 |
| 3.40 | 500 | 5.30 | 1,650 | 7.20 | 3,045 | 9.10 | 4,470 |
| 3.50 | 550 | 5.40 | 1,720 | 7.30 | 3,120 | 9.20 | 4,545 |
| 3.60 | 600 | 5.50 | 1,790 | 7.40 | 3,195 | 9.30 | 4,620 |
| 3.70 | 650 | 5.60 | 1,860 | 7.50 | 3,270 | 9.40 | 4,695 |
| 3.80 | 700 | 5.70 | 1,930 | 7.60 | 3,345 | 9.50 | 4,770 |
| 3.90 | 750 | 5.80 | 2,000 | 7.70 | 3,420 | 9.60 | 4,845 |
| 4.00 | 800 | 5.90 | 2,070 | 7.80 | 3,495 | 9.70 | 4,920 |
| 4.10 | 850 | 6.00 | 2,145 | 7.90 | 3,570 | 9.80 | 4,995 |
| 4.20 | 910 | 6.10 | 2,220 | 8.00 | 3,645 | 9.90 | 5,070 |
| 4.30 | 970 | 6.20 | 2,295 | 8.10 | 3,720 | | |

*Estimated monthly discharge of South Branch of Potomac River, near Springfield, West Virginia.*

[Drainage area, 1,443 square miles.]

| Month. | Discharge in second-feet. | | | Run-off. | |
|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | Depth in inches. | Second-feet per square mile. |
| 1894. | | | | | |
| June | 1,720 | 400 | 800 | 0.61 | 0.55 |
| July *a* | 700 | 210 | 317 | 0.25 | 0.22 |
| August | 400 | 180 | 232 | 0.18 | 0.16 |
| September | 1,930 | 180 | 395 | 0.30 | 0.27 |
| October 1 to 20 | 910 | 210 | 500 | 0.40 | 0.35 |
| 1895. | | | | | |
| April 12 to 30 | 3,270 | 800 | 1,667 | 1.28 | 1.15 |
| May | 3,570 | 1,030 | 2,204 | 1.76 | 1.53 |
| June | 1,230 | 270 | 600 | 0.47 | 0.42 |
| July | 1,300 | 240 | 512 | 0.40 | 0.35 |
| 1896. | | | | | |
| January | 2,820 | 600 | 856 | 0.68 | 0.59 |
| February | 4,695 | 500 | 2,023 | 1.51 | 1.40 |

*a* Record incomplete; figures missing from July 15 to 21, 1894.

## CUMBERLAND STATION ON POTOMAC RIVER.

This station is 1,000 feet below the mouth of Wills Creek, in latitude 39° 39′, longitude 78° 46′. It is described in Bulletin 131, page 88. The river gage consists of a vertical rod 10 feet long, bolted to the east side of the abutment of the head gate of the eastern canal feeder just above the dam. The top of the rod, or the 10-foot mark, is 5.40 feet below the top of the abutment. Measurements of the river are made from the West Virginia Central Railroad bridge, about 200 yards below the dam across the Potomac. At high water the section is fairly smooth and the velocity high. At low water rocks, riffles, and angular currents appear. Measurements of the canal feeders have also been made near the head gates. The record of daily river heights at this station were continued throughout 1896, and are shown in Water-Supply and Irrigation Paper No. 11, page 8. The drainage area above this station is 891 square miles, and is shown in part on the Piedmont and Romney sheets of the Topographic Atlas.

*List of discharge measurements made on Potomac River at Cumberland, Maryland.*[1]

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | May 24 | C. C. Babb ..... | 23 | ..... | 1,166 | 2.60 | 3,037 |
| | 1895. | | | | | | |
| 2 | Mar. 30 | .....do ..... | 29 l | 4.50 | 1,088 | 3.17 | 3,446 |
| 3 | Apr. 10 | .....do ..... | 29 l | 5.40 | 1,560 | 3.88 | 6,054 |
| 4 | Apr. 25 | .....do ..... | 29 h | 3.30 | 423 | 1.49 | 630 |
| 5 | May 3 | .....do ..... | 29 h | 3.75 | 722 | 2.39 | 1,728 |
| 6 | May 9 | .....do ..... | 29 h | 3.40 | 465 | 1.67 | 777 |
| 7 | May 23 | .....do ..... | 29 h | 3.40 | 569 | 1.46 | 831 |
| 8 | June 5 | .....do ..... | 29 h | 2.95 | 373 | 0.69 | 256 |
| 9 | June 6 | .....do ..... | 29 h | 3.10 | 445 | 1.37 | 609 |
| 10 | June 13 | .....do ..... | 29 h | 3.00 | 334 | 0.86 | 287 |
| 11 | July 17 | .....do ..... | 76 | 3.05 | 357 | 0.97 | 345 |
| | 1896. | | | | | | |
| 12 | June 24 | D. C. Humphreys .. | W. B. | 3.31 | 580 | 1.42 | 822 |
| 13 | Aug. 6 | .....do ..... | W. B. | 3.30 | 355 | 1.71 | 605 |
| 14 | Nov. 18 | A. P. Davis ..... | 68 | 3.38 | 577 | 1.33 | 765 |

[1] Gagings include discharge of canal feeders.

*Rating table of Potomac River at Cumberland, Maryland.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.7 | 160 | 3.6 | 1,285 | 4.5 | 3,580 | 5.4 | 5,875 |
| 2.8 | 200 | 3.7 | 1,540 | 4.6 | 3,835 | 5.5 | 6,130 |
| 2.9 | 240 | 3.8 | 1,795 | 4.7 | 4,090 | 5.6 | 6,385 |
| 3.0 | 300 | 3.9 | 2,050 | 4.8 | 4,345 | 5.7 | 6,640 |
| 3.1 | 400 | 4.0 | 2,305 | 4.9 | 4,600 | 5.8 | 6,895 |
| 3.2 | 500 | 4.1 | 2,560 | 5.0 | 4,855 | 5.9 | 7,150 |
| 3.3 | 650 | 4.2 | 2,815 | 5.1 | 5,110 | 6.0 | 7,405 |
| 3.4 | 800 | 4.3 | 3,070 | 5.2 | 5,365 | | |
| 3 5 | 1,000 | 4.4 | 3,325 | 5.3 | 5,620 | | |

*Estimated monthly discharge of Potomac River at Cumberland, Maryland.*

[Drainage area, 891 square miles.]

| Month. | Discharge in second-feet. | | | Run-off. | |
|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | |
| January | 7,405 | 325 | 1,844 | 2.39 | 2.07 |
| February | 4,855 | 650 | 1,128 | 1.32 | 1.27 |
| March | 7,405 | 1,540 | 3,185 | 4.12 | 3.57 |
| April | 6,385 | 525 | 1,875 | 2.35 | 2.10 |
| May | 1,795 | 425 | 870 | 1.13 | 0.98 |
| June | 650 | 200 | 355 | 0.45 | 0.40 |
| July | 1,540 | 160 | 431 | 0.55 | 0.48 |

*Estimated monthly discharge of Potomac River at Cumberland, Maryland.*

[Drainage area, 891 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 2,815 | 240 | 438 | 26,931 | 0.56 | 0.49 |
| February | 4,600 | 400 | 1,498 | 86,165 | 1.81 | 1.68 |
| March | 12,505 | 300 | 1,991 | 122,422 | 2.57 | 2.23 |
| April | 4,855 | 650 | 1,792 | 106,631 | 2.24 | 2.01 |
| May | 3,580 | 240 | 1,351 | 83,070 | 1.75 | 1.52 |
| June | 2,560 | 500 | 1,396 | 83,068 | 1.75 | 1.57 |
| July | 17,600 | 300 | 2,141 | 131,644 | 2.77 | 2.40 |

*Estimated monthly discharge of Potomac River at Cumberland, Maryland*—Continued.

[Drainage area, 891 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 1,795 | 200 | 656 | 40,335 | 0.85 | 0.74 |
| September | 17,600 | 140 | 859 | 51,115 | 1.07 | 0.96 |
| October | 6,130 | 240 | 868 | 53,370 | 1.12 | 0.97 |
| November | 6,130 | 400 | 1,116 | 66,406 | 1.39 | 1.25 |
| December | 1,540 | 400 | 654 | 40,212 | 0.84 | 0.73 |
| Per annum | 17,600 | 140 | 1,230 | 891,369 | 18.72 | 1.38 |

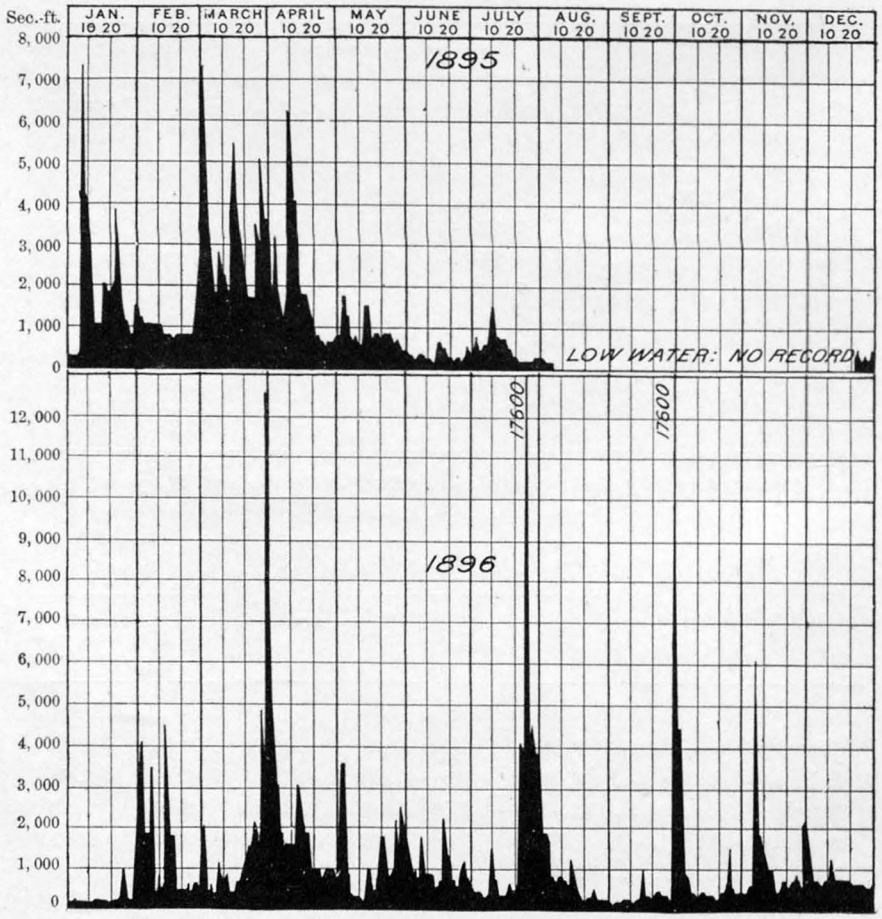



FIG. 1.—Discharge of Potomac River at Cumberland, Maryland, 1895-96.

GREAT CACAPON STATION, WEST VIRGINIA, ON POTOMAC RIVER.

Observations were carried on at this point from January 1 to March 7, 1896, the height ranging from 1.10 to 4.10 feet. This station is described on page 47 of Bulletin No. 140.

## SHENANDOAH RIVER.

PORT REPUBLIC STATION, ON NORTH AND SOUTH RIVERS.

This locality is described in Bulletin 140, page 50. On August 6, 1895, gages were established on the North and South rivers, which form the South Fork of the Shenandoah at Port Republic, Virginia. The gage for the North River is located on the county highway bridge, at Port Republic, and 500 feet above the mouth of South River. A painted rod was fastened to the third panel of the first span on the lower side of the bridge. It is nailed to the wooden uprights and fastened by wire to the iron diagonals. The zero of the rod is opposite the middle of the third upright, and is 4.50 feet from the outside edge of the pulley. The distance from the end of the weight to the marker is 31.98 feet. The bridge seat on lower end of right bank abutment is 24.6 feet above the datum of gage.

The gage for the South River is located on the county iron bridge, just east of the town, and 300 feet above the mouth of North River. It is a wire gage. The edge of the pulley is 2.54 feet from the north edge of the third vertical. The marks on the gage are made by tacks driven into the rail on the upper side of the bridge at the fourth panel. The zero is 1 foot from the edge of the pulley. The distance from the bottom of the weight to the wire marker or zero point is 26.12. The top of the third floor beam from right bank, upper side of bridge, is 22.52 feet above gage datum. The zero of North River gage is 2.56 feet below the zero of South River gage.

The drainage area of these stations is entirely mapped, and may be found on the Franklin, Harrisonburg, Staunton, Buckingham, and Lexington sheets.

On August 29, 1895, a gaging of the South Fork of the Shenandoah was made just below the junction of the North and South rivers, giving an area of section of 165 square feet, mean velocity 2.09 feet per second, and a discharge of 345 second-feet. Deducting 87 second-feet, the discharge of South River on that date, gave a discharge of 258 second-feet for the North River. Similarly, on July 31, 1895, the discharge of the South Fork below the junction gave, area, 203; mean velocity, 2.33, and discharge 474. The discharge of the North River would be 335 second-feet. All gagings of South River include discharge of mill race. Measurements of discharge at this station are not sufficiently comprehensive to warrant the construction of rating curves. The record of daily gage height for both rivers for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 9.

*List of discharge measurements made on North River, at Port Republic, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 6 | C. C. Babb..... | 29 | 2.18 | 281 | 1.33 | 375 |
| 2 | Aug. 29 | D. C. Humphreys.. | N. | 2.09 | ..... | ..... | *a* 258 |
| | 1896. | | | | | | |
| 3 | June 5 | .....do ..... | W. B. | 2.20 | 276 | 1.55 | 427 |
| 4 | July 31 | .....do ..... | W. B. | 2.48 | 310 | 1.38 | 428 |
| 5 | ....do ... | .....do ..... | W. B. | 2.46 | ..... | ..... | *b* 335 |

*a* Result obtained by deducting the discharge of the South River, 87 second-feet, from total discharge of the South Fork of Shenandoah, 345 second-feet, measured below the junction.

*b* Result obtained as on August 29, 1895, by deducting 139 second-feet, discharge of South River, from 474 second-feet, discharge of South Fork.

*List of discharge measurements made on South River, at Port Republic, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| | Aug. 5 | C. C. Babb ..... | 29 | ..... | 56 | 1.30 | *a* 72 |
| 1 | Aug. 6 | ....do ..... | 29 | 1.62 | 74 | 1.55 | 114 |
| 2 | Aug. 29 | D. C. Humphreys.. | W. L. U. | 1.34 | 68 | 1.28 | 87 |
| | 1896. | | | | | | |
| 3 | June 5 | D. C. Humphreys.. | W. B. | 1.40 | 79 | 1.43 | 113 |
| 4 | July 30 | .....do ..... | W. B. | 1.63 | 83 | 1.68 | 139 |

*a* Measurement made at Basic City, 200 feet above iron highway bridge. The surface of the water then was 19.29 feet below the top of the foot rail of the bridge, opposite the third or center vertical on the upper side of the bridge.

## MILLVILLE STATION ON SHENANDOAH RIVER.

A station for measuring Shenandoah River was established at a point 4 miles above Harpers Ferry, where there is a cable stretched across the river—the property of Becker Bros., of Baltimore. Permission was obtained to utilize this cable by swinging from it a suitable box from which discharge measurements could be made. On April 15, 1895, a vertical gage was placed in the river and securely fastened to the overhanging trunk of a tree. A deep notch was cut in the tree opposite the 8-foot mark. Daily observations were begun at this time. A further description of this station is given in Bulletin 140, page 53.

The station is shown on the Harpers Ferry sheet, and is 200 feet above the mouth of Flowing Run, in latitude 39° 17′ and longitude 77° 47′. The drainage basin is entirely included on the Harpers Ferry, Winchester, Luray, Woodstock, Franklin, Harrisonburg, Staunton, Buckingham, and Lexington atlas sheets.

On October 1, 1896, the cable was carried out by high water, and has not yet been replaced. On November 17 a copper bolt bench mark was driven into an auger hole in the root of a large sycamore tree on the left bank of the river, about 150 feet below the gage rod. The top of the bench mark is 1.78 feet below the 5-foot mark on the gage. The high-water mark of the flood of October 1 was connected by a level line with the gage, and found to be at gage height 19.72. The rating table is applicable only from January 1 to September 30. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 10.

*List of discharge measurements made on Shenandoah River at Millville, West Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 24 | C. C. Babb..... | 29 h | 1.90 | 1,825 | 1.18 | 2,162 |
| 2 | May 1 | .....do ..... | 29 h | 7.50 | 4,843 | 4.07 | 19,711 |
| 3 | May 2 | .....do ..... | 29 h | 6.80 | 4,393 | 3.61 | 15,859 |
| 4 | May 4 | .....do ..... | 29 h | 5.20 | 3,463 | 3.17 | 10,981 |
| 5 | May 8 | .....do ..... | 29 h | 3.08 | 2,397 | 1.80 | 4,311 |
| 6 | May 21 | .....do ..... | 29 h | 3.60 | 3,256 | 1.76 | 5,745 |
| 7 | June 8 | .....do ..... | 29 h | 1.50 | 1,645 | 0.92 | 1,516 |
| 8 | June 15 | .....do ..... | 29 h | 2.35 | 2,135 | 1.42 | 3,044 |
| 9 | June 22 | .....do ..... | 29 h | 1.10 | 1,464 | 0.77 | 1,126 |
| 10 | July 12 | .....do ..... | 29 h | 1.30 | 1,549 | 0.74 | 1,150 |
| | 1896. | | | | | | |
| 11 | June 22 | D. C. Humphreys .. | W. B. | 1.99 | 1,903 | 1.32 | 2,513 |

U. S. GEOLOGICAL SURVEY LIBRARY

*Rating table for Shenandoah River at Millville, West Virginia.*

[This table is applicable from January 1, 1896, to January 1, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0 60 | 890 | 2. 10 | 2, 500 | 3. 50 | 5, 490 | 4. 90 | 9, 950 |
| 0. 70 | 940 | 2. 20 | 2, 670 | 3. 60 | 5, 790 | 5. 00 | 10, 275 |
| 0. 80 | 990 | 2. 30 | 2, 840 | 3. 70 | 6, 090 | 5. 10 | 10, 600 |
| 0. 90 | 1, 040 | 2. 40 | 3, 020 | 3. 80 | 6, 390 | 5. 20 | 10, 925 |
| 1. 00 | 1, 090 | 2. 50 | 3, 210 | 3. 90 | 6, 700 | 5. 30 | 11, 250 |
| 1. 10 | 1, 140 | 2. 60 | 3, 400 | 4. 00 | 7, 025 | 5. 40 | 11, 575 |
| 1. 20 | 1, 200 | 2. 70 | 3, 590 | 4. 10 | 7, 350 | 5. 50 | 11, 900 |
| 1. 30 | 1, 300 | 2. 80 | 3, 780 | 4. 20 | 7, 675 | 5. 60 | 12, 225 |
| 1. 40 | 1, 400 | 2. 90 | 3, 980 | 4. 30 | 8, 000 | 5. 70 | 12, 550 |
| 1. 50 | 1, 510 | 3. 00 | 4, 180 | 4. 40 | 8, 325 | 5. 80 | 12, 875 |
| 1. 60 | 1, 650 | 3. 10 | 4, 390 | 4. 50 | 8, 650 | 5. 90 | 13, 200 |
| 1. 70 | 1, 820 | 3. 20 | 4, 630 | 4. 60 | 8, 975 | 6. 00 | 13, 525 |
| 1. 80 | 1, 990 | 3. 30 | 4, 900 | 4. 70 | 9, 300 | 6. 10 | 13, 850 |
| 1. 90 | 2, 160 | 3. 40 | 5, 190 | 4. 80 | 9, 625 | 6. 20 | 14, 175 |
| 2. 00 | 2, 330 | | | | | | |

*Estimated monthly discharge of Shenandoah River at Millville, West Virginia.*

[Drainage area, 2,995 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 11, 250 | 1, 040 | 2, 453 | 150, 829 | 0. 94 | 0. 82 |
| February | 12, 225 | 1, 400 | 3, 725 | 214, 264 | 1. 34 | 1. 24 |
| March | 11, 900 | 1, 400 | 3, 772 | 231, 931 | 1. 45 | 1. 26 |
| April | 8, 975 | 1, 400 | 2, 750 | 163, 636 | 1. 02 | 0. 92 |
| May | 4, 180 | 1, 140 | 2, 060 | 126, 664 | 0. 79 | 0. 69 |
| June | 3, 780 | 990 | 2, 129 | 126, 684 | 0. 79 | 0. 71 |
| July | 9, 300 | 1, 300 | 2, 798 | 172, 041 | 1. 07 | 0. 93 |
| August | 1, 820 | 990 | 1, 233 | 75, 814 | 0. 47 | 0. 41 |
| September | 12, 550 | 840 | 1, 285 | 76, 462 | 0. 48 | 0. 43 |
| October 3 to 30 | 12, 225 | 1, 040 | 2, 192 | 121, 717 | 0. 79 | 0. 73 |
| November | 4, 630 | 1, 040 | 1, 958 | 116, 509 | 0. 72 | 0. 65 |
| December | 6, 390 | 1, 400 | 2, 237 | 137, 548 | 0. 86 | 0. 75 |
| Per annum | 12, 550 | 840 | 2, 383 | 1, 714, 099 | 11. 72 | 0. 79 |

## POTOMAC RIVER BELOW SHENANDOAH RIVER.

### POINT OF ROCKS STATION ON POTOMAC RIVER, MARYLAND.

This station is in latitude 39° 16′, longitude 77° 33′, in Harpers Ferry quadrangle. It is about 6 miles above the mouth of Monocacy River, and also a number of smaller streams, and therefore the measurements

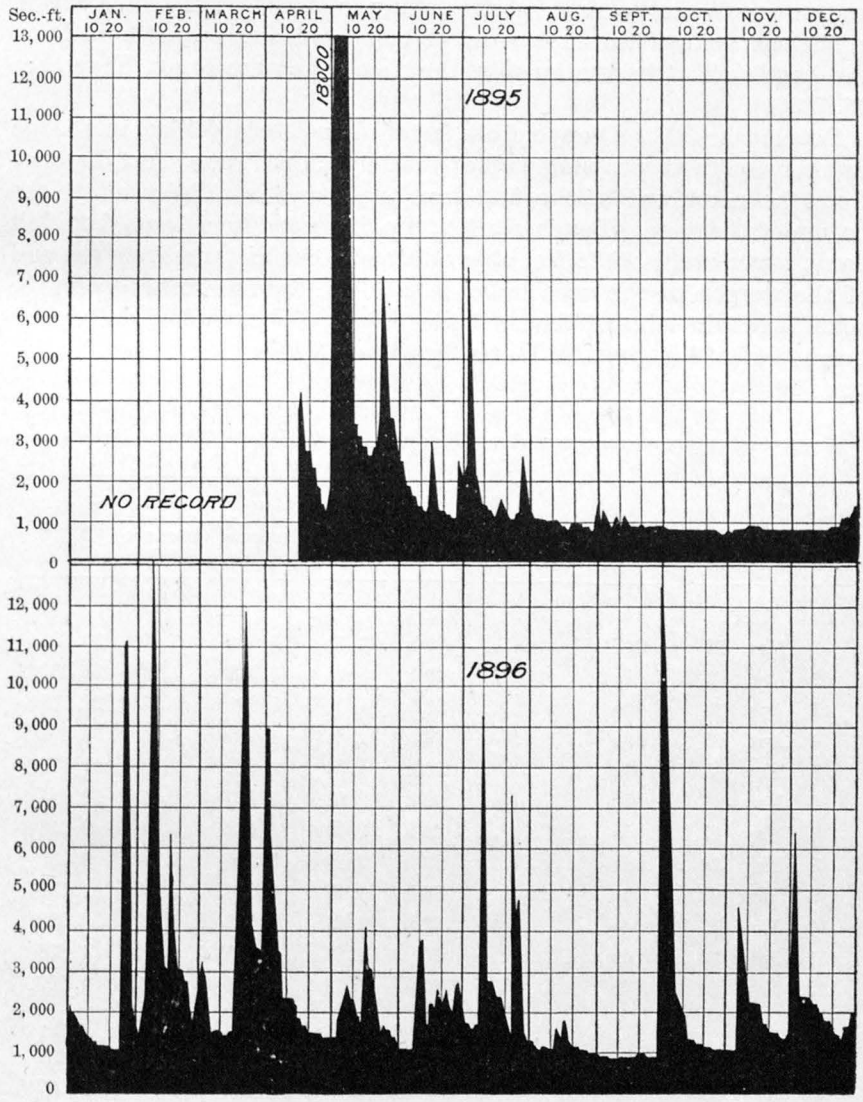



FIG. 2.—Discharge of Shenandoah River at Millville, West Virginia, 1895–96.

of discharge do not represent the entire flow of the Potomac River. The drainage area here is estimated to be 9,654 square miles. It is largely mapped on Topographic Atlas sheets Harpers Ferry, Winchester, Romney, Piedmont, Warrenton, Luray, Woodstock, Franklin,

Beverly, Harrisonburg, Staunton, Monterey, Buckingham, and Lexington. The station is described in Bulletin 140, page 54.

At this point a toll bridge has been erected, crossing the stream 1,000 feet below the mouth of Catoctin Creek.

A wire gage was placed on the toll bridge on February 17, 1895, near the center of the third span. The wire becoming badly rusted and frequently broken, a new wire gage was placed on the same datum at the east side of the first span. The scale is marked with nails on the hand rail. Observations on the new gage were begun November 16, 1896.

Bench mark 1 is a copper bolt fastened in a hole drilled in a large capstone on the lower wing wall of the north abutment a short distance from the north end of the first iron truss, and is 41.3 feet above the datum of the gage. Bench mark 2, top of second floor beam from left bank, lower end, is 39.28 feet above datum. The distance from the end of the weight to the wire index is 44.19 feet. The initial point for sounding is the edge of the north abutment. The record of daily gage height for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 10.

*List of discharge measurements made on Potomac River at Point of Rocks, Maryland.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Mar. 25 | C. C. Babb..... | 29 h | 2.79 | 10,524 | 1.68 | 10,524 |
| 2 | Apr. 5 | .....do ..... | 29 h | 3.16 | 6,338 | 2.21 | 14,032 |
| 3 | Apr. 13 | .....do ..... | 29 h | 4.01 | 7,851 | 2.23 | 17,516 |
| 4 | Apr. 23 | .....do ..... | 29 h | 1.84 | 4,765 | 1.55 | 7,371 |
| 5 | May 1 | .....do ..... | 29 h | 4.09 | 7,717 | 2.73 | 21,073 |
| 6 | May 7 | .....do ..... | 29 h | 2.84 | 5,780 | 2.16 | 12,484 |
| 7 | May 17 | .....do ..... | 29 h | 2.09 | 5,118 | 1.74 | 8,918 |
| 8 | May 28 | .....do ..... | 29 h | 2.19 | 5,290 | 1.74 | 9,189 |
| 9 | June 3 | .....do ..... | 29 h | 1.27 | 3,998 | 1.13 | 4,536 |
| 10 | June 17 | .....do ..... | 29 h | 1.04 | 3,793 | 1.12 | 4,233 |
| 11 | July 10 | .....do ..... | 76 | 1.24 | 4,695 | 1.14 | 4,695 |
| 12 | Nov. 16 | .....do ..... | 62 | 0.14 | 2,355 | 0.51 | 1,202 |
| | 1896. | | | | | | |
| 13 | June 28 | D. C. Humphreys.. | W.B.1A | 1.82 | 5,386 | 1.20 | 6,462 |
| 14 | Aug. 4 | .....do ..... | W.B.1A | 1.86 | 4,526 | 1.55 | 7,057 |
| 15 | Nov. 16 | A. P. Davis..... | 68 | 1.60 | 4,121 | 1.48 | 6,109 |
| | 1897. | | | | | | |
| 16 | Feb. 9 | C. C. Babb..... | 70 | 7.95 | 11,668 | 3.49 | 40,654 |
| 17 | Feb. 23 | .....do ..... | 70 | 21.70 | 29,627 | 5.74 | 169,913 |

*Rating table for Potomac River at Point of Rocks, Maryland.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 1,000 | 4.10 | 17,820 | 8.20 | 42,880 | 12.30 | 81,420 |
| 0.10 | 1,200 | 4.20 | 18,340 | 8.30 | 43,820 | 12.40 | 82,360 |
| 0.20 | 1,400 | 4.30 | 18,860 | 8.40 | 44,760 | 12.50 | 83,300 |
| 0.30 | 1,650 | 4.40 | 19,380 | 8.50 | 45,700 | 12.60 | 84,240 |
| 0.40 | 1,900 | 4.50 | 19,900 | 8.60 | 46,640 | 12.70 | 85,180 |
| 0.50 | 2,150 | 4.60 | 20,420 | 8.70 | 47,580 | 12.80 | 86,120 |
| 0.60 | 2,400 | 4.70 | 20,940 | 8.80 | 48,520 | 12.90 | 87,060 |
| 0.70 | 2,700 | 4.80 | 21,460 | 8.90 | 49,460 | 13.00 | 88,000 |
| 0.80 | 3,050 | 4.90 | 21,980 | 9.00 | 50,400 | 13.10 | 88,940 |
| 0.90 | 3,400 | 5.00 | 22,500 | 9.10 | 51,340 | 13.20 | 89,880 |
| 1.00 | 3,800 | 5.10 | 23.050 | 9.20 | 52,280 | 13.30 | 90,820 |
| 1.10 | 4,150 | 5.20 | 23,600 | 9.30 | 53,220 | 13.40 | 91,760 |
| 1.20 | 4,500 | 5.30 | 24,150 | 9.40 | 54,160 | 13.50 | 92,700 |
| 1.30 | 4,850 | 5.40 | 24,700 | 9.50 | 55,100 | 13.60 | 93,640 |
| 1.40 | 5,200 | 5.50 | 25,250 | 9.60 | 56,040 | 13.70 | 94,580 |
| 1.50 | 5,550 | 5.60 | 25,800 | 9.70 | 56,980 | 13.80 | 95,520 |
| 1.60 | 5,900 | 5.70 | 26,350 | 9.80 | 57,920 | 13.90 | 96,460 |
| 1.70 | 6,300 | 5.80 | 26,900 | 9.90 | 58,860 | 14.00 | 97,400 |
| 1.80 | 6,700 | 5.90 | 27,450 | 10.00 | 59,800 | 14.10 | 98,340 |
| 1.90 | 7,150 | 6.00 | 28,000 | 10.10 | 60,740 | 14.20 | 99,280 |
| 2.00 | 7,600 | 6.10 | 28,550 | 10.20 | 61,680 | 14.30 | 100,220 |
| 2.10 | 8,050 | 6.20 | 29,100 | 10.30 | 62,620 | 14.40 | 101,160 |
| 2.20 | 8,500 | 6.30 | 29,650 | 10.40 | 63,560 | 14.50 | 102,100 |
| 2.30 | 8,950 | 6.40 | 30,200 | 10.50 | 64,500 | 14.60 | 103,040 |
| 2.40 | 9,400 | 6.50 | 30,750 | 10.60 | 65,440 | 14.70 | 103,980 |
| 2.50 | 9,850 | 6.60 | 31,300 | 10.70 | 66,380 | 14.80 | 104,920 |
| 2.60 | 10,300 | 6.70 | 31,850 | 10.80 | 67,320 | 14.90 | 105,860 |
| 2.70 | 10,750 | 6.80 | 32,400 | 10.90 | 68,260 | 15.00 | 106,800 |
| 2.80 | 11,200 | 6.90 | 32,950 | 11.00 | 69,200 | 15.10 | 107,740 |
| 2.90 | 11,650 | 7.00 | 33,500 | 11.10 | 70,140 | 15.20 | 108,680 |
| 3.00 | 12,100 | 7.10 | 33,250 | 11.20 | 71,080 | 15.30 | 109,620 |
| 3.10 | 12,620 | 7.20 | 35,000 | 11.30 | 72,020 | 15.40 | 110,560 |
| 3.20 | 13,140 | 7.30 | 35,700 | 11.40 | 72,960 | 15.50 | 111,500 |
| 3.30 | 13,660 | 7.40 | 36,500 | 11.50 | 73,900 | 15.60 | 112,440 |
| 3.40 | 14,180 | 7.50 | 37,250 | 11.60 | 74,840 | 15.70 | 113,380 |
| 3.50 | 14,700 | 7.60 | 38,000 | 11.70 | 75,780 | 15.80 | 114,320 |
| 3.60 | 15,220 | 7.70 | 38,750 | 11.80 | 76,720 | 15.90 | 115,260 |
| 3.70 | 15,740 | 7.80 | 39,500 | 11.90 | 77,660 | 16.00 | 116,200 |
| 3.80 | 16,260 | 7.90 | 40,250 | 12.00 | 78,600 | 16.10 | 117,140 |
| 3.90 | 16,780 | 8.00 | 41,000 | 12.10 | 79,540 | 16.20 | 118,080 |
| 4.00 | 17,300 | 8.10 | 41,940 | 12.20 | 80,480 | 16.30 | 119,020 |

*Rating table for Potomac River at Point of Rocks, Maryland*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 16.40 | 119,960 | 18.10 | 135,940 | 19.80 | 151,920 | 21.50 | 167,900 |
| 16.50 | 120,900 | 18.20 | 136,880 | 19.90 | 152,860 | 21.60 | 168,840 |
| 16.60 | 121,840 | 18.30 | 137,820 | 20.00 | 153,800 | 21.70 | 169,780 |
| 16.70 | 122,780 | 18.40 | 138,760 | 20.10 | 154,740 | 21.80 | 170,720 |
| 16.80 | 123,720 | 18.50 | 139,700 | 20.20 | 155,680 | 21.90 | 171,660 |
| 16.90 | 124,660 | 18.60 | 140,640 | 20.30 | 156,620 | 22.00 | 172,600 |
| 17.00 | 125,600 | 18.70 | 141,580 | 20.40 | 157,560 | 22.10 | 173,540 |
| 17.10 | 126,540 | 18.80 | 142,520 | 20.50 | 158,500 | 22.20 | 174,480 |
| 17.20 | 127,480 | 18.90 | 143,460 | 20.60 | 159,440 | 22.30 | 175,420 |
| 17.30 | 128,420 | 19.00 | 144,400 | 20.70 | 160,380 | 22.40 | 176,360 |
| 17.40 | 129,360 | 19.10 | 145,340 | 20.80 | 161,320 | 22.50 | 177,300 |
| 17.50 | 130,300 | 19.20 | 146,280 | 20.90 | 162,260 | 22.60 | 178,240 |
| 17.60 | 131,240 | 19.30 | 147,220 | 21.00 | 163,200 | 22.70 | 179,180 |
| 17.70 | 132,180 | 19.40 | 148,160 | 21.10 | 164,140 | 22.80 | 180,120 |
| 17.80 | 133,120 | 19.50 | 149,100 | 21.20 | 165,080 | 22.90 | 181,060 |
| 17.90 | 134,060 | 19.60 | 150,040 | 21.30 | 166,020 | 23.00 | 182,000 |
| 18.00 | 135,000 | 19.70 | 150,980 | 21.40 | 166,960 | | |

*Estimated monthly discharge of Potomac River at Point of Rocks, Maryland.*

[Drainage area, 9,654 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| February 17 to 28 | 14,900 | 5,000 | 7,142 | 396,647 | 0.77 | 0.74 |
| March | 49,900 | 11,400 | 21,884 | 1,345,595 | 2.62 | 2.27 |
| April | 50,900 | 5,900 | 13,383 | 796,342 | 1.55 | 1.39 |
| May | 26,400 | 6,900 | 12,109 | 744,558 | 1.45 | 1.26 |
| June | 7,400 | 2,150 | 3,655 | 217,487 | 0.43 | 0.38 |
| July | 10,400 | 2,400 | 3,882 | 238,696 | 0.46 | 0.40 |
| August | 3,050 | 1,200 | 1,852 | 113,876 | 0.22 | 0.19 |
| September | 2,400 | 1,000 | 1,428 | 84,972 | 0.17 | 0.15 |
| October | 1,200 | 825 | 984 | 60,504 | 0.12 | 0.10 |
| November | 1,400 | 1,000 | 1,180 | 70,215 | 0.13 | 0.12 |
| December | 5,000 | 1,000 | 2,084 | 128,141 | 0.25 | 0.22 |
| 1896. | | | | | | |
| January | 21,980 | 1,650 | 5,633 | 346,360 | 0.67 | 0.58 |
| February | 33,500 | 3,400 | 10,908 | 627,434 | 1.23 | 1.14 |
| March | | | | | | |

*Estimated monthly discharge of Potomac River at Point of Rocks, Maryland*—Continued.

[Drainage area, 9,654 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| April | | | | | | |
| May 11 to 31 | 5,900 | 2,150 | 3,286 | 136,872 | 0.27 | 0.34 |
| June | 14,180 | 1,650 | 5,982 | 355,953 | 0.69 | 0.62 |
| July | 28,000 | 3,800 | 9,613 | 591,080 | 1.15 | 1.00 |
| August | 9,850 | 2,150 | 4,134 | 254,190 | 0.49 | 0.43 |
| September | 24,150 | 1,650 | 2,665 | 158,579 | 0.31 | 0.28 |
| October | 171,660 | 2,700 | 13,470 | 828,238 | 1.61 | 1.40 |
| November | 28,000 | 2,700 | 7,368 | 438,426 | 0.84 | 0.76 |
| December | 12,100 | 2,700 | 5,385 | 331,110 | 0.64 | 0.56 |

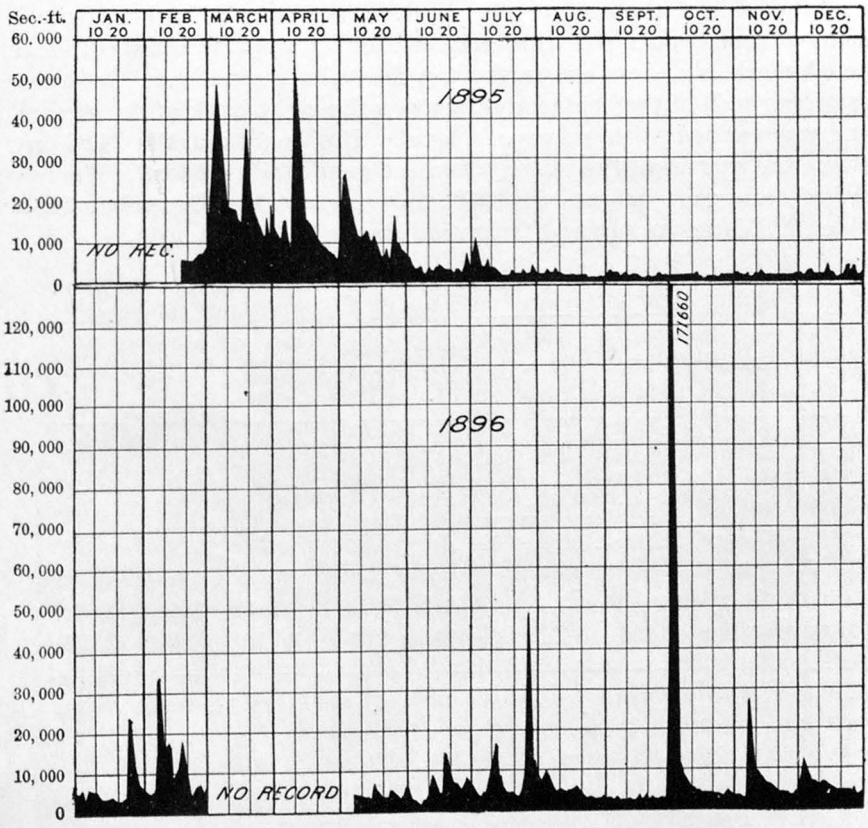



FIG. 3.—Discharge of Potomac River at Point of Rocks, Maryland, 1895–96.

## FREDERICK STATION ON MONOCACY RIVER.

This station was established by Mr. E. G. Paul, August 4, 1896, at the county iron bridge on the turnpike 4 miles northeast of Frederick, on the road leading from Frederick to Mount Pleasant, Maryland, about 2,000 feet above the mouth of Israel Creek and 3,000 feet below mouth of Tuscarora Creek on the Frederick atlas sheet. Latitude 39° 27′, longitude 77° 22′. The drainage area is 665 square miles. A wire gage was attached to the floor timber on the lower side of the bridge, the pulley being 115 feet from an initial point established for making soundings. The bridge has been measured, and distances from the initial point stenciled every 5 feet on the top timber of the bridge floor.

The stream at this station has two channels, being divided by a small, low island, which serves as a foundation for the middle pier of the bridge. The right channel was sounded and rated from the lower side of the bridge and the left channel from the upper side of the bridge, as these sections are freer from rocks than a continuous section on either side of the bridge. The stream is subject to high water and sudden floods, owing to the character of its upper watershed. The bench-mark is a cross cut in the top face of a capstone on the lower retaining wall of the bridge abutment on the right bank of the stream, and was verified with surveyor's level. The bench-mark is 24.97 feet above the surface of the water when the gage reads 4.2 feet. The record of daily gage heights for 1896, from August 4 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 11.

*List of discharge measurements made on Monocacy River at Frederick, Maryland.*

| No. | Date. | Hydrogapher. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 5 | E. G. Paul | 68 | 4.10 | 168 | 1.05 | 176 |
| 2 | Sept. 16 | do | 67 | 3.80 | 103 | 0.85 | 87 |
| 3 | Nov. 19 | do | 68 | 4.20 | 165 | 1.25 | 206 |
| | 1897. | | | | | | |
| 4 | Feb. 9 | E. G. Paul | 68 | 6.00 | 419 | 2.43 | 1,019 |
| 5 | Feb. 24 | C. C. Babb | 70 | 8.95 | 1,266 | 2.82 | 3,569 |

*Rating table for Monocacy River at Frederick, Maryland.*

[This table is applicable from August 1, 1896, to December 31, 1896.]

| Gage height | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.60 | 45 | 4.80 | 420 | 6.00 | 1,020 | 7.20 | 2,052 |
| 3.70 | 65 | 4.90 | 460 | 6.10 | 1,106 | 7.30 | 2,138 |
| 3.80 | 90 | 5.00 | 500 | 6.20 | 1,192 | 7.40 | 2,224 |
| 3.90 | 120 | 5.10 | 550 | 6.30 | 1,278 | 7.50 | 2,310 |
| 4.00 | 150 | 5.20 | 600 | 6.40 | 1,364 | 7.60 | 2,396 |
| 4.10 | 180 | 5.30 | 650 | 6.50 | 1,450 | 7.70 | 2,482 |
| 4.20 | 210 | 5.40 | 700 | 6.60 | 1,536 | 7.80 | 2,568 |
| 4.30 | 245 | 5.50 | 750 | 6.70 | 1,622 | 7.90 | 2,654 |
| 4.40 | 270 | 5.60 | 800 | 6.80 | 1,708 | 8.00 | 2,740 |
| 4.50 | 305 | 5.70 | 850 | 6.90 | 1,794 | | |
| 4.60 | 340 | 5.80 | 900 | 7.00 | 1,880 | | |
| 4.70 | 380 | 5.90 | 960 | 7.10 | 1,966 | | |

*Estimated monthly discharge of Monocacy River at Frederick, Maryland.*

[Drainage area, 665 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August 4 to 31 | 270 | 45 | 119 | 6,604 | 0.19 | 0.18 |
| September | 500 | 45 | 104 | 6,188 | 0.18 | 0.16 |
| October | 420 | 90 | 142 | 8,732 | 0.24 | 0.21 |
| November | 2,310 | 120 | 320 | 19,041 | 0.53 | 0.47 |
| December | 420 | 120 | 196 | 11,928 | 0.33 | 0.29 |

## CHAIN BRIDGE STATION ON POTOMAC RIVER.

This station is described in Bulletin No. 140, on pages 56 to 61. Observations (not published) were continued until February 22, 1896, when the station was discontinued, owing to the many unfavorable features interfering with the accuracy of results. No measurements were made during 1896. It is within the area mapped on the Mount Vernon sheet of the Topographic Atlas, in latitude 38° 56′ and longitude 77° 7′. A portion of the area drained is mapped on the Topographic Atlas sheets Frederick, Mount Vernon, Harpers Ferry, Winchester, Romney, Piedmont, Warrenton, Luray, Woodstock, Franklin, Beverly, Harrisonburg, Staunton, Monterey, Buckingham, and Lexington.

## JAMES RIVER BASIN.

### JAMES RIVER.

This stream is described in Bulletin 140, page 61, and its water powers are discussed by Prof. George F. Swain in Volume XVI of the Tenth Census reports.

#### GLASGOW STATION ON NORTH RIVER.

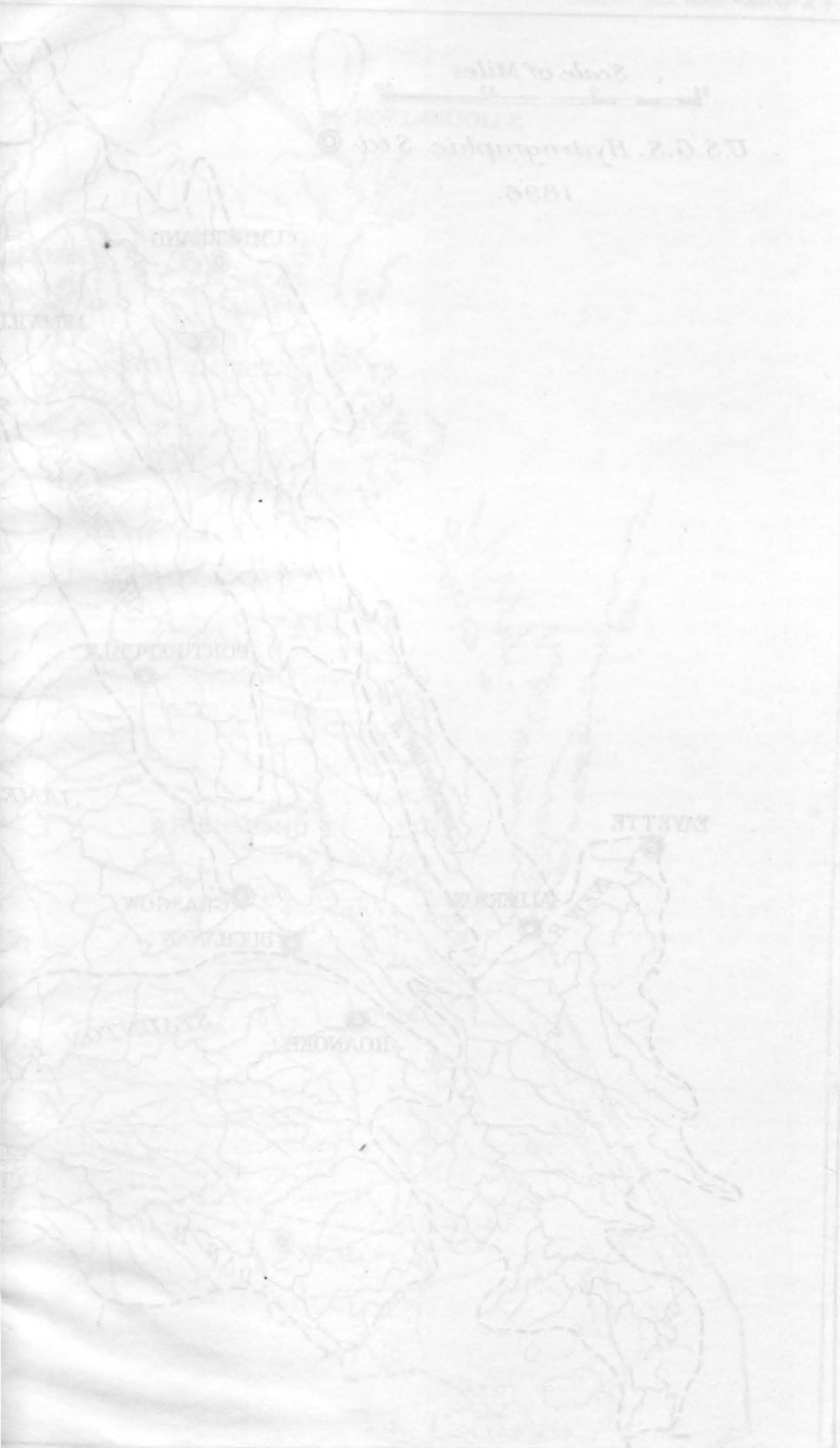
A station was established at the East Glasgow County bridge, about 1 mile above the mouth of North River, and observations were begun on August 21, 1895. The height of water is observed by means of a wire gage, the marks being placed on the guard rail on the lower side of the bridge. The distance from the top of the bridge over the gage to the zero is 32.20 feet, and that from the end of the weight to the marker of the gage is 27.86 feet. Discharge measurements were made at the rapids, 1 mile above the bridge. The initial point for sounding is on the right bank. The channel above the station is straight for about 200 feet, and curved below, the water moving with moderate velocity. At the place where observations of height are taken the stream is confined within its channel by the bridge abutments, and the bed is composed of rock and gravel, being fairly permanent. This station is in the Lexington quadrangle, in latitude 37° 38′, longitude 79° 27′. Its entire drainage area is mapped on the Lexington, Monterey, Staunton, and Natural Bridge sheets. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 11.

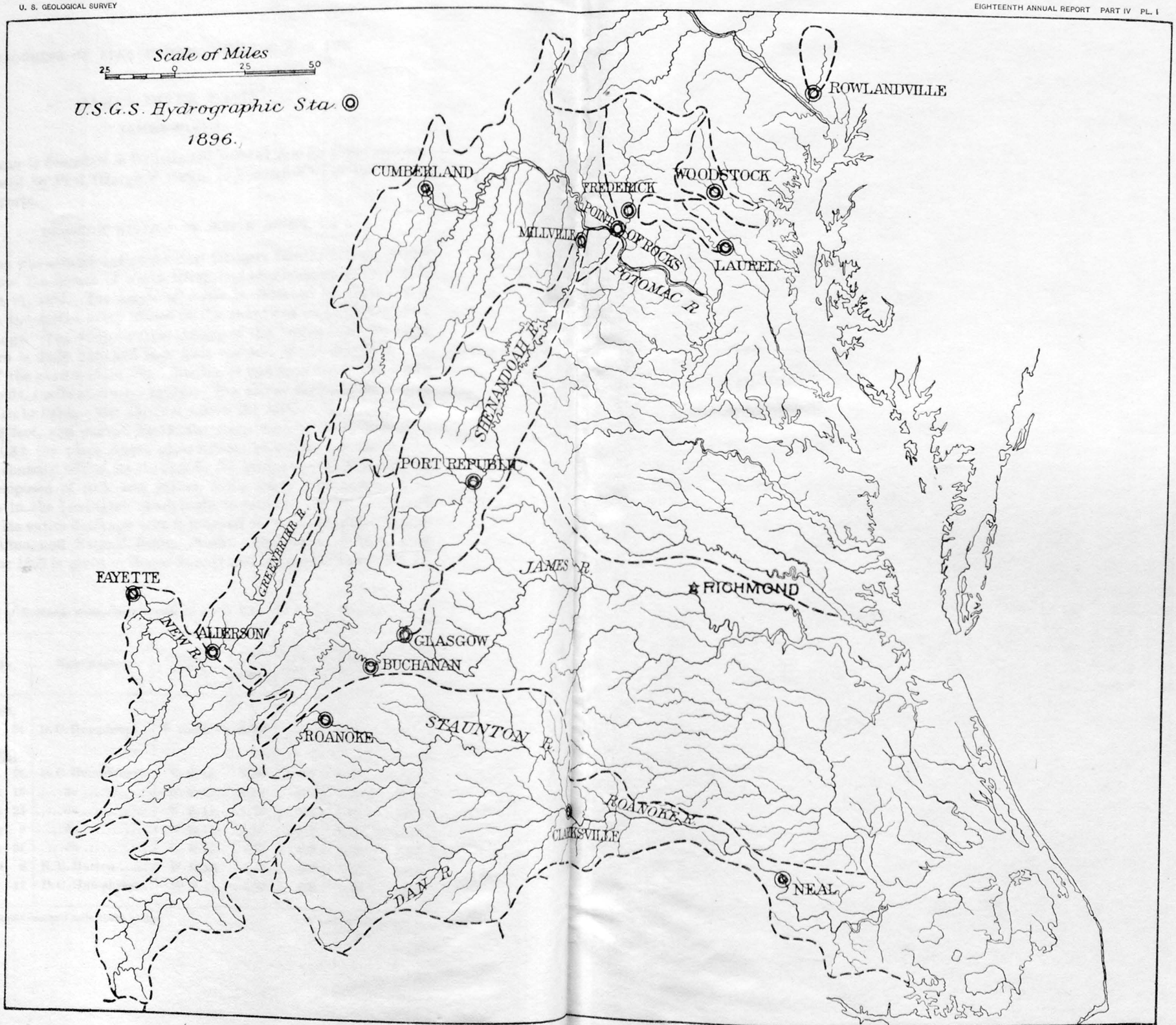
*List of discharge measurements made on North River at Glasgow, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 24 | D. C. Humphreys .. | W. and L.U. | 0.935 | 129 | 1.55 | *a* 201 |
| | 1896. | | | | | | |
| 2 | Jan. 25 | D. C. Humphreys .. | W. B. 1A. | 3.80 | 1,080 | 2.75 | 2,975 |
| 3 | May 16 | .....do ..... | W. B. 1A. | 1.88 | 672 | .75 | 504 |
| 4 | May 23 | .....do ..... | W. B. 1A. | 1.70 | 631 | .95 | 603 |
| 5 | July 9 | .....do ..... | W. B. 1A. | 7.58 | 1,818 | 5.57 | *b* 10,141 |
| 6 | July 24 | .....do ..... | W. B. 1A. | 1.75 | 623 | 1.02 | 634 |
| 7 | Sept. 8 | R. E. Hutton ..... | W. B. 1A. | 1.40 | 566 | .45 | 257 |
| 8 | Dec. 17 | D. C. Humphreys .. | W. B. 1A. | 1.80 | 698 | .69 | 480 |

*a* At rapids one-half mile above bridge.

*b* By surface velocities.






VIRGINIA DRAINAGE MAP.

*Rating table, North River, at Glasgow, Virginia.*

| Gage. | Discharge. | Gage. | Discharge. | Gage. | Discharge. | Gage. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.6 | 60 | 3.5 | 2,530 | 6.4 | 7,550 | 9.3 | 14,450 |
| 0.7 | 75 | 3.6 | 2,675 | 6.5 | 7,750 | 9.4 | 14,700 |
| 0.8 | 100 | 3.7 | 2,825 | 6.6 | 7,950 | 9.5 | 14,975 |
| 0.9 | 125 | 3.8 | 2,975 | 6.7 | 8,150 | 9.6 | 15,250 |
| 1.0 | 150 | 3.9 | 3,125 | 6.8 | 8,350 | 9.7 | 15,525 |
| 1.1 | 180 | 4.0 | 3,275 | 6.9 | 8,550 | 9.8 | 15,800 |
| 1.2 | 215 | 4.1 | 3,425 | 7.0 | 8,750 | 9.9 | 16,100 |
| 1.3 | 250 | 4.2 | 3,575 | 7.1 | 8,950 | 10.0 | 16,400 |
| 1.4 | 300 | 4.3 | 3,725 | 7.2 | 9,200 | 10.1 | 16,700 |
| 1.5 | 350 | 4.4 | 3,900 | 7.3 | 9,450 | 10.2 | 17,000 |
| 1.6 | 410 | 4.5 | 4,075 | 7.4 | 9,700 | 10.3 | 17,300 |
| 1.7 | 475 | 4.6 | 4,250 | 7.5 | 9,950 | 10.4 | 17,600 |
| 1.8 | 540 | 4.7 | 4,425 | 7.6 | 10,200 | 10.5 | 17,925 |
| 1.9 | 630 | 4.8 | 4,600 | 7.7 | 10,450 | 10.6 | 18,250 |
| 2.0 | 720 | 4.9 | 4,775 | 7.8 | 10,700 | 10.7 | 18,575 |
| 2.1 | 820 | 5.0 | 4,950 | 7.9 | 10,950 | 10.8 | 18,900 |
| 2.2 | 930 | 5.1 | 5,125 | 8.0 | 11,200 | 10.9 | 19,225 |
| 2.3 | 1,040 | 5.2 | 5,300 | 8.1 | 11,450 | 11.0 | 19,550 |
| 2.4 | 1,150 | 5.3 | 5,475 | 8.2 | 11,700 | 11.1 | 19,875 |
| 2.5 | 1,260 | 5.4 | 5,650 | 8.3 | 11,950 | 11.2 | 20,200 |
| 2.6 | 1,370 | 5.5 | 5,825 | 8.4 | 12,200 | 11.3 | 20,525 |
| 2.7 | 1,480 | 5.6 | 6,000 | 8.5 | 12.450 | 11.4 | 20,850 |
| 2.8 | 1,600 | 5.7 | 6,175 | 8.6 | 12,700 | 11.5 | 21,175 |
| 2.9 | 1,720 | 5.8 | 6,350 | 8.7 | 12,950 | 11.6 | 21,500 |
| 3.0 | 1,850 | 5.9 | 6,550 | 8.8 | 13,200 | 11.7 | 21,850 |
| 3.1 | 1,980 | 6.0 | 6,750 | 8.9 | 13,450 | 11.8 | 22,200 |
| 3.2 | 2,110 | 6.1 | 6,950 | 9.0 | 13,700 | 11.9 | 22,550 |
| 3.3 | 2,250 | 6.2 | 7,150 | 9.1 | 13,950 | 12.0 | 22,900 |
| 3.4 | 2,390 | 6.3 | 7,350 | 9.2 | 14,200 | | |

*Estimated monthly discharge of North River at Glasgow, Virginia.*

[Drainage area, 831 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| September | 132 | 75 | 114 | 6,783 | 0.15 | 0.14 |
| October | 137 | 92 | 111 | 6,825 | 0.15 | 0.13 |
| November | 187 | 137 | 156 | 9,283 | 0.21 | 0.19 |
| December | 875 | 117 | 272 | 16,725 | 0.38 | 0.33 |
| 1896. | | | | | | |
| January | 5,262 | 250 | 701 | 43,102 | 0.98 | 0.85 |
| February | 4,120 | 370 | 1,653 | 95,081 | 2.15 | 1.99 |
| March | 8,490 | 420 | 1,889 | 117,140 | 2.63 | 2.28 |
| April | 5,830 | 550 | 1,080 | 64,264 | 1.45 | 1.30 |
| May | ..... | 370 | 704 | 43,286 | 0.98 | 0.85 |
| June | 1,260 | 250 | 480 | 28,562 | 0.64 | 0.58 |
| July | 12,450 | 330 | 1,470 | 90,386 | 2.04 | 1.77 |
| August | 2,300 | 290 | 541 | 33,264 | 0.75 | 0.65 |
| September | 37,250 | 190 | 1,595 | 95,503 | 2.14 | 1.92 |
| October | 5,260 | 420 | 880 | 54,109 | 1.22 | 1.06 |
| November | 6,400 | 420 | 1,240 | 73,785 | 1.67 | 1.50 |
| December | 3,550 | 370 | 797 | 49,005 | 1.49 | 0.96 |
| Per annum | ..... | 190 | 1,086 | 787,487 | 18.14 | 1.33 |

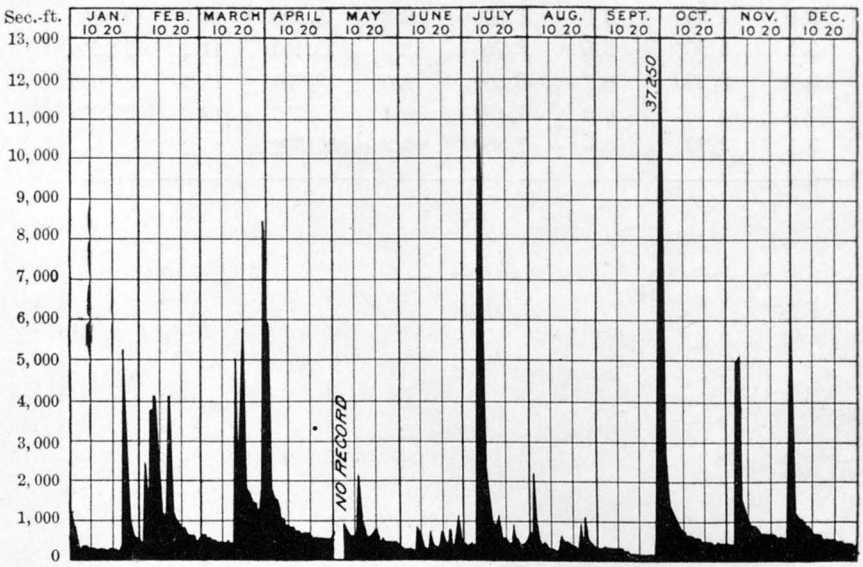



FIG. 4.—Discharge of North Fork of James River, Glasgow, Virginia, 1896.

## BUCHANAN STATION ON JAMES RIVER.

This point was described in Bulletin 140, page 63. It is on James River, about 20 miles above the mouth of North River, and one-half mile above mouth of Purgatory Creek, in latitude 37° 32′, longitude 79° 41′, in the Natural Bridge quadrangle of the topographic surveys. The area drained past this point is mapped on the Staunton, Monterey, Lewisburg, Dublin, Christiansburg, and Roanoke sheets. Measurements of river discharge were made at this point largely because of the fact that the Weather Bureau has maintained a gage here for about two years, with daily observations. The bridge at this point is of wood, is covered, and crosses the river on two spans.

The Weather Bureau rod was fastened to the upper face of the pier in the middle of the river, and is therefore about 150 feet from the shore. This gage has been washed out. A wire gage was therefore established at this point. The gage board is nailed on the outer rail on the lower side of the bridge, about 40 feet from the left bank, and referred to the zero of the old gage. The bench mark at this point is the offset in the pier, which is opposite the 4-foot mark of the old rod. The top of stone post under southwest corner of porch C. & O. passenger station is 22.68 above zero of gage.

Discharge measurements are made at a bridge about three-fourths of a mile above, as the section at the covered bridge where the gage is located is not favorable, owing to the sluggish current during low water. At the point where measurements are made, the initial point for soundings is taken on the right bank, the channel is nearly straight both above and below, and the bed of the stream changes but little, if any. The record of daily gage heights for 1896, from January 25 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 12.

*List of discharge measurements made on James River, at Buchanan, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 31 | C. C. Babb..... | 29h | —0.13 | 686 | 0.742 | 509 |
| 2 | Aug. 1 | .....do ..... | 29h | —0.19 | 525 | 1.04 | 543 |
| 3 | Sept. 6 | D. C. Humphreys.. | W B, 1 A | —0.48 | 386 | 1.03 | 397 |
| | 1896. | | | | | | |
| 4 | Jan. 25 | D. C. Humphreys .. | W B, 1 A | 4.13 | 2,526 | 2.11 | 5,337 |
| 5 | May 22 | .....do ..... | W B, 1 A | 1.90 | 915 | 2.44 | 2,234 |
| 6 | July 9 | .....do ..... | Floats | 11.51 | 4,033 | 6.74 | 27,144 |
| 7 | July 24 | .....do ..... | W B, 1 A | 0.56 | 822 | 1.38 | 1,142 |

*Rating table for James River, at Buchanan, Virginia.*

[This table is applicable from January 1, 1896, to January 1, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| —0.10 | 600 | 3.30 | 4,060 | 7.10 | 11,350 | 10.90 | 24,200 |
| —0.20 | 540 | 3.40 | 4,200 | 7.20 | 11,600 | 11.00 | 24,700 |
| —0.30 | 490 | 3.50 | 4,350 | 7.30 | 11,850 | 11.10 | 25,200 |
| —0.40 | 440 | 3.60 | 4,500 | 7.40 | 12,100 | 11.20 | 25,700 |
| —0.50 | 390 | 3.70 | 4,650 | 7.50 | 12,350 | 11.30 | 26,200 |
| —0.60 | 340 | 3.80 | 4,800 | 7.60 | 12,600 | 11.40 | 26,700 |
| 0.00 | 660 | 3.90 | 4,950 | 7.70 | 12,875 | 11.50 | 27,200 |
| 0.10 | 720 | 4.00 | 5,100 | 7.80 | 13,150 | 11.60 | 27,700 |
| 0.20 | 780 | 4.10 | 5,260 | 7.90 | 13,425 | 11.70 | 28,200 |
| 0.30 | 840 | 4.20 | 5,420 | 8.00 | 13,700 | 11.80 | 28,700 |
| 0.40 | 910 | 4.30 | 5,590 | 8.10 | 13,975 | 11.90 | 29,350 |
| 0.50 | 980 | 4.40 | 5,770 | 8.20 | 14,250 | 12.00 | 30,000 |
| 0.60 | 1,050 | 4.50 | 5,950 | 8.30 | 14,525 | 12.10 | 30,650 |
| 0.70 | 1,130 | 4.60 | 6,130 | 8.40 | 14,800 | 12.20 | 31,300 |
| 0.80 | 1,210 | 4.70 | 6,310 | 8.50 | 15,075 | 12.30 | 31,950 |
| 0.90 | 1,290 | 4.80 | 6,490 | 8.60 | 15,350 | 12.40 | 32,600 |
| 1.00 | 1,370 | 4.90 | 6,670 | 8.70 | 15,650 | 12.50 | 33,250 |
| 1.10 | 1,460 | 5.00 | 6,850 | 8.80 | 15,950 | 12.60 | 33,900 |
| 1.20 | 1,550 | 5.10 | 7,030 | 8.90 | 16,250 | 12.70 | 34,650 |
| 1.30 | 1,640 | 5.20 | 7,210 | 9.00 | 16,600 | 12.80 | 35,400 |
| 1.40 | 1,740 | 5.30 | 7,400 | 9.10 | 16,950 | 12.90 | 36,150 |
| 1.50 | 1,840 | 5.40 | 7,600 | 9.20 | 17,300 | 13.00 | 37,000 |
| 1.60 | 1,950 | 5.50 | 7,800 | 9.30 | 17,650 | 13.10 | 37,850 |
| 1.70 | 2,060 | 5.60 | 8,000 | 9.40 | 18,000 | 13.20 | 38,700 |
| 1.80 | 2,170 | 5.70 | 8,200 | 9.50 | 18,375 | 13.30 | 39,600 |
| 1.90 | 2,280 | 5.80 | 8,400 | 9.60 | 18,750 | 13.40 | 40,500 |
| 2.00 | 2,390 | 5.90 | 8,600 | 9.70 | 19,125 | 13.50 | 41,400 |
| 2.10 | 2,500 | 6.00 | 8,800 | 9.80 | 19,500 | 13.60 | 42,300 |
| 2.20 | 2,620 | 6.10 | 9,015 | 9.90 | 19,875 | 13.70 | 43,250 |
| 2.30 | 2,740 | 6.20 | 9,230 | 10.00 | 20,250 | 13.80 | 44,200 |
| 2.40 | 2,860 | 6.30 | 9,460 | 10.10 | 20,625 | 13.90 | 45,150 |
| 2.50 | 2,980 | 6.40 | 9,690 | 10.20 | 21,000 | 14.00 | 46,100 |
| 2.60 | 3,100 | 6.50 | 9,920 | 10.30 | 21,400 | 14.10 | 47,100 |
| 2.70 | 3,230 | 6.60 | 10,150 | 10.40 | 21,800 | 14.20 | 48,100 |
| 2.80 | 3,360 | 6.70 | 10,380 | 10.50 | 22,250 | 14.30 | 49,200 |
| 2.90 | 3,500 | 6.80 | 10,610 | 10.60 | 22,700 | 14.40 | 50,300 |
| 3.00 | 3,640 | 6.90 | 10,850 | 10.70 | 23,200 | 14.50 | 51,450 |
| 3.10 | 3,780 | 7.00 | 11,100 | 10.80 | 23,700 | 14.60 | 52,600 |
| 3.20 | 3,920 | | | | | | |

*Estimated monthly discharge of James River at Buchanan, Virginia.*

[Drainage area, 2,058 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| September | 490 | 390 | 430 | 25,587 | 0.19 | 0.17 |
| October | 440 | 440 | 440 | 27,055 | 0.20 | 0.17 |
| November | 600 | 490 | 596 | 35,464 | 0.26 | 0.23 |
| December 1 to 28 | 3,640 | 600 | 1,214 | 67,421 | 0.49 | 0.47 |
| 1896. | | | | | | |
| January | a5,100 | 600 | 1,008 | 61,982 | 0.56 | 0.49 |
| February | 7,210 | 980 | 2,510 | 144,351 | 1.31 | 1.21 |
| March | 16,950 | 980 | 3,385 | 208,126 | 1.88 | 1.63 |
| April | 11,100 | 440 | 1,814 | 107,921 | 0.98 | 0.88 |
| May | 1,895 | 340 | 992 | 60,996 | 0.55 | 0.48 |
| June | 2,445 | 780 | 1,136 | 67,617 | 0.61 | 0.55 |
| July | 21,200 | 780 | 2,311 | 142,099 | 1.29 | 1.12 |
| August | 1,840 | 600 | 962 | 59,177 | 0.54 | 0.46 |
| September | 31,950 | 490 | 1,566 | 93,183 | 0.84 | 0.76 |
| October | 7,400 | 540 | 1,083 | 66,565 | 0.60 | 0.52 |
| November | 11,600 | 540 | 1,333 | 79,335 | 0.72 | 0.64 |
| December | 5,770 | 780 | 1,469 | 90,347 | 0.89 | 0.71 |
| Per annum | 31,950 | 340 | 1,631 | 1,181,699 | 10.77 | 0.79 |

*a* For the first twenty-four days of January the gage was not read, but the river is known to have been nearly stationary and about zero. The assumption has been made that the reading was zero.

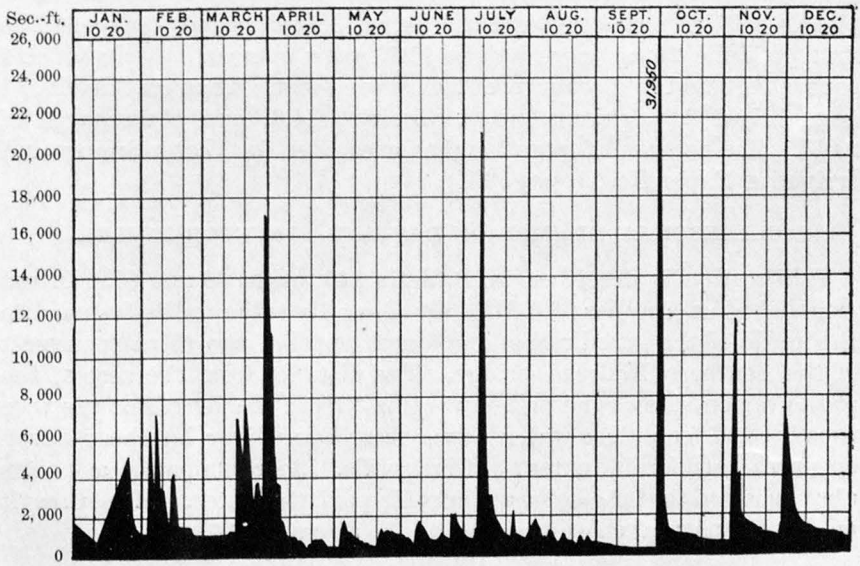



FIG. 5.—Discharge of James River at Buchanan, Virginia, 1896.

## SOUTH ATLANTIC WATERSHED.

The topography and water powers of this region are discussed in detail by Mr. George F. Swain, special agent, in Volume XVI of the report of the Tenth Census, pages 667 to 824. Other references to various localities comprised in this classification may be found in Bulletin 140 of the United States Geological Survey.

### ROANOKE RIVER.

The main Roanoke River is formed by the junction of the Dan and Staunton at Clarksville, near the southern boundary of Virginia. The Staunton River is, however, in its upper portion also known as the Roanoke.

#### ROANOKE STATION ON ROANOKE RIVER.

This station was established by Prof. D. C. Humphreys July 10, 1896. It is located in the Roanoke quadrangle, in latitude 37° 16′, longitude 79° 56′, and is in the edge of the town of Roanoke, Va., on the Walnut street car line. The drainage area is 388 square miles, and is mapped on the Roanoke and Christiansburg sheets.

The gage is of wire, and the scale is painted in feet and tenths on a horizontal rod fastened to the floor of the bridge. The distance from the end of weight to marker is 24.39 feet. The top of lower end of first floor beam is 21.99 feet above datum of gage height. The right bank is above high water, but the left may overflow at extreme high water. The channel is nearly straight and the current good. The observer is A. B. Rawn, son of Mr. J. C. Rawn, a prominent engineer of Roanoke.

Two discharge measurements were made in 1896 by Professor Humphreys, with Haskell meter No. 1 A, at Walnut street bridge. The first, on June 26, at gage height 1.21, gave a mean velocity of 128 square feet and a discharge of 244 second-feet. That on July 10, at gage height 3.28, gave a mean velocity of 4.34 and a discharge of 2,057. The records of gage heights are given in Water-Supply and Irrigation Paper No. 11, page 11.

#### CLARKSVILLE STATION ON DAN AND STAUNTON RIVERS.

This station is described in Bulletin 140, pages 66 and 67. It was established on October 28, 1895. On Dan River the rod is fastened to the inside of the guard rail of the fourth panel of the third span west of the Southern Railroad bridge. The distance from the zero of the rod to the outside of the pulley wheel is 3 feet; the length of the wire rope is 33.17 feet. The water power from Dan River has been developed to a considerable extent at Clarksville. An examination at points above showed that the dams at Danville pond the water, and as a result modify the natural characteristics of the stream.

The gage on Staunton River is fastened to the inside of the guard rail of the fourth panel of the third span from the west. The distance from the zero to the outside of the pulley wheel is 3 feet; the length of the wire gage is 33 feet; the distance of the water surface below the top and upper end of the third-floor beam of the second span from the west was 27.15 feet when the gage height was 0.25 foot. The distance from the east abutment of the Dan River bridge to the west abutment of the Staunton River bridge is 165 feet. The observer is Lucius Wootton.

About 4 miles above the junction of the Dan and Staunton rivers is a cut-off, apparently occupying an old channel, diverting water from the Dan to the Staunton. The banks are 10 feet high and about 225 feet apart. At its mouth is a shoal or riffle about 70 feet long. The average width of the water surface in the channel is 150 feet. The total fall between the two rivers was estimated to be 2 feet, occurring principally at the riffle at the mouth of the channel. The total length of the channel is about 1,000 feet. This cut-off, by carrying water from the Dan, vitiates the separate computations of discharge made at the stations below, but does not affect the total discharge for the Roanoke. The Weather Bureau has a gage on Roanoke River about 1,000 feet below the railroad crossing. This gage is attached firmly to the projecting trunk of an old tree. The records of daily gage heights for 1896, from February 7 to December 31, are given in Water-Supply and Irrigation Paper No. 11, pages 12 and 13.

*List of discharge measurements made on Dan River at Clarksville, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second. | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 2 | C. C. Babb..... | 29 | 0.38 | 591 | 1.31 | 773 |
| 2 | Oct. 28 | .....do ..... | 29 | 0.65 | 719 | 1.44 | 1,032 |
| 3 | Dec. 5 | .....do ..... | 62 | 1.12 | 865 | 1.60 | 1,382 |
| | 1896. | | | | | | |
| 4 | Apr. 22 | E. W. Myers..... | 21 | 2.43 | 1,209 | 1.89 | 2,291 |
| 5*a* | May 5 | .....do ..... | 21 | 2.30 | 1,465 | 1.83 | 2,694 |
| 6 | May 26 | .....do ..... | 21 | 2.30 | 1,465 | 1.47 | 2,155 |
| 7 | July 15 | .....do ..... | 21 | 3.50 | 1,932 | 2.39 | 4,626 |
| 8 | Sept. 15 | A. P. Davis ..... | 68 | 1.70 | 953 | 1.50 | 1,433 |

*a* For measurement No. 5 channel had cut out badly, averaging almost all way across a cut of 1 foot.

*Rating table for Dan River at Clarksville, Virginia.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 590 | 3.10 | 4,575 | 6.20 | 12,650 | 9.30 | 21,075 |
| 0.10 | 645 | 3.20 | 4,800 | 6.30 | 12,925 | 9.40 | 21,350 |
| 0.20 | 700 | 3.30 | 5,025 | 6.40 | 13,200 | 9.50 | 21,625 |
| 0.30 | 760 | 3.40 | 5,250 | 6.50 | 13,475 | 9.60 | 21,900 |
| 0.40 | 825 | 3.50 | 5,475 | 6.60 | 13,750 | 9.70 | 22,175 |
| 0.50 | 895 | 3.60 | 5,725 | 6.70 | 14,025 | 9.80 | 22,450 |
| 0.60 | 965 | 3.70 | 5,975 | 6.80 | 14,300 | 9.90 | 22,725 |
| 0.70 | 1,040 | 3.80 | 6,225 | 6.90 | 14,575 | 10.00 | 23,000 |
| 0.80 | 1,115 | 3.90 | 6,475 | 7.00 | 14,800 | 10.10 | 23,275 |
| 0.90 | 1,195 | 4.00 | 6,725 | 7.10 | 15,075 | 10.20 | 23,550 |
| 1.00 | 1,280 | 4.10 | 6,975 | 7.20 | 15,350 | 10.30 | 23,825 |
| 1.10 | 1,365 | 4.20 | 7,225 | 7.30 | 15,625 | 10.40 | 24,100 |
| 1.20 | 1,450 | 4.30 | 7,475 | 7.40 | 15,900 | 10.50 | 24,375 |
| 1.30 | 1,545 | 4.40 | 7,725 | 7.50 | 16,175 | 10.60 | 24,650 |
| 1.40 | 1,645 | 4.50 | 7,975 | 7.60 | 16,450 | 10.70 | 24,925 |
| 1.50 | 1,760 | 4.60 | 8,250 | 7.70 | 16,725 | 10.80 | 25,200 |
| 1.60 | 1,880 | 4.70 | 8,525 | 7.80 | 17,000 | 10.90 | 25,475 |
| 1.70 | 2,000 | 4.80 | 8,800 | 7.90 | 17,275 | 11.00 | 25,750 |
| 1.80 | 2,130 | 4.90 | 9,075 | 8.00 | 17,550 | 11.10 | 26,025 |
| 1.90 | 2,275 | 5.00 | 9,250 | 8.10 | 17,825 | 11.20 | 26,300 |
| 2.00 | 2,425 | 5.10 | 9,525 | 8.20 | 18,100 | 11.30 | 26,575 |
| 2.10 | 2,575 | 5.20 | 9,800 | 8.30 | 18,375 | 11.40 | 26,850 |
| 2.20 | 2,725 | 5.30 | 10,075 | 8.40 | 18,650 | 11.50 | 27,125 |
| 2.30 | 2,900 | 5.40 | 10,350 | 8.50 | 18,925 | 11.60 | 27,400 |
| 2.40 | 3,075 | 5.50 | 10,625 | 8.60 | 19,200 | 11.70 | 27,675 |
| 2.50 | 3,250 | 5.60 | 10,900 | 8.70 | 19,475 | 11.80 | 27,950 |
| 2.60 | 3,525 | 5.70 | 11,175 | 8.80 | 19,750 | 11.90 | 28,225 |
| 2.70 | 3,725 | 5.80 | 11,450 | 8.90 | 20,025 | 12.00 | 28,500 |
| 2.80 | 3,925 | 5.90 | 11,825 | 9.00 | 20,300 | 12.10 | 28,775 |
| 2.90 | 4,125 | 6.00 | 12,100 | 9.10 | 20,575 | 12.20 | 29,050 |
| 3.00 | 4,350 | 6.10 | 12,375 | 9.20 | 20,800 | | |

*Estimated monthly discharge of Dan River at Clarksville, Virginia.*

[Drainage area, 3,700 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| February | 20,163 | 2,091 | 5,070 | 291,626 | 1.48 | 1.37 |
| March | 17,245 | 2,231 | 4,935 | 303,453 | 1.53 | 1.33 |
| April | 24,017 | 2,091 | 4,777 | 284,231 | 1.44 | 1.29 |
| May | 7,650 | 1,255 | 2,715 | 166,940 | 0.84 | 0.73 |
| June | 5,900 | 1,255 | 2,145 | 127,636 | 0.64 | 0.58 |
| July | a33,000 | 1,131 | 4,800 | 295,152 | 1.49 | 1.29 |
| August | 2,605 | 839 | 1,204 | 74,034 | 0.37 | 0.32 |
| September | 10,542 | 825 | 1,373 | 81,693 | 0.41 | 0.37 |
| October | 20,218 | 1,131 | 1,856 | 114,125 | 0.58 | 0.50 |
| November | 14,620 | 1,251 | 2,260 | 134,470 | 0.68 | 0.61 |
| December | 8,855 | 1,469 | 2,365 | 145,424 | 0.72 | 0.63 |

*a* Estimated.

*List of discharge measurements made on Staunton River at Clarksville, Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 3 | C. C. Babb | 29 | 0.07 | 550 | 0.97 | 533 |
| 2 | Oct. 28 | do | 76 | 0.28 | 659 | 1.31 | 861 |
| 3 | Dec. 5 | do | 62 | 0.61 | 917 | 1.25 | 1,151 |
| | 1896. | | | | | | |
| 4 | April 22 | E. W. Myers | 21 | 3.43 | 1,256 | 1.58 | 1,971 |
| 5 | May 26 | do | 21 | 3.20 | 1,401 | 1.39 | 1,956 |
| 6 | July 15 | do | 21 | 4.70 | 1,890 | 2.25 | 4,252 |
| 7 | Sept. 15 | A. P. Davis | 68 | 2.00 | 723 | 1.03 | 748 |

*Rating table for Staunton River at Clarksville, Virginia.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 685 | 2 20 | 3,395 | 5.50 | 11,475 | 8.80 | 20,800 |
| —0.10 | 630 | 2.30 | 3,575 | 5.60 | 11,750 | 8.90 | 21,100 |
| —0.20 | 580 | 2.40 | 3,760 | 5.70 | 12,025 | 9.00 | 21,400 |
| —0.30 | 535 | 2.50 | 3,950 | 5.80 | 12,300 | 9.10 | 21,700 |
| —0.40 | 500 | 2.60 | 4,150 | 5.90 | 12,575 | 9.20 | 22,000 |
| —0.50 | 470 | 2.70 | 4,370 | 6.00 | 12,850 | 9.30 | 22,300 |
| —0.60 | 440 | 2.80 | 4,600 | 6.10 | 13,125 | 9.40 | 22,600 |
| —0.70 | 410 | 2.90 | 4,850 | 6.20 | 13,400 | 9.50 | 22,900 |
| —0.80 | 380 | 3.00 | 5,100 | 6.30 | 13,675 | 9.60 | 23,200 |
| —0.90 | 350 | 3.10 | 5,350 | 6.40 | 13,950 | 9.70 | 23,500 |
| —1.00 | 330 | 3.20 | 5,600 | 6.50 | 14,225 | 9.80 | 23,800 |
| 0.00 | 685 | 3.30 | 5,850 | 6.60 | 14,500 | 9.90 | 24,100 |
| 0.10 | 745 | 3.40 | 6,100 | 6.70 | 14,775 | 10.00 | 24,400 |
| 0.20 | 820 | 3.50 | 6,350 | 6.80 | 15,050 | 10.10 | 24,700 |
| 0.30 | 900 | 3.60 | 6,600 | 6.90 | 15,325 | 10.20 | 25,000 |
| 0.40 | 980 | 3.70 | 6,850 | 7.00 | 15,600 | 10.30 | 25,300 |
| 0.50 | 1,065 | 3.80 | 7,100 | 7.10 | 15,890 | 10.40 | 25,600 |
| 0.60 | 1,160 | 3.90 | 7,350 | 7.20 | 16,180 | 10.50 | 25,900 |
| 0.70 | 1,255 | 4.00 | 7,600 | 7.30 | 16,370 | 10.60 | 26,200 |
| 0.80 | 1,350 | 4.10 | 7,850 | 7.40 | 16,660 | 10.70 | 26,500 |
| 0.90 | 1,455 | 4.20 | 8,100 | 7.50 | 16,950 | 10.80 | 26,800 |
| 1.00 | 1,560 | 4.30 | 8,350 | 7.60 | 17,240 | 10.90 | 27,100 |
| 1.10 | 1,680 | 4.40 | 8,600 | 7.70 | 17,530 | 11.00 | 27,400 |
| 1.20 | 1,810 | 4.50 | 8,850 | 7.80 | 17,820 | 11.10 | 27,700 |
| 1.30 | 1,950 | 4.60 | 9,100 | 7.90 | 18,110 | 11.20 | 28,000 |
| 1.40 | 2,095 | 4.70 | 9,350 | 8.00 | 18,400 | 11.30 | 28,300 |
| 1.50 | 2,240 | 4.80 | 9,600 | 8.10 | 18,700 | 11.40 | 28,600 |
| 1.60 | 2,395 | 4.90 | 9,850 | 8.20 | 19,000 | 11.50 | 28,900 |
| 1.70 | 2,555 | 5.00 | 10,100 | 8.30 | 19,300 | 11.60 | 29,200 |
| 1.80 | 2,715 | 5.10 | 10,375 | 8.40 | 19,600 | 11.70 | 29,500 |
| 1.90 | 2,880 | 5.20 | 10,650 | 8.50 | 19,900 | 11.80 | 29,800 |
| 2.00 | 3,050 | 5.30 | 10,925 | 8.60 | 20,200 | 11.90 | 30,100 |
| 2.10 | 3,220 | 5.40 | 11,200 | 8.70 | 20,500 | 12.00 | 30,400 |

*Estimated monthly discharge of Staunton River at Clarksville, Virginia.*

[Drainage area, 3,450 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896 | | | | | | |
| February | 19,660 | 1,852 | 4,554 | 261,946 | 1.42 | 1.32 |
| March | 16,554 | 1,852 | 3,084 | 189,635 | 1.02 | 0.89 |
| April | 23,890 | 1,732 | 3,990 | 237,405 | 1.28 | 1.15 |
| May | 7,325 | 916 | 2,240 | 137,737 | 0.75 | 0.65 |
| June | 5,450 | 680 | 1,608 | 95,682 | 0.52 | 0.46 |
| July | a36,000 | 823 | 3,611 | 222,040 | 1.20 | 1.04 |
| August | 2,459 | 635 | 860 | 52,881 | 0.28 | 0.24 |
| September | 3,899 | 645 | 1,150 | 68,425 | 0.37 | 0.33 |
| October | 19,900 | 892 | 1,620 | 99,614 | 0.54 | 0.47 |
| November | 14,005 | 1,023 | 1,979 | 117,850 | 0.63 | 0.57 |
| December | 5,125 | 1,245 | 2,008 | 123,472 | 0.67 | 0.58 |

*a* Estimated.

## NEAL STATION ON ROANOKE RIVER.

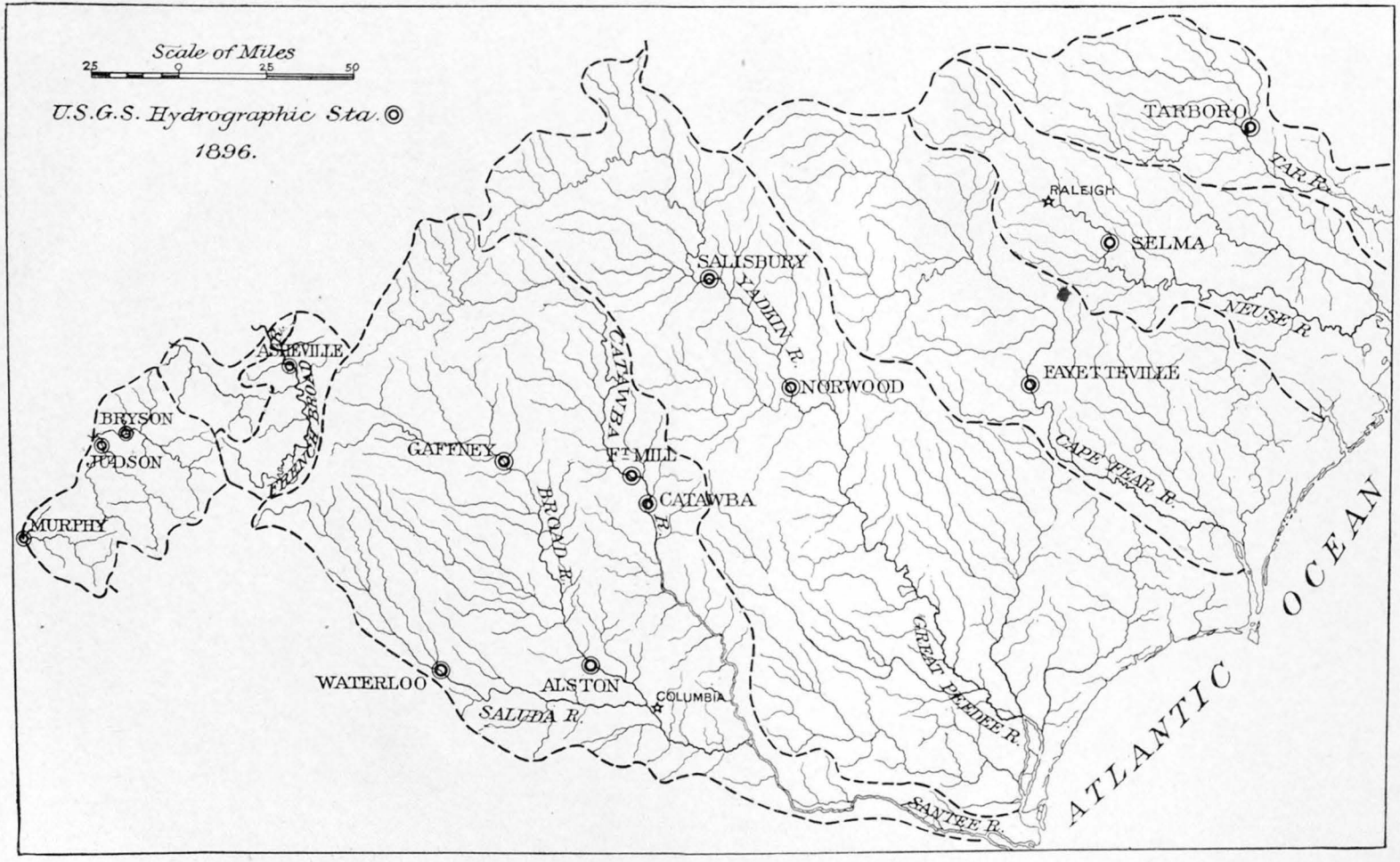
The gage on this stream is on the Norfolk and Carolina Railroad bridge near Neal, North Carolina. The zero of the gage rod is over the center of the fourth floor beam of the second span from the north end of the bridge. The distance from the zero of the rod to the outer rim of the pulley is 2.47 feet, and the distance from the end of the weight to the pointer on the wire is 44.66 feet. The section is a fairly good one, the course of the river being straight for some distance above and below the station, and the bottom smooth, but being muddy it is apt to cut out in seasons of high water. Both banks are also liable to overflow. The observer is W. M. Adams, Neal, North Carolina. The seven discharge measurements given in the table are the basis for the construction of a rating table for this station. The record of daily gage heights for 1896, from July 27 to December 31, is found in Water-Supply and Irrigation Paper No. 11, page 15.

*List of discharge measurements made on Roanoke River at Neal, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896 | | | | | | |
| 1 | July 27.. | E. W. Myers ... | 2154 | 7.05 | 3,152 | 1.53 | 4,849 |
| 2 | Sept. 7 .. | .....do ..... | 2154 | 1.31 | 2,148 | 1.21 | 2,610 |
| 3 | Dec. 19 .. | .....do ..... | 2154 | 11.60 | 5,214 | 1.76 | 9,180 |
| | 1897 | | | | | | |
| 4 | Jan. 23 .. | E. W. Myers ... | 2154 | 12.65 | 5,551 | 2.37 | 13,155 |
| 5 | Feb. 27 .. | .....do ..... | 2154 | 27.95 | 44,666 | 1.44 | 64,132 |
| 6 | Mar. 17.. | .....do ..... | 2154 | 24.71 | 31,590 | 1.19 | 37,659 |
| 7 | May 17. . | .....do ..... | 2154 | 18.40 | 7,240 | 2.65 | 19,219 |

*Rating table for Roanoke River at Neal, North Carolina.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 2,200 | 2.70 | 2,995 | 5.40 | 4,015 | 8.10 | 5,790 |
| 0.10 | 2,210 | 2.80 | 3,030 | 5.50 | 4,060 | 8.20 | 5,880 |
| 0.20 | 2,220 | 2.90 | 3,065 | 5.60 | 4,105 | 8.30 | 5,970 |
| 0.30 | 2,230 | 3.00 | 3,100 | 5.70 | 4,150 | 8.40 | 6,060 |
| 0.40 | 2,245 | 3.10 | 3,135 | 5.80 | 4,200 | 8.50 | 6,150 |
| 0.50 | 2,265 | 3.20 | 3,170 | 5.90 | 4,250 | 8.60 | 6,240 |
| 0.60 | 2,285 | 3.30 | 3,205 | 6.00 | 4,300 | 8.70 | 6,330 |
| 0.70 | 2,310 | 3.40 | 3,240 | 6.10 | 4,350 | 8.80 | 6,420 |
| 0.80 | 2,335 | 3.50 | 3,275 | 6.20 | 4,400 | 8.90 | 6,510 |
| 0.90 | 2,365 | 3.60 | 3,310 | 6.30 | 4,450 | 9.00 | 6,600 |
| 1.00 | 2,400 | 3.70 | 3,345 | 6.40 | 4,500 | 9.10 | 6,690 |
| 1.10 | 2,435 | 3.80 | 3,380 | 6.50 | 4,555 | 9.20 | 6,780 |
| 1.20 | 2,470 | 3.90 | 3,415 | 6.60 | 4,610 | 9.30 | 6,870 |
| 1.30 | 2,505 | 4.00 | 3,450 | 6.70 | 4,665 | 9.40 | 6,960 |
| 1.40 | 2,540 | 4.10 | 3,490 | 6.80 | 4,720 | 9.50 | 7,050 |
| 1.50 | 2,575 | 4.20 | 3,530 | 6.90 | 4,775 | 9.60 | 7,140 |
| 1.60 | 2,610 | 4.30 | 3,570 | 7.00 | 4,850 | 9.70 | 7,230 |
| 1.70 | 2,645 | 4.40 | 3,610 | 7.10 | 4,925 | 9.80 | 7,320 |
| 1.80 | 2,680 | 4.50 | 3,650 | 7.20 | 5,010 | 9.90 | 7,410 |
| 1.90 | 2,715 | 4.60 | 3,690 | 7.30 | 5,095 | 10.00 | 7,500 |
| 2.00 | 2,750 | 4.70 | 3,730 | 7.40 | 5,180 | 10.10 | 7,600 |
| 2.10 | 2,785 | 4.80 | 3,770 | 7.50 | 5,265 | 10.20 | 7,700 |
| 2.20 | 2,820 | 4.90 | 3,810 | 7.60 | 5,350 | 10.30 | 7,800 |
| 2.30 | 2,855 | 5.00 | 3,850 | 7.70 | 5,435 | 10.40 | 7,900 |
| 2.40 | 2,890 | 5.10 | 3,890 | 7.80 | 5,420 | 10.50 | 8,000 |
| 2.50 | 2,925 | 5.20 | 3,930 | 7.90 | 5,510 | 10.60 | 8,100 |
| 2.60 | 2,960 | 5.30 | 3,970 | 8.00 | 5,700 | 10.70 | 8,200 |




CAROLINA DRAINAGE MAP.

*Rating table for Roanoke River at Neal, North Carolina*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* |
| 10.80 | 8,300 | 15.20 | 13,905 | 19.50 | 21,160 | 23.80 | 33,740 |
| 10.90 | 8,400 | 15.30 | 14,060 | 19.60 | 21,600 | 23.90 | 34,140 |
| 11.00 | 8,500 | 15.40 | 14,215 | 19.70 | 21,820 | 24.00 | 34,550 |
| 11.10 | 8,600 | 15.50 | 14,370 | 19.80 | 22,040 | 24.10 | 34,970 |
| 11.20 | 8,710 | 15.60 | 14,525 | 19.90 | 22,270 | 24.20 | 35,400 |
| 11.30 | 8,820 | 15.70 | 14,680 | 20.00 | 22,500 | 24.30 | 35,840 |
| 11.40 | 8,930 | 15.80 | 14,835 | 20.10 | 22,730 | 24.40 | 36,290 |
| 11.50 | 9,040 | 15.90 | 14,990 | 20.20 | 22,970 | 24.50 | 36,750 |
| 11.60 | 9,150 | 16.00 | 15,150 | 20.30 | 23,220 | 24.60 | 37,220 |
| 11.70 | 9,260 | 16.10 | 15,310 | 20.40 | 23,470 | 24.70 | 37,700 |
| 11.80 | 9,370 | 16.20 | 15,470 | 20.50 | 23,720 | 24.80 | 38,190 |
| 11.90 | 9,485 | 16.30 | 15,630 | 20.60 | 23,970 | 24.90 | 38,690 |
| 12.00 | 9,600 | 16.40 | 15,790 | 20.70 | 24,220 | 25.00 | 39,200 |
| 12.10 | 9,715 | 16.50 | 15,950 | 20.80 | 24,480 | 25.10 | 39,720 |
| 12.20 | 9,830 | 16.60 | 16,110 | 20.90 | 24,740 | 25.20 | 40,250 |
| 12.30 | 9,950 | 16.70 | 16,270 | 21.00 | 25,000 | 25.30 | 40,790 |
| 12.40 | 10,070 | 16.80 | 16,430 | 21.10 | 25,260 | 25.40 | 41,340 |
| 12.50 | 10,190 | 16.90 | 16,590 | 21.20 | 25,520 | 25.50 | 41,900 |
| 12.60 | 10,310 | 17.00 | 16,750 | 21.30 | 25,780 | 25.60 | 42,460 |
| 12.70 | 10,430 | 17.10 | 16,910 | 21.40 | 26,050 | 25.70 | 43,030 |
| 12.80 | 10,550 | 17.20 | 17,070 | 21.50 | 26,320 | 25.80 | 43,610 |
| 12.90 | 10,670 | 17.30 | 17,235 | 21.60 | 26,590 | 25.90 | 44,200 |
| 13.00 | 10,800 | 17.40 | 17,400 | 21.70 | 26,860 | 26.00 | 44,800 |
| 13.10 | 10,930 | 17.50 | 17,565 | 21.80 | 27,140 | 26.10 | 45,420 |
| 13.20 | 11,060 | 17.60 | 17,730 | 21.90 | 27,420 | 26.20 | 46,060 |
| 13.30 | 11,190 | 17.70 | 17,895 | 22.00 | 27,700 | 26.30 | 46,730 |
| 13.40 | 11,325 | 17.80 | 18,060 | 22.10 | 27,990 | 26.40 | 47,430 |
| 13.50 | 11,460 | 17.90 | 18,225 | 22.20 | 28,280 | 26.50 | 48,170 |
| 13.60 | 11,595 | 18.00 | 18,400 | 22.30 | 28,580 | 26.60 | 48,950 |
| 13.70 | 11,730 | 18.10 | 18,575 | 22.40 | 28,880 | 26.70 | 49,770 |
| 13.80 | 11,870 | 18.20 | 18,750 | 22.50 | 29,190 | 26.80 | 50,630 |
| 13.90 | 12,010 | 18.30 | 18,930 | 22.60 | 29,500 | 26.90 | 51,540 |
| 14.00 | 12,150 | 18.40 | 19,120 | 22.70 | 29,810 | 27.00 | 52,500 |
| 14.10 | 12,290 | 18.50 | 19,310 | 22.80 | 30,130 | 27.10 | 53,500 |
| 14.20 | 12,430 | 18.60 | 19,500 | 22.90 | 30,460 | 27.20 | 54,500 |
| 14.30 | 12,570 | 18.70 | 19,690 | 23.00 | 30,800 | 27.30 | 55,600 |
| 14.40 | 12,715 | 18.80 | 19,890 | 23.10 | 31,140 | 27.40 | 56,700 |
| 14.50 | 12,860 | 18.90 | 20,090 | 23.20 | 31,490 | 27.50 | 57,900 |
| 14.60 | 13,005 | 19.00 | 20,300 | 23.30 | 31,840 | 27.60 | 59,100 |
| 14.70 | 13,150 | 19.10 | 20,510 | 23.40 | 32,200 | 27.70 | 60,400 |
| 14.80 | 13,300 | 19.20 | 20,720 | 23.50 | 32,570 | 27.80 | 61,700 |
| 14.90 | 13,450 | 19.30 | 20,940 | 23.60 | 32,950 | 27.90 | 63,000 |
| 15.00 | 13,600 | 19.40 | 21,380 | 23.70 | 33,340 | 28.00 | 64,300 |
| 15.10 | 13,750 | | | | | | |

*Estimated monthly discharge of Roanoke River at Neal, North Carolina.*

[Drainage area, 8,717 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 4,105 | 2,750 | 3,154 | 193,933 | 0.41 | 0.36 |
| September | 6,510 | 2,400 | 3,217 | 191,424 | 0.41 | 0.37 |
| October | 39,720 | 2,890 | 9,117 | 560,586 | 1.21 | 1.05 |
| November | 23,220 | 2,890 | 5,896 | 350,836 | 0.75 | 0.68 |
| December | 21,820 | 3,415 | 7,423 | 456,425 | 0.98 | 0.85 |

## TAR, NEUSE, AND CAPE FEAR RIVERS.

### TARBORO STATION ON TAR RIVER.

The gage on this stream is on the Atlantic Coast Line bridge that crosses the river at Tarboro, North Carolina, and was put in July 25, 1896. The zero of the gage is over the center of the fifth floor beam from the east end of the bridge. The outer rim of the pulley is 3 feet from the zero of the gage, and the distance from the end of the weight to the pointer on the wire is 38.30 feet. The gage reading is zero when the weight touches the bottom of the stream. The river here is a little obstructed by sand bars, and the gage was put in here only temporarily and will soon be moved to the new steel county bridge which crosses about 100 yards above. The observer is R. H. Williams.

Four discharge measurements were made in 1896, and three have been made in 1897, from which a rating table has been constructed, and discharges estimated, for 1896. The record of daily gage height for 1896, from July 26 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 15.

*List of discharge measurements made on Tar River at Tarboro, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | July 25 | E. W. Myers | 2154 | 4.35 | 1,061 | 1.85 | 1,963 |
| 2 | Sept. 5 | do | 2154 | 0.43 | 225 | 1.67 | 376 |
| 3 | Sept. 17 | A. P. Davis | 68 | 4.51 | 1,081 | 2.12 | 2,294 |
| 4 | Dec. 17 | E. W. Myers | 2154 | 13.20 | 3,676 | 2.35 | 8,651 |
| | 1897. | | | | | | |
| 5 | Jan. 23 | E. W. Myers | 2154 | 6.65 | 1,822 | 1.98 | 3,520 |
| 6 | Feb. 26 | do | 2154 | 13.53 | 3,489 | 2.32 | 8,106 |
| 7 | Mar. 15 | do | 2154 | 18.13 | 5,263 | 2.46 | 12,993 |

*Rating table for Tar River at Tarboro, North Carolina.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 280 | 4.60 | 2,240 | 9.20 | 5,240 | 13.80 | 8,820 |
| 0.10 | 302 | 4.70 | 2,300 | 9.30 | 5,310 | 13.90 | 8,910 |
| 0.20 | 324 | 4.80 | 2,360 | 9.40 | 5,380 | 14.00 | 9,000 |
| 0.30 | 346 | 4.90 | 2,420 | 9.50 | 5,450 | 14.10 | 9,090 |
| 0.40 | 368 | 5.00 | 2,480 | 9.60 | 5,520 | 14.20 | 9,180 |
| 0.50 | 390 | 5.10 | 2,540 | 9.70 | 5,590 | 14.30 | 9,270 |
| 0.60 | 412 | 5.20 | 2,600 | 9.80 | 5,660 | 14.40 | 9,360 |
| 0.70 | 434 | 5.30 | 2,660 | 9.90 | 5,730 | 14.50 | 9,460 |
| 0.80 | 456 | 5.40 | 2,720 | 10.00 | 5,800 | 14.60 | 9,560 |
| 0.90 | 478 | 5.50 | 2,780 | 10.10 | 5,870 | 14.70 | 9,660 |
| 1.00 | 500 | 5.60 | 2,840 | 10.20 | 5,940 | 14.80 | 9,760 |
| 1.10 | 530 | 5.70 | 2,905 | 10.30 | 6,010 | 14.90 | 9,860 |
| 1.20 | 560 | 5.80 | 2,970 | 10.40 | 6,080 | 15.00 | 9,960 |
| 1.30 | 595 | 5.90 | 3,035 | 10.50 | 6,150 | 15.10 | 10,050 |
| 1.40 | 630 | 6.00 | 3,100 | 10.60 | 6,220 | 15.20 | 10,140 |
| 1.50 | 670 | 6.10 | 3,160 | 10.70 | 6,290 | 15.30 | 10,240 |
| 1.60 | 710 | 6.20 | 3,220 | 10.80 | 6,360 | 15.40 | 10,340 |
| 1.70 | 750 | 6.30 | 3,280 | 10.90 | 6,430 | 15.50 | 10,440 |
| 1.80 | 790 | 6.40 | 3,340 | 11.00 | 6,500 | 15.60 | 10,540 |
| 1.90 | 830 | 6.50 | 3,400 | 11.10 | 6,570 | 15.70 | 10,640 |
| 2.00 | 870 | 6.60 | 3,460 | 11.20 | 6,640 | 15.80 | 10,740 |
| 2.10 | 910 | 6.70 | 3,520 | 11.30 | 6,710 | 15.90 | 10,840 |
| 2.20 | 950 | 6.80 | 3,580 | 11.40 | 6,780 | 16.00 | 10,940 |
| 2.30 | 990 | 6.90 | 3,645 | 11.50 | 6,860 | 16.10 | 11,030 |
| 2.40 | 1,035 | 7.00 | 3,710 | 11.60 | 6,940 | 16.20 | 11,120 |
| 2.50 | 1,070 | 7.10 | 3,775 | 11.70 | 7,020 | 16.30 | 11,220 |
| 2.60 | 1,120 | 7.20 | 3,840 | 11.80 | 7,100 | 16.40 | 11,320 |
| 2.70 | 1,170 | 7.30 | 3,910 | 11.90 | 7,180 | 16.50 | 11,420 |
| 2.80 | 1,220 | 7.40 | 3,980 | 12.00 | 7,260 | 16.60 | 11,520 |
| 2.90 | 1,270 | 7.50 | 4,050 | 12.10 | 7,340 | 16.70 | 11,620 |
| 3.00 | 1,320 | 7.60 | 4,120 | 12.20 | 7,420 | 16.80 | 11,720 |
| 3.10 | 1,370 | 7.70 | 4,190 | 12.30 | 7,500 | 16.90 | 11,820 |
| 3.20 | 1,420 | 7.80 | 4,260 | 12.40 | 7,580 | 17.00 | 11,920 |
| 3.30 | 1,475 | 7.90 | 4,330 | 12.50 | 7,660 | 17.10 | 12,010 |
| 3.40 | 1,530 | 8.00 | 4,400 | 12.60 | 7,740 | 17.20 | 12,100 |
| 3.50 | 1,585 | 8.10 | 4,470 | 12.70 | 7,830 | 17.30 | 12,200 |
| 3.60 | 1,640 | 8.20 | 4,540 | 12.80 | 7,920 | 17.40 | 12,300 |
| 3.70 | 1,700 | 8.30 | 4,610 | 12.90 | 8,010 | 17.50 | 12,400 |
| 3.80 | 1,760 | 8.40 | 4,680 | 13.00 | 8,100 | 17.60 | 12,500 |
| 3.90 | 1,820 | 3.50 | 4,750 | 13.10 | 8,190 | 17.70 | 12,600 |
| 4.00 | 1,880 | 8.60 | 4,820 | 13.20 | 8,280 | 17.80 | 12,700 |
| 4.10 | 1,940 | 8.70 | 4,890 | 13.30 | 8,370 | 17.90 | 12,800 |
| 4.20 | 2,000 | 8.80 | 4,960 | 13.40 | 8,460 | 18.00 | 12,900 |
| 4.30 | 2,060 | 8.90 | 5,030 | 13.50 | 8,550 | | |
| 4.40 | 2,120 | 9.00 | 5,100 | 13.60 | 8,640 | | |
| 4.50 | 2,180 | 9.10 | 5,170 | 13.70 | 8,730 | | |

*Estimated monthly discharge of Tar River at Tarboro, North Carolina.*

[Drainage area, 2,290 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| July 26 to 31 | 1,618 | 774 | 1,268 | 15,090 | 0.13 | 0.55 |
| August | 1,574 | 390 | 628 | 38,614 | 0.31 | 0.27 |
| September | 3,910 | 302 | 1,190 | 70,809 | 0.58 | 0.52 |
| October | 2,000 | 408 | 703 | 43,226 | 0.35 | 0.30 |
| November | 1,910 | 476 | 842 | 50,102 | 0.41 | 0.37 |
| December | 9,460 | 1,420 | 3,739 | 229,904 | 1.88 | 1.63 |

## SELMA STATION ON NEUSE RIVER.

This gage is located on the Southern Railway bridge about 3 miles from Selma, North Carolina, and was put in July 29, 1896. The zero of the gage rod is over the center of the fifth floor beam of the first span from the south end of the bridge. The distance from the zero of the gage to the outer rim of the pulley is 4 feet, and the distance from the end of the weight to the pointer on the wire is 41.05 feet. The bed of the river here is sand and mud and is liable to change by high water. The course of the river is straight and there is only one pier obstruction. The observer is C. Richardson, Selma, North Carolina. Three discharge measurements were made in 1896, and three in 1897, from which a rating table has been constructed and discharge estimated. The record of daily gage heights for 1896, from July 29 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 16.

*List of discharge measurements made on Neuse River at Selma, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | July 29 | E. W. Myers.. | 2154 | 1.18 | 285 | 1.28 | 333 |
| 2 | Sept. 5 | .....do ..... | 2154 | 0.30 | 215 | 0.94 | 203 |
| 3 | Sept. 19 | A. P. Davis... | 68 | 0.00 | 220 | 0.56 | 123 |
| | 1897. | | | | | | |
| 4 | Jan. 24 | E. W. Myers.. | 2154 | 8.00 | 1,038 | 1.74 | 1,810 |
| 5 | Feb. 23 | .....do ..... | 2154 | 10.60 | 1,842 | 2.19 | 4,052 |
| 6 | Mar. 10 | .....do ..... | 2154 | 7.95 | 1,379 | 1.92 | 2,639 |

*Rating table for Neuse River at Selma, North Carolina, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 125 | 2.80 | 700 | 5.60 | 1,515 | 8.40 | 2,590 |
| 0.10 | 140 | 2.90 | 725 | 5.70 | 1,550 | 8.50 | 2,640 |
| 0.20 | 155 | 3.00 | 750 | 5.80 | 1,580 | 8.60 | 2,695 |
| 0.30 | 170 | 3.10 | 775 | 5.90 | 1,615 | 8.70 | 2,750 |
| 0.40 | 185 | 3.20 | 800 | 6.00 | 1,650 | 8.80 | 2,805 |
| 0.50 | 200 | 3.30 | 825 | 6.10 | 1,685 | 8.90 | 2,860 |
| 0.60 | 220 | 3.40 | 850 | 6.20 | 1,720 | 9.00 | 2,920 |
| 0.70 | 240 | 3.50 | 875 | 6.30 | 1,755 | 9.10 | 2,980 |
| 0.80 | 260 | 3.60 | 900 | 6.40 | 1,790 | 9.20 | 3,040 |
| 0.90 | 280 | 3.70 | 930 | 6.50 | 1,825 | 9.30 | 3,100 |
| 1.00 | 300 | 3.80 | 960 | 6.60 | 1,860 | 9.40 | 3,160 |
| 1.10 | 320 | 3.90 | 990 | 6.70 | 1,895 | 9.50 | 3,220 |
| 1.20 | 340 | 4.00 | 1,020 | 6.80 | 1,930 | 9.60 | 3,280 |
| 1.30 | 360 | 4.10 | 1,050 | 6.90 | 1,965 | 9.70 | 3,340 |
| 1.40 | 380 | 4.20 | 1,080 | 7.00 | 2,000 | 9.80 | 3,400 |
| 1.50 | 400 | 4.30 | 1,110 | 7.10 | 2,040 | 9.90 | 3,465 |
| 1 60 | 420 | 4.40 | 1,140 | 7.20 | 2,080 | 10.00 | 3,540 |
| 1.70 | 440 | 4.50 | 1,170 | 7.30 | 2,120 | 10.10 | 3,610 |
| 1.80 | 460 | 4.60 | 1,200 | 7.40 | 2,160 | 10.20 | 3,690 |
| 1.90 | 480 | 4.70 | 1,230 | 7.50 | 2,200 | 10.30 | 3,770 |
| 2.00 | 500 | 4.80 | 1,260 | 7.60 | 2,240 | 10.40 | 3,855 |
| 2.10 | 525 | 4.90 | 1,295 | 7.70 | 2,280 | 10.50 | 3,960 |
| 2.20 | 550 | 5.00 | 1,325 | 7.80 | 2,320 | 10.60 | 4,050 |
| 2.30 | 575 | 5.10 | 1,355 | 7.90 | 2,360 | 10.70 | 4,140 |
| 2.40 | 600 | 5.20 | 1,390 | 8.00 | 2,400 | 10.80 | 4,230 |
| 2.50 | 625 | 5.30 | 1,420 | 8.10 | 2,445 | 10.90 | 4,320 |
| 2.60 | 650 | 5.40 | 1,450 | 8.20 | 2,490 | | |
| 2.70 | 675 | 5.50 | 1,480 | 8.30 | 2,540 | | |

*Estimated monthly discharge of Neuse River at Selma, North Carolina.*

[Drainage area, 1,175 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 1,480 | 170 | 443 | 27,239 | 44 | 0.38 |
| September | 1,337 | 125 | 213 | 12,674 | 20 | 0.18 |
| October | 2,080 | 140 | 315 | 19,369 | 31 | 0.27 |
| November | 1,260 | 185 | 321 | 19,101 | 30 | 0.27 |
| December | 2,920 | 340 | 874 | 53,741 | 85 | 0.74 |

### FAYETTEVILLE STATION ON CAPE FEAR RIVER.

This station is described in Bulletin 140, page 69. It was established in September, 1895, at a railroad bridge about a mile east of Fayetteville. The Weather Bureau has a gage fastened to the lower side of the east abutment of the covered highway bridge, this being about 400 feet above the railroad bridge from which discharge measurements are made. For the lower 29 feet this gage consists of a rod divided into tenths and firmly fastened to the abutment. Above the 29-foot mark a scale is painted on the rock. The observer is Frank Glover, who has charge of the steamboat landing just below the railroad bridge. For his convenience he has placed a subsidiary gage at the steamboat landing reading about the same as the official gage, and from this observations are taken. Ten gagings have been made at this point, from which a rating table has been constructed. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 16.

*List of discharge measurements made on Cape Fear River at Fayetteville, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 26 | C. C. Babb | ..... | 1.59 | ..... | ..... | 489 |
| 2 | Dec. 7 | .....do | ..... | 2.90 | ..... | ..... | 1,109 |
| | 1896. | | | | | | |
| 3 | Apr. 5 | E. W. Myers | 21 | 19.30 | 4,868 | 2.16 | 10,525 |
| 4 | Apr. 25 | .....do | 21 | 4.00 | 932 | 1.73 | 1,618 |
| 5 | May 23 | .....do | 21 | 4.00 | 1,270 | 1.04 | 1,322 |
| 6 | June 8 | .....do | 21 | 10.00 | 2,901 | 1.73 | 5,041 |
| 7 | June 8 | .....do | 21 | 9.20 | 2,446 | 1.72 | 4,207 |
| 8 | July 11 | .....do | 21 | 49.10 | 22,352 | 2.24 | 51,115 |
| 9 | Sept. 2 | .....do | 2154 | 1.10 | 400 | 1.29 | 519 |
| 10 | Sept. 19 | A. P. Davis | 68 | 1.88 | 517 | 1.50 | 770 |

*Rating table for Cape Fear River at Fayetteville, North Carolina, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 489 | 5.20 | 2,264 | 9.40 | 4,550 | 13.60 | 7,033 |
| 1.10 | 519 | 5.30 | 2,318 | 9.50 | 4,616 | 13.70 | 7,093 |
| 1.20 | 550 | 5.40 | 2,372 | 9.60 | 4,672 | 13.80 | 7,153 |
| 1.30 | 581 | 5.50 | 2,426 | 9.70 | 4,728 | 13.90 | 7,213 |
| 1.40 | 612 | 5.60 | 2,470 | 9.80 | 4,784 | 14.00 | 7,273 |
| 1.50 | 645 | 5.70 | 2,524 | 9.90 | 4,840 | 14.10 | 7,333 |
| 1.60 | 678 | 5.80 | 2,578 | 10.00 | 4,898 | 14.20 | 7,393 |
| 1.70 | 711 | 5.90 | 2,632 | 10.10 | 4,955 | 14.30 | 7,453 |
| 1.80 | 744 | 6.00 | 2,686 | 10.20 | 5,013 | 14.40 | 7,513 |
| 1.90 | 777 | 6.10 | 2,740 | 10.30 | 5,071 | 14.50 | 7,573 |
| 2.00 | 810 | 6.20 | 2,794 | 10.40 | 5,129 | 14.60 | 7,633 |
| 2.10 | 843 | 6.30 | 2,848 | 10.50 | 5,187 | 14.70 | 7,693 |
| 2.20 | 876 | 6.40 | 2,902 | 10.60 | 5,245 | 14.80 | 7,753 |
| 2.30 | 909 | 6.50 | 2,956 | 10.70 | 5,303 | 14.90 | 7,813 |
| 2.40 | 942 | 6.60 | 3,010 | 10.80 | 5,361 | 15.00 | 7,873 |
| 2.50 | 975 | 6.70 | 3,064 | 10.90 | 5,419 | 15.10 | 7,933 |
| 2.60 | 1,008 | 6.80 | 3,118 | 11.00 | 5,477 | 15.20 | 7,993 |
| 2.70 | 1,041 | 6.90 | 3,172 | 11.10 | 5,535 | 15.30 | 8,053 |
| 2.80 | 1,075 | 7.00 | 3,226 | 11.20 | 5,593 | 15.40 | 8,113 |
| 2.90 | 1,109 | 7.10 | 3,280 | 11.30 | 5,653 | 15.50 | 8,173 |
| 3.00 | 1,145 | 7.20 | 3,334 | 11.40 | 5,713 | 15.60 | 8,233 |
| 3.10 | 1,187 | 7.30 | 3,388 | 11.50 | 5,773 | 15.70 | 8,293 |
| 3.20 | 1,229 | 7.40 | 3,442 | 11.60 | 5,833 | 15.80 | 8,355 |
| 3.30 | 1,273 | 7.50 | 3,496 | 11.70 | 5,893 | 15.90 | 8,417 |
| 3.40 | 1,319 | 7.60 | 3,550 | 11.80 | 5,953 | 16.00 | 8,479 |
| 3.50 | 1,367 | 7.70 | 3,604 | 11.90 | 6,013 | 16.10 | 8,541 |
| 3.60 | 1,417 | 7.80 | 3,658 | 12.00 | 6,073 | 16.20 | 8,603 |
| 3.70 | 1,467 | 7.90 | 3,712 | 12.10 | 6,133 | 16.30 | 8,665 |
| 3.80 | 1,517 | 8.00 | 3,766 | 12.20 | 6,193 | 16.40 | 8,727 |
| 3.90 | 1,567 | 8.10 | 3,822 | 12.30 | 6,253 | 16.50 | 8,789 |
| 4.00 | 1,620 | 8.20 | 3,878 | 12.40 | 6,313 | 16.60 | 8,851 |
| 4.10 | 1,674 | 8.30 | 3,934 | 12.50 | 6,373 | 16.70 | 8,913 |
| 4.20 | 1,728 | 8.40 | 3,990 | 12.60 | 6,433 | 16.80 | 8,975 |
| 4.30 | 1,782 | 8.50 | 4,046 | 12.70 | 6,493 | 16.90 | 9,037 |
| 4.40 | 1,836 | 8.60 | 4,102 | 12.80 | 6,553 | 17.00 | 9,099 |
| 4.50 | 1,890 | 8.70 | 4,158 | 12.90 | 6,613 | 17.10 | 9,161 |
| 4.60 | 1,940 | 8.80 | 4,214 | 13.00 | 6,673 | 17.20 | 9,223 |
| 4.70 | 1,994 | 8.90 | 4,270 | 13.10 | 6,733 | 17.30 | 9,285 |
| 4.80 | 2,048 | 9.00 | 4,326 | 13.20 | 6,793 | 17.40 | 9,347 |
| 4.90 | 2,102 | 9.10 | 4,382 | 13.30 | 6,853 | 17.50 | 9,409 |
| 5.00 | 2,156 | 9.20 | 4,438 | 13.40 | 6,913 | 17.60 | 9,471 |
| 5.10 | 2,210 | 9.30 | 4,494 | 13.50 | 6,973 | 17.70 | 9,533 |

*Rating table for Cape Fear River at Fayetteville, North Carolina, for 1896*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 17.80 | 9,595 | 19.00 | 10,339 | 28.00 | 22,441 | 40.00 | 38,749 |
| 17.90 | 9,657 | 19.10 | 10,401 | 29.00 | 23,800 | 41.00 | 40,108 |
| 18.00 | 9,719 | 19 20 | 10,463 | 30.00 | 25,159 | 42.00 | 41,467 |
| 18.10 | 9,781 | 19.30 | 10,525 | 31.00 | 26,458 | 43.00 | 42,826 |
| 18.20 | 9,843 | 20.00 | 11,569 | 32.00 | 27,877 | 44.00 | 44,185 |
| 18.30 | 9,905 | 21.00 | 12,928 | 33.00 | 29,236 | 45.00 | 45,554 |
| 18.40 | 9,967 | 22.00 | 14,287 | 34.00 | 30,595 | 46.00 | 46,903 |
| 18.50 | 10,029 | 23.00 | 15,646 | 35.00 | 31,954 | 47.00 | 48,262 |
| 18.60 | 10,091 | 24.00 | 17,005 | 36.00 | 33,313 | 48.00 | 49,621 |
| 18.70 | 10,153 | 25.00 | 18,364 | 37.00 | 34,672 | 49.00 | 50,980 |
| 18.80 | 10,215 | 26.00 | 19,723 | 38.00 | 36,031 | 50.00 | 52,339 |
| 18.90 | 10,277 | 27.00 | 21,082 | 39.00 | 37,390 | | |

*Estimated monthly discharge of Cape Fear River at Fayetteville, North Carolina.*

[Drainage area, 4,493 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile |
| 1895. | | | | | | |
| October | 810 | 399 | 608 | 37,369 | 0.16 | 0.14 |
| November | 4,270 | 1,075 | 1,833 | 109,071 | 0.46 | 0.41 |
| December | 10,029 | 1,008 | 2,737 | 168,292 | 0.70 | 0.61 |
| 1896. | | | | | | |
| January *a* | 19,723 | 1,620 | 6,463 | 246,387 | 1.07 | 1.44 |
| February *b* | 49,621 | 2,956 | 10,190 | 586,129 | 2.47 | 2.29 |
| March | 5,477 | 2,318 | 3,501 | 215,269 | 0.91 | 0.789 |
| April *b* | 14,967 | 1,367 | 3,087 | 183,676 | 0.77 | 0.689 |
| May | 9,347 | 843 | 2,686 | 165,260 | 0.69 | 0.598 |
| June *b* | 11,569 | 1,041 | 3,492 | 207,774 | 0.81 | 0.777 |
| July *b* | 52,340 | 1,319 | 7,303 | 449,061 | 1.87 | 1.625 |
| August | 7,093 | 612 | 1,081 | 66,471 | 0.28 | 0.240 |
| September | 4,616 | 489 | 1,240 | 73,780 | 0.30 | 0.275 |
| October *b* | 26,458 | 843 | 2,623 | 161,278 | 0.67 | 0.583 |
| November *b* | 10,954 | 975 | 2,399 | 142,740 | 0.59 | 0.534 |
| December | 8,113 | 1,940 | 4,158 | 255,667 | 1.06 | 0.92 |
| Per annum (1896). | 52,340 | 489 | 4,019 | 2,753,492 | 11.49 | 0.548 |

*a* Twenty days in January.

*b* Maximum approximate.

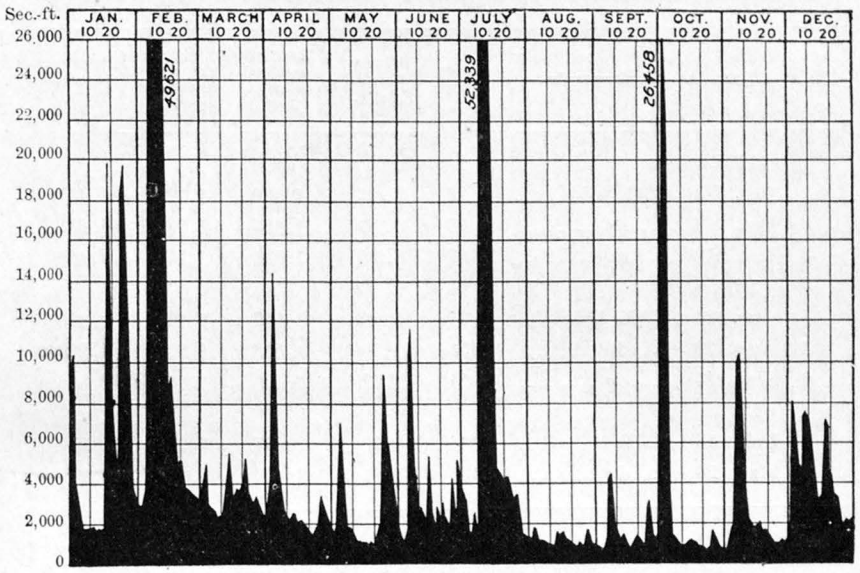



FIG. 6.—Discharge of Cape Fear River at Fayetteville, North Carolina, 1896.

## YADKIN RIVER.

The Yadkin River is one of the most important water-power streams of North Carolina. Its possibilities in this line are briefly discussed in Bulletin 140, page 66. Two stations are in operation on this stream.

### SALISBURY STATION ON YADKIN RIVER.

The point of measurement for Yadkin River is at the Southern Railroad bridge at Holtsburg, below the mouth of Grants Creek, about 4 miles from Salisbury, North Carolina. The drainage area is partly mapped on atlas sheets Statesville, Hickory, Wilkesboro, Yadkinville, and Hillsville. A gage rod was located here September 24, 1895. The 10-foot mark of the rod is opposite the center of the sixth floor beam on the lower side of the first span from the west end. The distance from the zero of the rod to the outside of the pulley wheel is 1.85 feet. The length of the wire rope and weight is 55.10 feet. The post-office address of the observer is Sapona, North Carolina, the nearest railroad station, Holtsburg, being merely a siding. The locality is reached by wagon from Salisbury. This station is described in Bulletin 140, page 70. Observations have been continued throughout the year. Following is a list of gagings that have been made at this point since the establishment of the station, from which a rating table has been constructed. The record of daily gage heights for 1896 is given in Water-Supply and Irigation Paper No. 11, page 17.

*List of discharge measurements made on Yadkin River at Salisbury, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 5 | C. C. Babb..... | 29 | 1.44 | 1,190 | 1.22 | 1,457 |
| 2 | Oct. 26 | .....do ..... | 76 | 1.45 | 1,159 | 1.33 | 1,538 |
| 3 | Dec. 10 | .....do ..... | 62 | 1.74 | 1,534 | 1.57 | 2,415 |
| | 1896. | | | | | | |
| 4 | Apr. 20 | E. W. Myers... | 21 | 2.00 | 1,553 | 1.87 | 2,916 |
| 5 | Aug. 29 | .....do ..... | 2154 | 1.50 | 1,318 | 0.98 | 1,293 |
| 6 | Sept. 14 | .....do ..... | 21 | 1.79 | 1,486 | 1.66 | 2,368 |
| | 1897. | | | | | | |
| 7 | Feb. 13 | E. W. Myers... | 2154 | 4.20 | 2,997 | 3.38 | 10,141 |
| 8 | Mar. 20 | .....do ..... | 2154 | 4.45 | 3,436 | 3.44 | 11,837 |

*Rating table for Yadkin River at Salisbury, North Carolina, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet.* |
| 1.00 | 100 | 2.00 | 3,000 | 3.00 | 6,400 | 4.00 | 9,800 |
| 1.10 | 250 | 2.10 | 3,340 | 3.10 | 6,740 | 4.10 | 10,160 |
| 1.20 | 460 | 2.20 | 3,680 | 3.20 | 7,080 | 4.20 | 10,540 |
| 1.30 | 710 | 2.30 | 4,020 | 3.30 | 7,420 | 4.30 | 10,940 |
| 1.40 | 1,000 | 2.40 | 4,360 | 3.40 | 7,760 | 4.40 | 11,390 |
| 1.50 | 1,310 | 2.50 | 4,700 | 3.50 | 8,100 | 4.50 | 11,840 |
| 1.60 | 1,640 | 2.60 | 5,040 | 3.60 | 8,440 | 4.60 | 12,290 |
| 1.70 | 1,980 | 2.70 | 5,380 | 3.70 | 8,780 | 4.70 | 12,740 |
| 1.80 | 2,320 | 2.80 | 5,720 | 3.80 | 9,120 | 4.80 | 13,200 |
| 1.90 | 2,660 | 2.90 | 6,060 | 3.90 | 9,460 | 4.90 | 13,700 |

*Estimated monthly discharge of Yadkin River at Salisbury, North Carolina.*

[Drainage area, 3,400 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| October | 1,500 | 1,400 | 1,426 | 87,681 | 0.48 | 0.42 |
| November | 4,020 | 1,310 | 2,004 | 119,246 | 0.65 | 0.59 |
| December | 10,160 | 1,640 | 2,683 | 164,971 | 0.91 | 0.79 |
| 1896. | | | | | | |
| January | 10,940 | 1,640 | 4,485 | 275,774 | 1.52 | 1.32 |
| February | *a*24,200 | 2,320 | 7,817 | 449,638 | 2.48 | 2.30 |
| March | 5,380 | 2,320 | 3,472 | 213,485 | 1.18 | 1.02 |
| April | *a*29,200 | 2,660 | 5,242 | 311,920 | 1.72 | 1.54 |
| May | 6,060 | 1,310 | 2,507 | 154,149 | 0.85 | 0.74 |
| June | 9,460 | 1,310 | 3,159 | 187,974 | 1.03 | 0.93 |
| July | *a*64,200 | 1,640 | 11,584 | 712,277 | 3.94 | 3.41 |
| August | 6,060 | 1,000 | 2,411 | 148,248 | 0.82 | 0.71 |
| September | *a*32,200 | 1,000 | 3,087 | 183,689 | 1.01 | 0.91 |
| October | *a*31,200 | 1,310 | 3,122 | 191,965 | 1.06 | 0.92 |
| November | *a*23,200 | 1,980 | 5,206 | 309,779 | 1.65 | 1.48 |
| December | *a*22,700 | 3,000 | 6,037 | 371,202 | 2.05 | 1.78 |
| Per annum (1896) | *a*64,200 | 1,000 | 4,844 | 3,510,100 | 19.31 | 1.42 |

*a* Estimated.

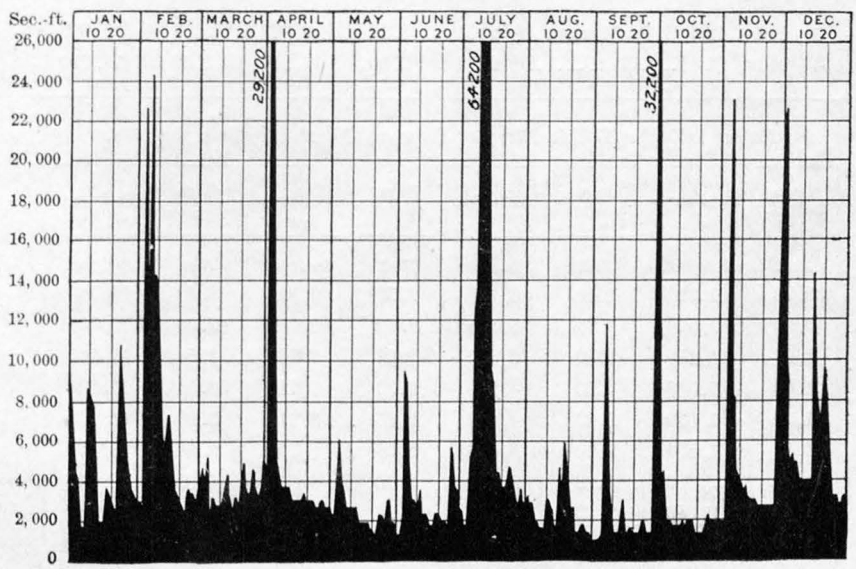



FIG. 7.—Discharge of Yadkin River at Salisbury, North Carolina, 1896.

## NORWOOD STATION ON YADKIN (PEDEE) RIVER.

This gage was established September 1, 1896, near Blalocks Ferry, 1 mile above Richland Creek, about 2 miles from Norwood, North Carolina. The gage is a vertical rod divided into feet and tenths, and is securely spiked and braced to an overhanging tree near the ferry. The rod is referred to a bench mark consisting of a large nail driven into a notch cut in the root of a birch tree about 50 feet northwest of the rod, and the tree is immediately in front of the turn of the road that leads to the ferry. The zero of the gage rod is 5.93 feet below the elevation of the bench mark. The river here is broad and shallow, with smooth bottom of sand and small rocks, giving a good section for gaging. The measurements are taken from the ferryboat. The observer is W. B. Nichols, Norwood, North Carolina. A portion of the area drained past this point is mapped on atlas sheets Statesville, Hickory, Wilkesboro, Yadkinville, and Hillsville. The record of daily gage heights for 1896 from September 1 to December 31 is given in Water-Supply and Irrigation Paper No. 11, page 16.

*List of discharge measurements made on Yadkin River near Norwood, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Sept. 1 | E. W. Myers ... | 2154 | 1.00 | 1,859 | 0.82 | 1,537 |
| 2 | Sept. 15 | .....do ..... | 2154 | 1.34 | 2,211 | 0.92 | 2,036 |
| | 1897. | | | | | | |
| 3 | Feb. 12 | E. W. Myers ... | 2154 | 3.32 | 3,779 | 2.54 | 9,607 |
| 4 | Mar. 21 | .....do ..... | 2154 | 3.80 | 4,517 | 2.59 | 11,710 |

*Rating table for Yadkin River at Norwood, North Carolina, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec.-feet.* | *Feet.* | *Sec.-feet.* | *Feet.* | *Sec.-feet.* | *Feet.* | *Sec.-feet.* |
| 0.70 | 1,300 | 1.60 | 3,100 | 2.50 | 6,565 | 3.40 | 10,100 |
| 0.80 | 1,370 | 1.70 | 3,485 | 2.60 | 6,950 | 3.50 | 10,500 |
| 0.90 | 1,450 | 1.80 | 3,870 | 2.70 | 7,335 | 3.60 | 10,900 |
| 1.00 | 1,540 | 1.90 | 4,255 | 2.80 | 7,720 | 3.70 | 11,300 |
| 1.10 | 1,640 | 2.00 | 4,640 | 2.90 | 8,110 | 3.80 | 11,700 |
| 1.20 | 1,830 | 2.10 | 5,025 | 3.00 | 8,500 | 3.90 | 12,100 |
| 1.30 | 2,080 | 2.20 | 5,410 | 3.10 | 8,900 | 4.00 | 12,500 |
| 1.40 | 2,380 | 2.30 | 5,795 | 3.20 | 9,300 | | |
| 1.50 | 2,720 | 2.40 | 6,180 | 3.30 | 9,700 | | |

*Estimated monthly discharge of Yadkin River at Norwood, North Carolina.*

[Drainage area, 4,614 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| September | 9,700 | 1,450 | 2,409 | 143,344 | 0.58 | 0.52 |
| October | a26,100 | 1,640 | 3,225 | 198,297 | 0.81 | 0.70 |
| November | 20,500 | 2,080 | 4,176 | 248,489 | 1.01 | 0.91 |
| December | 11,700 | 2,080 | 4,885 | 300,369 | 1.22 | 1.06 |

a Estimated.

## CATAWBA RIVER.

### ROCKHILL STATION ON CATAWBA RIVER.

This station is described in Bulletin 140, page 71. The drainage area is 2,987 square miles and is partly mapped on the Wilkesboro, Cranberry, Mount Mitchell, Morganton, Yadkinville, Hickory, and Statesville atlas sheets. It is located at the bridge of the Southern Railway 3 miles south of Fort Mill. A gage was placed here on September 3, 1895. It is fastened to the upper side of the guard rail, the 2-foot mark of the rod being about the center of the second vertical of the second truss from the south end of the bridge. The distance from the zero of the rod to the outside edge of the pulley wheel is 1.30 feet, and the length of wire rope to the end of the weight is 52.96 feet. The observer is W. A. Morris, Rockhill, South Carolina. It is most convenient, however, to reach the railroad bridge from the station of Fort Mill, about 3 miles distant. Observations of gage height have been kept continuously throughout the year, and the following measurements of discharge have been made, and a rating table for this station has been constructed and applied to the gage heights for 1895 and 1896. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 17.

*List of discharge measurements made on Catawba River at Rockhill, South Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 23 | C. C. Babb | 29 | 1.58 | 806 | 1.66 | 1,340 |
| 2 | Oct. 25 | do | 76 | 1.51 | 852 | 1.73 | 1,477 |
| | 1896. | | | | | | |
| 3 | Apr. 16 | E. W. Myers | 21 | 1.90 | 1,159 | 1.54 | 1,787 |
| 4 | Aug. 20 | do | 2154 | 1.78 | 924 | 1.63 | 1,508 |
| 5 | Sept. 17 | do | 2154 | 1.53 | 979 | 1.36 | 1,336 |
| | 1897. | | | | | | |
| 6 | Feb. 9 | E. W. Myers | 2154 | 4.50 | 3,178 | 3.05 | 9,711 |
| 7 | Apr. 6 | do | 76 | 12.10 | 10,121 | 4.54 | 46,040 |

*Rating table for Catawba River at Rockhill, South Carolina.*

[This table is applicable from September, 1895, to December, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec.-feet.* | *Fee* | *Sec.-feet.* | *Feet.* | *Sec.-feet.* | *Feet.* | *Sec.-feet* |
| 1.30 | 1,200 | 4.30 | 9,030 | 7.30 | 22,350 | 10.30 | 37,000 |
| 1.40 | 1,260 | 4.40 | 9,340 | 7.40 | 22,800 | 10.40 | 37,500 |
| 1.50 | 1,330 | 4.50 | 9,710 | 7.50 | 23,250 | 10.50 | 38,000 |
| 1.60 | 1,400 | 4.60 | 10,150 | 7.60 | 23,700 | 10.60 | 38,500 |
| 1.70 | 1,470 | 4.70 | 10,600 | 7.70 | 24,150 | 10.70 | 39,000 |
| 1.80 | 1,550 | 4.80 | 11,050 | 7.80 | 24,600 | 10.80 | 39,500 |
| 1.90 | 1,700 | 4.90 | 11,500 | 7.90 | 25,050 | 10.90 | 40,000 |
| 2.00 | 1,900 | 5.00 | 12,000 | 8.00 | 25,500 | 11.00 | 40,500 |
| 2.10 | 2,210 | 5.10 | 12,450 | 8.10 | 26,000 | 11.10 | 41,000 |
| 2.20 | 2,520 | 5.20 | 12,900 | 8.20 | 26,500 | 11.20 | 41,500 |
| 2.30 | 2,830 | 5.30 | 13,350 | 8.30 | 27,000 | 11.30 | 42,000 |
| 2.40 | 3,140 | 5.40 | 13,800 | 8.40 | 27,500 | 11.40 | 42,500 |
| 2.50 | 3,450 | 5.50 | 14,250 | 8.50 | 28,000 | 11.50 | 43,000 |
| 2.60 | 3,760 | 5.60 | 14,700 | 8.60 | 28,500 | 11.60 | 43,500 |
| 2.70 | 4,070 | 5.70 | 15,150 | 8.70 | 29,000 | 11.70 | 44,000 |
| 2.80 | 4,380 | 5.80 | 15,600 | 8.80 | 29,500 | 11.80 | 44,500 |
| 2.90 | 4,690 | 5.90 | 16,050 | 8.90 | 30,000 | 11.90 | 45,000 |
| 3.00 | 5,000 | 6.00 | 16,500 | 9.00 | 30,500 | 12.00 | 45,500 |
| 3.10 | 5,310 | 6.10 | 16,950 | 9.10 | 31,000 | 12.10 | 46,000 |
| 3.20 | 5,620 | 6.20 | 17,400 | 9.20 | 31,500 | 12.20 | 46,500 |
| 3.30 | 5,930 | 6.30 | 17,850 | 9.30 | 32,000 | 12.30 | 47,000 |
| 3.40 | 6,240 | 6.40 | 18,300 | 9.40 | 32,500 | 12.40 | 47,500 |
| 3.50 | 6,550 | 6.50 | 18,750 | 9.50 | 33,000 | 12.50 | 48,000 |
| 3.60 | 6,860 | 6.60 | 19,200 | 9.60 | 33,500 | 12.60 | 48,500 |
| 3.70 | 7,170 | 6.70 | 19,650 | 9.70 | 34,000 | 12.70 | 49,000 |
| 3.80 | 7,480 | 6.80 | 20,100 | 9.80 | 34,500 | 12.80 | 49,500 |
| 3.90 | 7,790 | 6.90 | 20,550 | 9.90 | 35,000 | 12.90 | 50,000 |
| 4.00 | 8,100 | 7.00 | 21,000 | 10.00 | 35,500 | | |
| 4.10 | 8,410 | 7.10 | 21,450 | 10.10 | 36,000 | | |
| 4.20 | 8,720 | 7.20 | 21,900 | 10.20 | 36,500 | | |

*Estimated monthly discharge of Catawba River at Rock Hill, South Carolina.*

[Drainage area, 2,987 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| September 23 to 30 | 1,350 | 1,300 | 1,318 | 20,912 | 0.13 | 0.44 |
| October | 1,400 | 1,300 | 1,364 | 83,869 | 0.53 | 0.46 |
| November 1 to 9, 17 to 30 | 2,237 | 1,400 | 1,546 | 70,518 | 0.44 | 0.52 |
| December | 6,860 | 1,400 | 2,192 | 134,782 | 0.84 | 0.73 |
| 1896. | | | | | | |
| January | 9,700 | 1,550 | 3,062 | 188,275 | 1.19 | 1.03 |
| February | 19,850 | 2,237 | 6,093 | 350,473 | 2.20 | 2.04 |
| March | 2,851 | 1,700 | 2,009 | 123,528 | 0.77 | 0.67 |
| April | 16,040 | 1,470 | 2,645 | 157,389 | 0.99 | 0.89 |
| May | 9,060 | 1,400 | 2,277 | 140,008 | 0.87 | 0.76 |
| June | 5,620 | 1,330 | 2,014 | 119,841 | 0.74 | 0.67 |
| July | *a*62,500 | 1,400 | 10,215 | 628,095 | 3.95 | 3.42 |
| August | 1,930 | 1,330 | 1,604 | 98,626 | 0.62 | 0.54 |
| September | 9,060 | 1,330 | 1,873 | 111,451 | 0.70 | 0.63 |
| October | 7,790 | 1,330 | 1,670 | 102,684 | 0.64 | 0.56 |
| November | 14,120 | 1,400 | 2,661 | 158,340 | 0.99 | 0.89 |
| December | 14,600 | 1,550 | 3,169 | 194,855 | 1.22 | 1.06 |
| Per annum (1896) | *a*62,500 | 1,330 | 3,274 | 2,373,565 | 14.88 | 1.10 |

*a* Estimated.

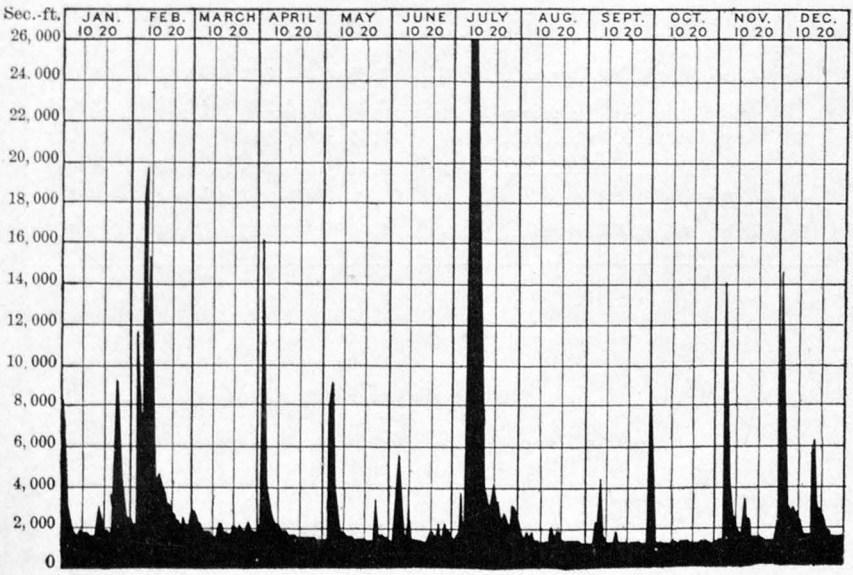



FIG. 8.—Discharge of Catawba River at Rock Hill, South Carolina, 1896.

## CATAWBA STATION ON CATAWBA RIVER.

This gage is located on the Southern Railway bridge about one-fourth of a mile from Catawba, North Carolina. The zero of the gage rod is 23 feet east of the west end of the second span of the bridge, and the distance from the zero of the gage rod to the outer rim of the pulley is 3 feet. The distance from the end of the weight to the marker on the wire is 35.58 feet, the reading being zero when the weight touches bottom. The section here is a fairly good one, as the bottom is smooth, but of sand or clay and seemingly liable to change on account of high water. The river is straight for several hundred yards above and below the bridge and the current velocity is evenly distributed across the stream. The observer is E. M. Brawley, Catawba, North Carolina. No measurements of flood discharge were obtained in 1896, but in February, 1897, a discharge of 9,711 feet was measured, with the aid of which a rating table has been constructed for 1896, and tables of discharge computed.

A portion of the area draining past this station is mapped on the atlas sheets Wilkesboro, Cranberry, Mount Mitchell, Yadkinville, Morganton, Hickory, and Statesville. The record of daily gage heights for 1896, from July 4 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 18.

*List of discharge measurements made on Catawba River at Catawba, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 30 | E. W. Myers... | 21 | 2.25 | 938 | 1.11 | 1,044 |
| 2 | July 4 | .....do ..... | 21 | 3.03 | 1,238 | 1.83 | 2,266 |
| 3 | Aug. 30 | .....do ..... | 2154 | 1.45 | 743 | 0.98 | 732 |
| 4 | Sept. 13 | .....do ..... | 2154 | 1.94 | 1,059 | 1.37 | 1,458 |
| | 1897. | | | | | | |
| 5 | Feb. 8 | E. W. Myers... | 2154 | 5.52 | 2,915 | 3.33 | 9,711 |

*Rating table for Catawba River at Catawba, North Carolina.*

[This table is applicable from July, 1896, to April, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet* |
| 1.00 | 540 | 2.50 | 1,630 | 4.00 | 5,000 | 5.50 | 9,500 |
| 1.10 | 570 | 2.60 | 1,740 | 4.10 | 5,300 | 5.60 | 9,800 |
| 1.20 | 610 | 2.70 | 1,860 | 4.20 | 5,600 | 5.70 | 10,100 |
| 1.30 | 655 | 2.80 | 1,990 | 4.30 | 5,900 | 5.80 | 10,400 |
| 1.40 | 710 | 2.90 | 2,140 | 4.40 | 6,200 | 5.90 | 10,700 |
| 1.50 | 770 | 3.00 | 2,300 | 4.50 | 6,500 | 6.00 | 11,000 |
| 1.60 | 835 | 3.10 | 2,480 | 4.60 | 6,800 | 6.10 | 11,300 |
| 1 70 | 910 | 3.20 | 2,700 | 4.70 | 7,100 | 6.20 | 11,600 |
| 1.80 | 980 | 3.30 | 2,950 | 4.80 | 7,400 | 6.30 | 11,900 |
| 1.90 | 1,060 | 3.40 | 3,220 | 4.90 | 7,700 | 6.40 | 12,200 |
| 2 00 | 1,140 | 3.50 | 3,500 | 5.00 | 8,000 | 6.50 | 12,500 |
| 2.10 | 1,230 | 3.60 | 3,800 | 5.10 | 8,300 | 6.60 | 12,800 |
| 2.20 | 1,320 | 3.70 | 4,100 | 5.20 | 8,600 | 6.70 | 13,100 |
| 2.30 | 1,420 | 3.80 | 4,400 | 5.30 | 8,900 | 6.80 | 13,400 |
| 2.40 | 1,530 | 3.90 | 4,700 | 5.40 | 9,200 | 6.90 | 13,700 |

*Estimated monthly discharge of Catawba River at Catawba, North Carolina.*

[Drainage area, 3,492 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| July 4 to 31 | *a*16,100 | 1,420 | 4,466 | 248,024 | 1.33 | 1.28 |
| August | 1,420 | 770 | 1,071 | 65,853 | 0.36 | 0.31 |
| September | 5,000 | 770 | 1,090 | 64,859 | 0.35 | 0.31 |
| October | 1,630 | 770 | 865 | 53,187 | 0.29 | 0.25 |
| November | *a*15,200 | 835 | 2,222 | 132,218 | 0.71 | 0.64 |
| December | 9,800 | 1,060 | 2,149 | 132,137 | 0.71 | 0.62 |

*a* Estimated.

## BROAD RIVER.

### GAFFNEY STATION ON BROAD RIVER.

This gage is on the Southern Railway bridge about 3 miles from Gaffney, South Carolina, and was put in July 1, 1896. The zero of the gage is 18 feet east of the west end of the third span of the bridge

from the east. The distance from the zero of the gage to the rim of the pulley is 2.5 feet, and that from the end of the weight to the pointer on the wire is 50.71 feet. The river here is straight for several hundred yards above and below the bridge, and the section is a good one, though the right bank is subject to overflow in very high water. The area drained above this station is 1,435 square miles, and is partly mapped on atlas sheets Morganton, Mount Mitchell, and Saluda. The record of daily gage heights for 1896 from July 10 to December 31 is given in Water-Supply and Irrigation Paper No. 11, page 18.

*List of discharge measurements made on Broad River at Gaffney, South Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 18 | E. W. Myers... | 2154 | 0.25 | 732 | 1.36 | 956 |
| 2 | Sept. 16 | .....do ..... | 2154 | 0.10 | 792 | 1.20 | 950 |
| | 1897. | | | | | | |
| 3 | Mar. 9 | E. W. Myers... | 2154 | 2.85 | 2,077 | 2.10 | 4,364 |
| 4 | Apr. 7 | .....do ..... | 76 | 3.49 | 2,286 | 2.32 | 5,324 |

*Rating table for Broad River at Gaffney, South Carolina.*

[This table is applicable from July, 1896, to April, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 800 | 1.10 | 1,910 | 2.20 | 3,305 | 3.30 | 5,010 |
| 0.10 | 885 | 1.20 | 2,035 | 2.30 | 3,450 | 3.40 | 5,170 |
| 0.20 | 975 | 1.30 | 2,160 | 2.40 | 3,600 | 3.50 | 5,330 |
| 0.30 | 1,075 | 1.40 | 2,285 | 2.50 | 3,750 | 3.60 | 5,500 |
| 0.40 | 1,175 | 1.50 | 2,410 | 2.60 | 3,900 | 3.70 | 5,670 |
| 0.50 | 1,275 | 1.60 | 2,535 | 2.70 | 4,050 | 3.80 | 5,840 |
| 0.60 | 1,375 | 1.70 | 2,660 | 2.80 | 4,210 | 3.90 | 6,010 |
| 0.70 | 1,475 | 1.80 | 2,785 | 2.90 | 4,370 | 4.00 | 6,180 |
| 0.80 | 1,575 | 1.90 | 2,910 | 3.00 | 4,530 | | |
| 0.90 | 1,685 | 2.00 | 3,035 | 3.10 | 4,690 | | |
| 1.00 | 1,795 | 2.10 | 3,170 | 3.20 | 4,850 | | |

*Estimated monthly discharge of Broad River at Gaffney, South Carolina.*

[Drainage area, 1,435 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| July 12 to 31 | 2,585 | 1,255 | 1,496 | 59,340 | 0.77 | 1.04 |
| August | 1,445 | 885 | 1,093 | 67,206 | 0.87 | 0.76 |
| September | 2,585 | 843 | 1,119 | 66,585 | 0.87 | 0.78 |
| October | 1,585 | 930 | 1,086 | 66,776 | 0.87 | 0.76 |
| November | *a* 8,800 | 1,055 | 1,955 | 116,331 | 1.52 | 1.36 |
| December | 3,945 | 1,545 | 1,977 | 121,561 | 1.59 | 1.38 |

*a* Estimated.

## ALSTON STATION ON BROAD RIVER.

This gage is located on the Southern Railway bridge about 200 yards from Alston, South Carolina. The zero of the gage is over the center of the fourth floor beam of the second span from the east end of the bridge. The outer rim of the pulley is 4 feet from the zero of the gage, and the distance from the end of the weight to the pointer on the wire is 42.65 feet, the gage reading zero when the end of the weight touches bottom. The section here is not a very good one, being cut up by the foundations of an old bridge crossing at the same place as the present one, and the bottom is soft and muddy. The river is straight for a long distance above and below the station, and the current velocity is fairly uniform all the way across. The observer is D. R. Elkin, Alston, South Carolina. The discharge measurements are not sufficiently comprehensive to justify the construction of a rating table for this station. The record of daily gage heights for 1896 from July 3 to December 31 is given in Water-Supply and Irrigation Paper No. 11, page 18.

*List of discharge measurements made on Broad River at Alston, South Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | July 3 | E. W. Myers .. | 21 | 2.21 | 1,481 | 1.48 | 2,198 |
| 2 | Aug. 19 | .....do ..... | 2154 | 2.52 | 1,386 | 1.56 | 2,177 |
| 3 | Sept. 18 | .....do ..... | 2154 | 2.05 | 1,428 | 1.50 | 2,174 |

## SALUDA RIVER.

### WATERLOO STATION ON SALUDA RIVER.

This station is in the Abbeville quadrangle, 1 mile below the mouth of Reedy River, in latitude 34° 17.8′, longitude 82° 4.6′. Its drainage area is 1,056 square miles, and is partly mapped on atlas sheets Saluda, Pickens, Pisgah, and Abbeville. It was established August 30, 1896, by Mr. E. W. Myers. The gage is on the Port Royal and Western Carolina Railroad bridge about 3 miles from Coronaca station. The zero of the gage is over the center of the sixth floor beam of the first span from the east end of the bridge. The distance from the zero of the gage to the outer rim of the pulley is 2.75 feet, and that from the end of the weight to the pointer on the wire is 47 feet. The river here is straight for several hundred yards above and below the bridge. The bottom is of sand and mud and seemingly liable to change by high water, and the right bank is subject to overflow. The observer is R. N. Cunningham, Waterloo, South Carolina. A measurement was made by E. W. Myers on September 18, with Buff & Berger meter No. 2154, when the gage height was 3.14, area of section 442, mean velocity 1.61, and discharge 692 second-feet. The record of daily gage heights for 1896, from August 30 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 19.

## GENERAL DISCUSSION OF GEORGIA STREAMS.

The great ridge dividing the waters of the Atlantic Slope from those of the Gulf of Mexico enters Georgia from North Carolina on the line between Rabun and Townes counties, passes through Clarkesville and Mount Airy, thence along the Piedmont Air Line Railroad to Norcross, thence to Stone Mountain and along the Georgia Railroad to Atlanta, thence along the Central Railroad to Barnesville, through Culloden and along the Atlanta and Florida Railroad to Fort Valley, thence through Vienna and in a southeasterly direction to and through the Okefenokee Swamp and into Florida.

The drainage basins tributary to the Atlantic in Georgia and Alabama are the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys. In Georgia and Alabama the basins draining to the Gulf are the Suwanee, Ochlockonee, Apalachicola, Choctawhatchee, Pensacola, Mobile, and Tennessee or Mississippi. These basins are shown on the accompanying outline map, which shows the whole of Georgia and Alabama and parts of South Carolina, Florida, Tennessee, and North Carolina. The greater portion of the work so far has been done on streams that have many large water powers. These are confined to the Savannah, Altamaha, Apalachicola, Mobile, and Tennessee basins.

The other drainage basins mentioned above have the largest part of their areas in the low country where there is very little fall to the streams and consequently few water powers of importance. This section of low country has some very interesting hydrographic features that merit investigation. The only one of these that has so far received any attention is the Okefenokee Swamp.

## WATER-POWER STREAMS.

The great basins of the Savannah, Altamaha, Apalachicola, Mobile, and Tennessee receive their headwaters in the high lands, at elevations ranging from 800 to 2,000 feet above sea level, and therefore have many important water powers. These highlands are geologically in the crystalline formation, or region of granitic rocks. All the great water powers of Georgia are in this formation, while those of Alabama are partly in crystalline and partly in the Paleozoic country.

A bulletin of the Georgia Geological Survey [1] gives in tabulated form the results of all the hydrographic work done in this State by public surveys prior to the year 1895, and especially the work of Mr. C. C. Anderson, late assistant State geologist, showing gage-heights and discharge measurements on the Chattahoochee, Flint, and Ocmulgee rivers and some of their tributaries during the years 1891 and 1892. These surveys cover a period when the streams were at their average stage. Hence his low-water discharges are much greater than those which are given here as the result of measurements made in 1896 by Messrs. B. M. Hall and Max Hall, when the streams were at the lowest stage they have reached for many years—a minimum stage that they probably reach only once or twice in a century. This will be shown by a close study of the following table:

[1] Geological Survey of Georgia, W. S. Yeates, State geologist, Bulletin No. 3—A: A preliminary report on a part of the water powers of Georgia, compiled from the notes of C. C. Anderson, late assistant geologist, by B. M. Hall, special assistant, Atlanta, 1896.

*Monthly rainfall at Atlanta, Georgia.*

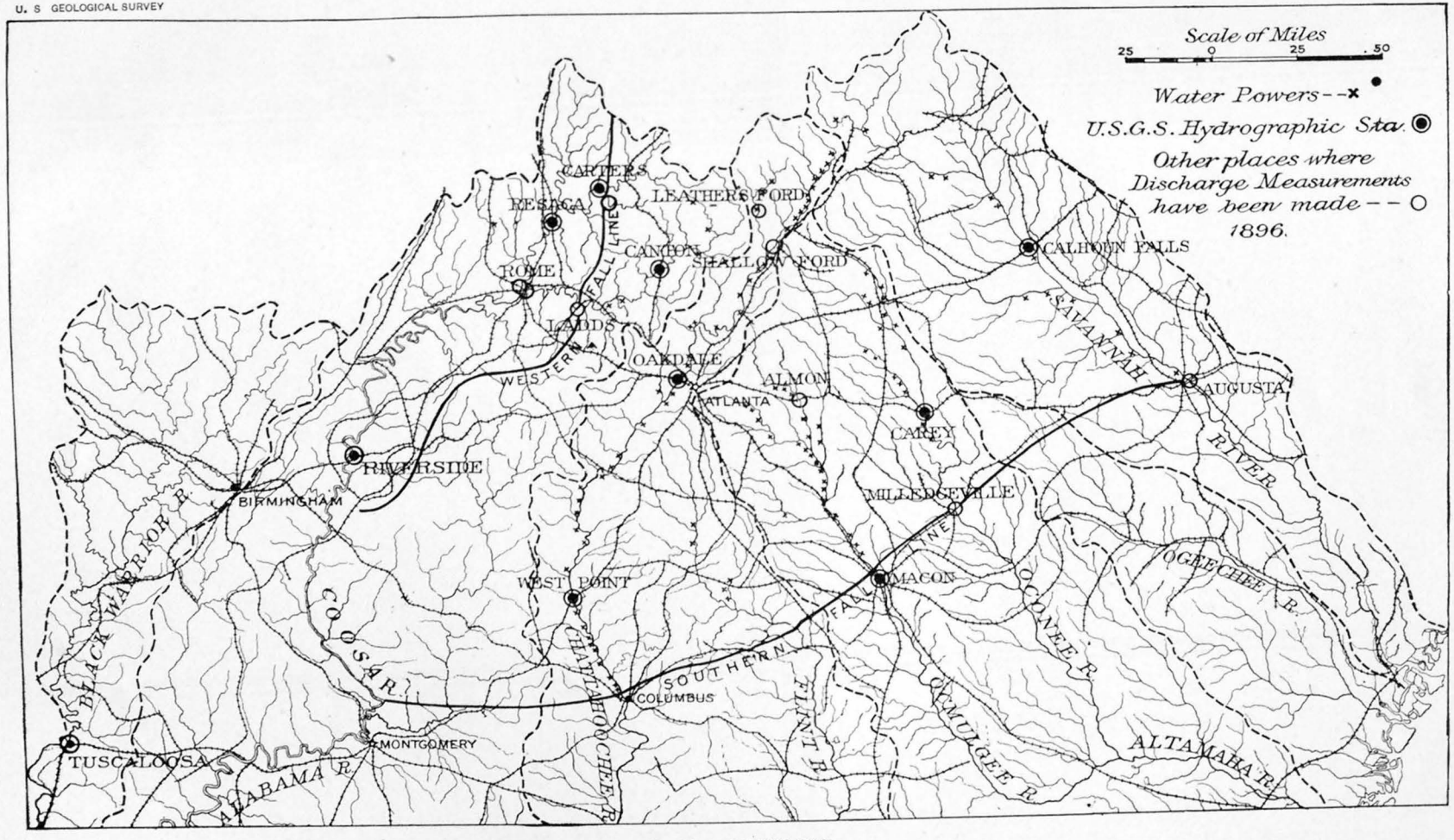
| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* | *Ins.* |
| 1870[a] | ..... | ..... | ..... | ..... | ..... | ..... | 2.25 | 2.69 | 9.40 | 0.67 | 5.42 | 3.74 | ..... |
| 1871 | 2.03 | 6.20 | 6.11 | 5.20 | 7.77 | 5.97 | 1.12 | 6.49 | 4.44 | 2.09 | 3.41 | 3.36 | 54.19 |
| 1872 | 2.94 | 5.28 | 7.66 | 3.09 | 3.75 | 1.82 | 3.91 | 5.84 | 2.26 | 0.74 | 2.12 | 4.48 | 43.89 |
| 1873 | 3.36 | 12.04 | 2.58 | 1.96 | 6.05 | 6.86 | 3.87 | 2.08 | 5.40 | 1.23 | 3.15 | 2.41 | 50.99 |
| 1874 | 3.14 | 6.86 | 7.38 | 10.42 | 3.00 | 7.71 | 4.70 | 10.00 | 0.47 | 0.80 | 3.19 | 3.09 | 60.67 |
| 1875[b] | 5.60 | 6.92 | 10.27 | 4.79 | 1.84 | 4.58 | 3.84 | 3.42 | 4.64 | 1.50 | 3.45 | 6.14 | 56.99 |
| 1876 | 3.32 | 5.37 | 5.59 | 6.01 | 5.00 | 3.25 | 3.49 | 5.32 | 0.82 | 1.81 | 2.56 | 4.35 | 46.87 |
| 1877 | 5.93 | 3.10 | 7.46 | 6.43 | 0.72 | 5.71 | 3.40 | 0.86 | 2.85 | 3.78 | 3.85 | 4.11 | 48.20 |
| 1878 | 3.76 | 6.54 | 6.72 | 3.15 | 2.25 | 5.39 | 1.77 | 3.76 | 1.75 | [c]1.99 | [c]4.54 | [c]5.80 | 47.42 |
| 1879[d] | 4.29 | 3.09 | 2.49 | 3.98 | 4.16 | 3.20 | 5.75 | 4.76 | 1.43 | 5.44 | 3.88 | 7.86 | 50.33 |
| 1880 | 2.86 | 3.11 | 11.87 | 7.07 | 4.52 | 3.57 | 3.16 | 3.61 | 6.21 | 2.81 | 8.21 | 5.70 | 62.70 |
| 1881 | 8.35 | 10.41 | 10.98 | 4.58 | 1.27 | 2.46 | 0.56 | 4.10 | 3.76 | 3.44 | 4.30 | 7.53 | 59.74 |
| 1882 | 6.40 | 10.29 | 4.16 | 5.21 | 3.02 | 3.22 | 6.61 | 5.86 | 3.51 | 1.35 | 4.22 | 4.37 | 58.22 |
| 1883 | 15.82 | 3.22 | 3.73 | 8.20 | 2.00 | 3.31 | 1.06 | 2.73 | 1.38 | 1.52 | 4.72 | 4.84 | 51.53 |
| 1884 | 5.20 | 5.84 | 9.70 | 5.86 | 1.33 | 10.73 | 2.42 | 2.06 | 0.08 | 0.70 | 2.84 | 6.09 | 52.85 |
| 1885 | 8.44 | 4.14 | 4.26 | 1.31 | 6.12 | 4.83 | 4.02 | 6.92 | 6.51 | 3.94 | 3.98 | 2.64 | 57.01 |
| 1886 | 7.33 | 1.53 | 11.16 | 2.53 | 6.21 | 8.68 | 2.08 | 2.36 | 0.53 | 0.03 | 5.32 | 3.03 | 50.78 |
| 1887 | 3.52 | 3.74 | 1.99 | 1.38 | 1.76 | 2.82 | 14.11 | 7.51 | 4.20 | 3.28 | 0.30 | 5.79 | 50.40 |
| 1888 | 3.89 | 5.91 | 8.16 | 1.34 | 6.86 | 4.71 | 1.85 | 3.89 | 14.26 | 3.99 | 4.70 | 5.42 | 64.98 |
| 1889 | 6.39 | 5.28 | 2.49 | 2.54 | 3.16 | 5.03 | 8.83 | 6.73 | 6.32 | 2.21 | 5.17 | 0.60 | 54.75 |
| 1890 | 2.95 | 3.36 | 3.13 | 2.04 | 6.32 | 1.12 | 5.37 | 3.99 | 5.36 | 4.89 | 0.18 | 3.89 | 42.60 |
| 1891 | 6.73 | 8.50 | 10.16 | 1.58 | 2.17 | 4.71 | 5.38 | 2.59 | 1.19 | 0.02 | 3.26 | 3.68 | 49.97 |
| 1892 | 8.93 | 3.44 | 5.71 | 4.75 | 1.37 | 4.65 | 3.77 | 6.66 | 2.70 | 0.59 | 4.41 | 2.89 | 49.87 |
| 1893 | 3.02 | 5.45 | 2.43 | 2.48 | 4.46 | 4.65 | 2.13 | 4.07 | 3.06 | 0.39 | 1.11 | 3.18 | 36.43 |
| 1894 | 5.09 | 4.98 | 2.99 | 3.06 | 1.49 | 1.29 | 5.55 | 3.70 | 5.78 | 2.62 | 0.92 | 3.45 | 40.92 |
| 1895 | 5.47 | 2.01 | 7.55 | 5.20 | 3.99 | 4.87 | 2.75 | 8.55 | 0.21 | 1.30 | 1.04 | 2.98 | 45.92 |
| 1896 | 3.12 | 3.04 | 3.29 | 0.58 | 1.95 | 2.66 | 7.55 | 1.97 | 1.36 | 1.28 | 5.90 | 1.42 | 34.12 |
| Average 26 years. | 5.30 | 5.37 | 6.16 | 4.03 | 3.56 | 4.53 | 4.19 | 4.61 | 3.48 | 2.07 | 3.47 | [e]4.29 | 50.96 |

[a] Maj. S. B. Wright, Georgia agricultural reports, 1870 to 1874.
[b] R. J. Redding, of Georgia agricultural department, 1875 to 1878.
[c] United States Weather Bureau.
[d] United States Weather Bureau, 1879 to 1896.
[e] December average includes December, 1870.

This average rainfall is distributed as follows: Spring, 13.75; summer, 13.33; autumn, 9.02; winter, 14.86.

The above table of rainfall at Atlanta, Georgia, from July, 1870, to December, 1896, inclusive—giving for the twenty-six complete years, 1871 to 1896, inclusive, an average annual rainfall of 50.96 inches—bears very strong evidence that the streams of this region have been lower during the present summer and autumn than at any time since 1870. There has been a continuous accumulating deficiency since 1890, which, however, did not begin to make a visible impression on the streams until 1893, though it naturally affected the supply of ground water available for the following years. But on top of this deficiency has come a period of four years, 1893 to 1896, inclusive, in which the average annual rainfall has been only 39.35 inches, distributed as follows: Spring, 9.87; summer, 12.43; autumn, 6.24; winter, 10.81.

Still more striking is the record for 1896, the last of these four years,




GEORGIA DRAINAGE MAP.

showing a total precipitation for the year of 34.12 inches, and the following distribution: Spring, 5.82; summer, 12.18; autumn, 8.54; winter, 7.58. The distribution for the last four years and for the year 1896 shows that the greatest rainfall has been in summer, when the amount of water taken up by vegetation and evaporation was greatest, a condition that has produced very fine crops and very low streams.

It is stated by the oldest inhabitants that the rivers are lower this season than they have ever seen them since the year 1845, and the statement is probably true, though it can not be verified by actual records reaching back to that year. They also state that the wells and springs have been getting lower and lower for four years, and that many have gone dry during this season which they have never before known to fail. To further emphasize the fact that the low water of this year is much lower than that of any ordinary year, the reader is referred to tables herewith of river gage heights for Canton, Resaca, Augusta, and Macon, Georgia, and Tuscaloosa, Alabama. The Augusta statement is a monthly statement of lowest water on the Savannah River for twelve years. (See pages 76 and 77.) Attention is also called to the discharge measurements of Mr. C. C. Anderson, late assistant State geologist of Georgia, above referred to, in which he shows that minimum low water during the years 1891 and 1892 was about 2,500 cubic feet per second at Oakdale, on the Chattahoochee, and about 2,100 cubic feet per second at Macon, on the Ocmulgee.

## OKEFENOKEE SWAMP.

This great swamp, situated in southeastern Georgia near the Florida line, and about 40 miles from the Atlantic coast, is a shallow freshwater lake, covering an area of 400,000 acres, and filled with black muck, derived mainly from the decomposition of aquatic plants. The muck has a depth of from 10 to 12 feet and rests upon a bed of fine sand, underlain by impervious clays and marls. A large part of this area is thickly covered with cypress, red bay, and white holly. There are also numerous islands having a heavy growth of pine and other timber. The rest of the tract is open prairie, the surface of the shallow water being entirely hidden by grass and water lilies.

The swamp is situated on a high plateau, which is the summit or divide between the Atlantic and the Gulf of Mexico, or, to be more explicit, between the St. Marys Basin and the Suwanee Basin. The Suwanee River flows out of its southwest corner toward the Gulf. The St. Marys River flows out of its southeast corner, runs south for a long distance, then east, and then, turning due north, comes back to within 6 miles of the eastern border of the swamp, after having made a circuit of about 100 miles. An accurate level line was run across this 6-mile neck, and it was found that the surface of the swamp was 120 feet above the surface of the St. Marys River. The river at this point having a tide of 4 feet, the swamp is 116 feet above high tide.

The top of the narrow rim or ridge dividing the swamp from the river is 1 mile from the swamp and 32 feet above the swamp level. The ground a mile farther from the swamp is below the swamp level. Hence, of this 6-mile distance, about 2 miles is above the level of the swamp and the other 4 below the swamp level.

This vast bog, 40 miles in length by about 25 miles in width, is the property of the Suwanee Canal Company. Ten miles or more of 40-foot canal have been dredged into it, and the company is floating out large quantities of cypress timber. An outlet canal has been partly excavated across the 6-mile neck above described, which, when completed, will drain the swamp and develop a vast area of rich agricultural lands. There will evidently be a surplus of fall in the outlet canal which can be used for water power. No discharge measurements have yet been made of the present outflow through the Suwanee and St. Marys. The greater part is probably lost by evaporation. The difference between highest and lowest water in the swamp is about 2 feet. In the excavations for outlet canal no fossils have yet been found, but a forest of stumps was encountered about 12 feet below the surface.

## SAVANNAH BASIN.

The Savannah River, the east bank of which at high water constitutes the line between the States of Georgia and South Carolina, is formed by the union of the Tugalo and Keowee rivers, which rise in the Blue Ridge Mountains of Georgia and South Carolina. The distance from this junction to Augusta, Georgia, the head of navigation, is a little over 100 miles. At Augusta the river leaps from its granitic bed rock to the younger geological formations, or crosses what is known as "the fall line." Its largest tributaries above Augusta are the Tugalo River—formed from the Tallulah and Chatuga rivers—Keowee River, Rocky River, Little River, and Hardlabor River from South Carolina, and the Broad River and Little River from Georgia.

Some of the most prominent undeveloped water powers are: On Tallulah River, Tallulah Falls, 335 feet fall. On Tugalo River, Tallulah Shoal, 75 feet fall; Guest Shoal, 17 feet fall; Hatton Shoal, 39 feet fall. On Broad River, Georgia, Anthony Shoal, about 90 feet fall. On Savannah River, McDaniels Shoal, 30 feet fall; Middletons, 14 feet fall; Trotters Shoal, or Calhoun Falls, 75 feet fall; Long Shoal, 35 feet fall; and the developed power at Augusta, 50 feet fall. There are also important powers on the South Carolina streams and on the smaller tributaries in Georgia. During the spring and early summer examinations were made to determine the best points for establishing permanent stations and making measurements of discharge.

The water powers of the Savannah Basin are accessible by means of the Southern Railway, the Seaboard Air Line, and the Georgia Railroad and its branches.

CALHOUN FALLS STATION ON SAVANNAH RIVER IN GEORGIA, NEAR CALHOUN FALLS, SOUTH CAROLINA.

This station is in the Elberton quadrangle, in latitude 34° 4.8′ and longitude 82° 38.3′. It is at the Seaboard Air Line bridge across the Savannah River above the mouth of Beaverdam Creek and below

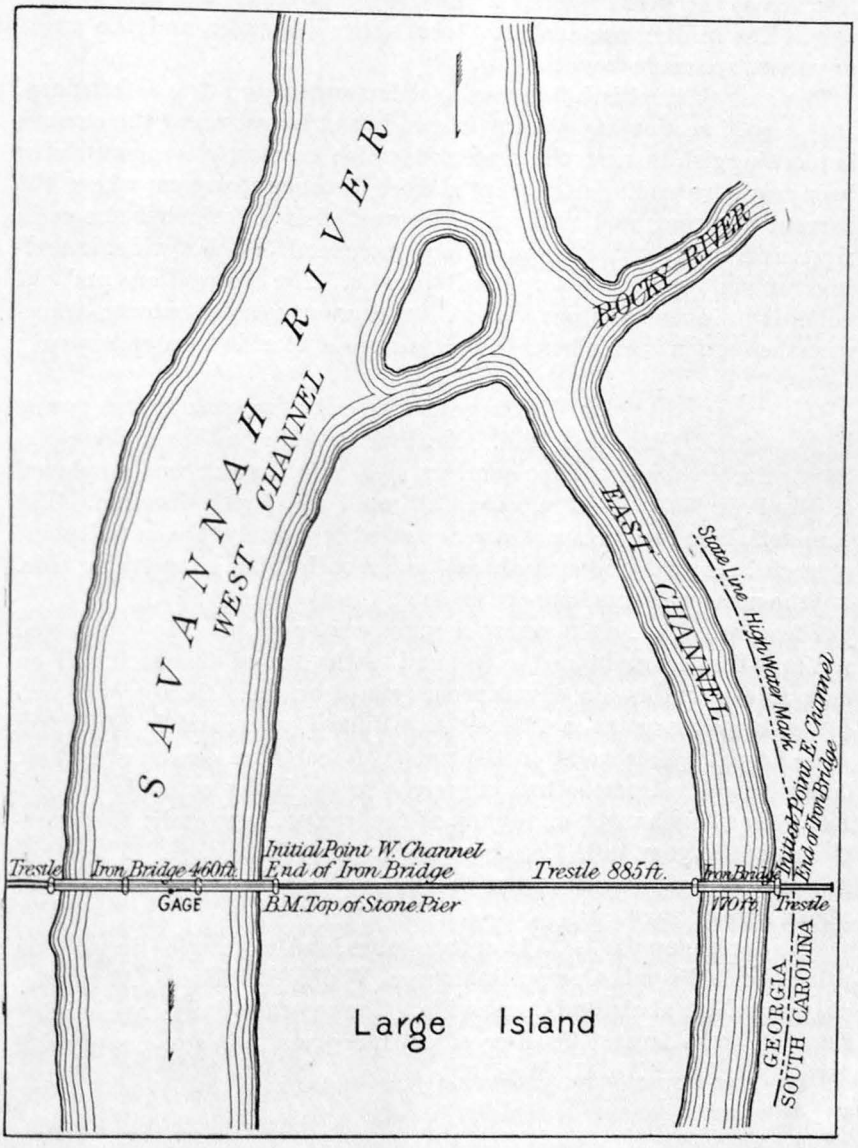



FIG. 9.—Gaging station near Calhoun Falls, South Carolina.

Rocky River, about 3 miles west of the town of Calhoun Falls, South Carolina, which is the nearest railroad station and post-office. This station is entirely in Georgia, as the South Carolina line is high-water

mark on the east side of the river. The river here is divided into two channels by a large island containing several hundred acres. Beginning at grade on east side, or left bank, and going toward the west, there is first about 100 feet of trestle, then 170 feet of iron bridge, single span, across the east channel, then 885 feet of trestle across the island, then an iron bridge consisting of three spans of 150 feet each, making 450 feet across the west channel; about 300 feet of trestle to grade on west side. The bridges are decked, 53 feet above low water, and the measurements are made from the top.

The east channel is 150 feet wide at low water, and 3 to 5 feet deep. It is a good section at ordinary stages, but at lowest water the current is too sluggish to turn the meter, in which case measurements have been made by wading at a point a short distance upstream, where the current is strong and uniform. The west channel, which is the main river, is from 1 to 8 feet deep at low water, and 390 feet wide, including two pie s and some very small islands. The obstructions and old cofferdams about the piers break the current to some extent; otherwise the section is excellent. The average depth of low water is nearly 4 feet.

On August 4, 1896, a discharge measurement was made and a wire gage put in by Mr. Max Hall. Mr. Peter Pfeiffer, a farmer living in South Carolina, about three-quarters of a mile distant, was employed as observer, his post-office being Calhoun Falls, South Carolina. The channels, being so far apart, are measured separately, the initial point of each being the east end of iron bridge on left bank, upstream side. All the measurements here are made on the upstream side.

The wire gage is on the west channel, center span. The graduated rod is 14 feet long, divided to feet and tenths, nailed to guard rail on east side of pulley on downstream side of bridge. Center of 3-inch pulley opposite point is 193 feet from initial point, and is 55.20 feet gage height. Zero point on the rod is 10 feet from center of pulley. The wire cable from bottom of weight to the index on cable is 65.40 feet. One bench mark on the top of the iron stringer under the cross-ties near the gage is 54 feet above the datum of the gage. The other is on the top of the east end of the pier, west channel, and is 30.85 feet above zero of gage.

The drainage area is 2,712 square miles, and is mapped in part on atlas sheets Pisgah, Cowee, Dahlonega, Walhalla, Pickens, Abbeville, Elberton, Nantahala, and Carnesville. The record of daily gage heights for 1896, from August 4 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 19.

*List of discharge measurements made on Savannah River, near Calhoun Falls, South Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 4 | Max Hall..... | 16 | 2.40 | 2,278 | 1.17 | 2,668 |
| 2 | Sept. 22 | .....do ..... | 11 | 1.77 | *a* 1,488 | *a* 0.98 | 1,531 |
| 3 | Oct. 31 | .....do ..... | 11 | 2.10 | 1,889 | 1.09 | 2,054 |

*a* West channel only.

*Rating table for Savannah River, near Calhoun Falls, South Carolina.*

[This table is applicable from August 4, 1896, to October 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.75 | 1,525 | 2.00 | 1,850 | 2.30 | 2,450 | 2.60 | 3,060 |
| 1.80 | 1,575 | 2.10 | 2,050 | 2.40 | 2,670 | 2.70 | 3,280 |
| 1.90 | 1,700 | 2.20 | 2,250 | 2.50 | 2,870 | 2 80 | 3,500 |

## SAVANNAH RIVER AT AUGUSTA, GEORGIA.

At the Piedmont Air Line bridge, on the Tugalo River, the section proved to be too poor to obtain a measurement of flow. At Augusta, Georgia, the section under the North Augusta highway bridge is excellent, and a very satisfactory discharge measurement was made by Professor Hall on October 3, 1896: Meter No. 8, height of water on city gage, 5 feet 5 inches; area, 3,178 square feet; mean velocity, 0.992 feet per second; discharge, 3,154 second-feet. It was not considered advisable, however, to establish a regular station here, as the intermittent flow caused by the factories is objectionable. The only way to avoid this will be to establish a station on the river above the Augusta dam, and far enough up not to be affected by back water. The bridge of the Augusta and Knoxville Railroad, not yet examined, will probably be a good point.

Mr. C. A. Maxwell, superintendent of the Augusta Canal, has kindly furnished the following table from the records of river height taken three times each day for the last twelve years on the city gage at the lower bridge. The rod is graded to feet and inches, and the table is a statement of lowest observed water in each month for the entire twelve years.

*Savannah River at Augusta, Georgia.*

[Lowest water on city gage in each month since 1884.]

| Month. | 1884. | | | | 1885. | | | | 1886. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. |
| January | ..... | ..... | ..... | ..... | 23 | 8.2 | 8.2 | 8.3 | 24 | 12.5 | 13 1 | 14.5 |
| February | ..... | ..... | ..... | ..... | 6 | 8.4 | 8.3 | 8.2 | 25 | ..... | 8 2 | ..... |
| March | ..... | ..... | ..... | ..... | 28 | 7.5 | 7.5 | 7.4 | 20 | ..... | 7 7 | ..... |
| April | ..... | ..... | ..... | ..... | 13 | 7.4 | ..... | ..... | 20 | 8.2 | 8.5 | 8.5 |
| May | ..... | ..... | ..... | ..... | 23 | 7.0 | 7.5 | 8.0 | 4 | 9.5 | 9.0 | 9.0 |
| June | ..... | ..... | ..... | ..... | 17 | 6.0 | 6.5 | 6.6 | 5 | 8.6 | 8.5 | 8.4 |
| July | ..... | ..... | ..... | ..... | 7 | 6.5 | 6.3 | 6.3 | 31 | 7.7 | 7.7 | 7.5 |
| August | 22 | 5.6 | 5.6 | 5.6 | 1 | 6.0 | ..... | 6.0 | 29 | 7.2 | 7.2 | 7 2 |
| September | 29 | 4.0 | 4.2 | 4.2 | 6 | 6.0 | ..... | 6.0 | 27 | 6.2 | 5.7 | 5.7 |
| October | 10 | 4.4 | 4.3 | 4.3 | 11 | 6.0 | ..... | 6.0 | 15 | 5.5 | 5.5 | 5.5 |
| November | 5 | 5.2 | ..... | ..... | 2 | 10.5 | ..... | ..... | 25 | 6.5 | 6.4 | 6.3 |
| December | 4 | 5.2 | ..... | ..... | 5 | 8.0 | ..... | ..... | 29 | 7.5 | ..... | ..... |

| Month. | 1887. | | | | 1888. | | | | 1889. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. |
| January | 5 | 7.5 | 7.5 | 7.5 | 30 | 8.5 | 8.5 | 8.6 | 16 | 10.4 | ..... | 10.5 |
| February | 19 | 10.5 | 10.3 | 10.0 | 2 | 8.2 | ..... | ..... | 13 | 10.1 | ..... | 10.0 |
| March | 28 | 7.0 | 7.0 | 7.0 | 19 | 8.2 | ..... | ..... | 31 | 9.8 | ..... | ..... |
| April | 10 | 7.0 | 7.0 | 7.0 | 30 | 8.5 | ..... | ..... | 30 | 8.5 | ..... | 8.4 |
| May | 12 | 7.5 | 7.5 | 7.5 | 5 | 8.2 | 8.2 | 8.3 | 26 | 7.0 | ..... | 6.8 |
| June | 1 | 7.5 | 9.5 | 13.5 | 27 | 7.0 | 7.2 | 7.0 | 27 | 6.6 | ..... | 6.6 |
| July | 28 | 7.5 | 7.5 | 7.5 | 27 | 6.4 | 6.3 | 6.3 | 25 | 6.5 | ..... | 6.4 |
| August | 26 | 8.5 | 8.2 | 8.2 | 9 | 5.8 | 6.0 | 6.0 | 24 | 7.0 | ..... | 7.0 |
| September | 28 | 6.5 | 6.5 | 6.5 | 29 | 10.2 | 10.1 | 10.0 | 18 | 6.7 | ..... | 6.7 |
| October | 13 | 6.2 | ..... | ..... | 22 | 8.0 | 8.0 | ..... | 22 | 6.2 | ..... | ..... |
| November | 29 | 6.1 | ..... | ..... | 8 | 9.2 | 9.1 | 9.0 | 3 | 6.7 | ..... | 7 0 |
| December | 5 | 6.0 | ..... | ..... | 9 | 8.8 | ..... | 8.9 | 29 | 5.4 | ..... | ..... |

| Month. | 1890. | | | | 1891. | | | | 1892. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. | Date. | 6 a.m. | 12 m. | 6 p.m. |
| January | 29 | 5.7 | ..... | 5.7 | 9 | 7.5 | ..... | ..... | 2 | 7.8 | ..... | ..... |
| February | 6 | 8.3 | ..... | 8.3 | 16 | 13.2 | 13.0 | 13.7 | 7 | 8.6 | ..... | 8.5 |
| March | 19 | 8.1 | ..... | 8.1 | 5 | 11.8 | ..... | 11.7 | 6 | 8.3 | ..... | 8.2 |
| April | 27 | 7.5 | ..... | 7.5 | 30 | 9.5 | ..... | ..... | 30 | 8.6 | 8.7 | 8.6 |
| May | 14 | 7.2 | ..... | 7.2 | 26 | 8.0 | 8.2 | ..... | 2 | 7.5 | 7.5 | 7.2 |
| June | 13 | 5.5 | ..... | 5.6 | 28 | 6.9 | 6.8 | ..... | 31 | 7.7 | 7.5 | 7.4 |
| July | 30 | 6.0 | ..... | 6.1 | 16 | 6.3 | 6.4 | 6.5 | 17 | 6.7 | 6.8 | 6 8 |
| August | 28 | 5.4 | ..... | 5.4 | 13 | 7.0 | ..... | ..... | 10 | 5.9 | 6.3 | 6.0 |
| September | 21 | 6.1 | ..... | 6.1 | 25 | 6.0 | 6.1 | ..... | 21 | 6 2 | 6.6 | ..... |
| October | 22 | 7.6 | 7.8 | 7.8 | 25 | 5.4 | 5.5 | 5.6 | 2 | 5.9 | 6.6 | 6.4 |
| November | 26 | 6.8 | ..... | ..... | 1 | 5.3 | 5.4 | 5.5 | 2 | 6.8 | 7.4 | 6.2 |
| December | 4 | 6.8 | ..... | ..... | 3 | 7.2 | 7.2 | 7.0 | 15 | 6.6 | 6.7 | 6.6 |

*Savannah River at Augusta, Georgia*—Continued.

[Lowest water on city gage in each month since 1884.]

| Month. | 1893. | | | | 1894. | | | | 1895. | | | | 1896. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date. | 6 a. m. | 12 m. | 6 p. m. | Date. | 6 a. m. | 12 m. | 6 p. m. | Date. | 6 a. m. | 12 m. | 6 p. m. | Date. | 6 a. m. | 12 m. | 6 p. m. |
| January | 18 | 6.3 | 6.6 | ..... | 6 | 7.1 | ..... | ..... | 8 | 7.7 | 7.8 | .... | 15 | 6.3 | 6.8 | 6.4 |
| February | 10 | 8.0 | 8.2 | 8.0 | 4 | 7.8 | 7.8 | 7.7 | 10 | 9.0 | 8.8 | 8.2 | 28 | 7.8 | 8.2 | 8.3 |
| March | 31 | 8.0 | ..... | ..... | 31 | 8.0 | 8.2 | 8.2 | 1 | 8.9 | ..... | 9.0 | 31 | 7.1 | 7.6 | 7.8 |
| April | 20 | 6.1 | 6.5 | ..... | 28 | 7.2 | 7.2 | 7.3 | 7 | 8.8 | 8.7 | 8.8 | 24 | 5.8 | 6.0 | 6.3 |
| May | 29 | 6.0 | 6.7 | ..... | 31 | 6.2 | 6.7 | 6.2 | 18 | 8.7 | 8.8 | 8.6 | 23 | 4.9 | 5.6 | 5.4 |
| June | 30 | 6.5 | 6.8 | 6.7 | 18 | 4.9 | 5.5 | 5.6 | 27 | 6.8 | 6.2 | 7.2 | 18 | 4.6 | 5.2 | 5.0 |
| July | 15 | 5.2 | 5.8 | 5.6 | 16 | 4.7 | 5.6 | 5.4 | 21 | 6.3 | 6.4 | 7.3 | 4 | 4.2 | 5.0 | 5.0 |
| August | 26 | 5.0 | 5.4 | 5.3 | 24 | 5.8 | 6.1 | 5.8 | 3 | 5.8 | 6.1 | 5.8 | 25 | 5.9 | 4.8 | 4.8 |
| September | 26 | 6.8 | 7.0 | 6.8 | 13 | 5.0 | 5.6 | ..... | 30 | 4.9 | 5.8 | 5.5 | *a*23 | 3.8 | 4.3 | 4.2 |
| October | 31 | 6.0 | 6.0 | 6.2 | 31 | 5.4 | 5.9 | 6.2 | 26 | 4.4 | 5.5 | 5.2 | *b*3 | 5.3 | 5.4 | 5.4 |
| November | 21 | 5.6 | 5.4 | 6.2 | 12 | 5.3 | 6.2 | 5.8 | 2 | 4.5 | 5.8 | 5.3 | .... | ..... | ..... | ..... |
| December | 15 | 6.2 | 6.4 | 6.3 | 3 | 5.3 | 6.0 | 5.3 | 8 | 5.3 | 5.5 | ..... | .... | ..... | ..... | ..... |

*a* The lowest gage height given occurred on September 23, 1896. *b* October 7, 6 a. m., 4.2; 12 m., 4.8.

## OGEECHEE BASIN.

Ogeechee Basin has some good powers on its head waters, but their importance is small in comparison with those of other basins, and no discharge measurements have yet been made.

## ALTAMAHA BASIN.

Altamaha Basin is a large basin in Georgia, the Altamaha River being formed by the union of two large rivers, the Oconee and the Ocmulgee. The Oconee River heads near Gainesville, Georgia, to the south of the Atlantic and Gulf divide, known locally as the Chattahoochee Ridge. It is made up of the North Oconee, Middle Oconee, and Apalachee rivers and many smaller tributaries. It crosses the fall line at Milledgeville, which is at the head of navigation. The stream and its tributaries form a succession of shoals from its head to Milledgeville. Some of the largest of these are: Hurricane Shoal, on North Oconee, 30 feet fall in 600 feet distance; Tallassee Bridge Shoal, on Middle Oconee, about 52 feet fall in less than a mile; High Shoals, on Apalachee River, 50 feet fall in 600 feet, and 20 feet more just above it; Barnett's Shoal, on Oconee River below junction of north and middle forks, 54 feet fall in 4,000 feet distance; and 35 or 40 feet just above Milledgeville, that can be utilized by a canal 5 or 6 miles long.

On October 19, 1895, Mr. C. C. Babb visited Milledgeville and made a discharge measurement at the highway bridge, where the water was 37.78 feet below the top of lower end of third floor beam of first span from the east. He found a mean velocity of 1.75 feet per second and a discharge of 1,108 second-feet. On September 3, 1896, Mr. Max

Hall made a discharge measurement at the same point, when the water was 0.42 foot lower than at the time of Mr. Babb's measurement, obtaining the following results: Area, 344 square feet; mean velocity, 1.81 feet per second; discharge, 623 second-feet. It can be safely assumed that this last measurement was at minimum stage for the driest years, and that such years are not liable to recur more than once or twice in a century.[1] On October 29, 1896, a regular station was established on the Oconee River just below the mouth of the Apalachee River, about 30 miles above Milledgeville, at a point where the Georgia Railroad crosses.

### CAREY STATION ON OCONEE RIVER.

This station is located at an iron-girder deck bridge on the Georgia Railway at the station of Carey, 6 miles west of Greensboro, Georgia, the nearest post-office. It is just below the junction of the Apalachee and Oconee rivers. It was established by Max Hall October 29, 1896. The observer is Mr. J. L. Carey, a farmer, living at a distance of about one-quarter of a mile, son of the bridge watchman. The bridge is 223 feet long, in three equal spans, and has an approach from the left bank consisting of about 600 feet of trestle work, and another from the right bank of about 175 feet. The gage is of wire. The length of the wire from index to end of weight is 46.32 feet. The scale is marked on a horizontal rod, 14 feet in length, nailed to the guard rail of the bridge on the downstream side. Its zero point is 24.5 feet, and the 14-foot mark is 10.5 feet from the initial point, which is the downstream end of the pier near the left bank at the end of the big iron girder. The top of the cord or iron girder 20 feet from the initial point on downstream side of bridge is 41.13 feet above datum of gage heights. The center of the 2½-inch pulley is 29.5 feet from the initial point and is 5 feet west of zero end of rod and 41.2 feet above datum of gage heights. The channel above the station on the Oconee is straight for about 2,000 feet and has a good current. That of the Apalachee is curved, but also has a good current. Both banks are low and liable to overflow under the trestles to the end of embankments. The bed of the stream is rocky and not easily changed. The gage was not put in until November 17, 1896, but gage heights were closely estimated from October 30 to November 16, inclusive, and referred to bench mark established October 29. This station is shown in the accompanying sketch.

During the spring and summer of 1896 examinations were made to find other suitable points for continuous measurements, but so far no other good sections have been found that are easily accessible. It was fully expected that proper sections on the North and Middle Oconees and the Apalachee, near Athens, Georgia, would be found, but unfavorable sections have been found under the bridges, and an intermittent

[1] See Atlanta rainfall table and gage heights on other streams.

flow caused by mills and factories. The water powers of the Oconee and its tributaries are accessible by the Southern Railway, the Seaboard Air Line Railway, and the Georgia Railroad and its branches.

*List of discharge measurements made on Oconee River at Carey, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Oct. 29 | Max Hall..... | 11 | 1.68 | 735 | 0.88 | 644 |
| 2 | Nov. 17 | B. M. Hall..... | 8 | 2.08 | 702 | 1.19 | 836 |
| 3 | Nov. 25 | .....do ..... | 8 | 1.90 | 715 | 1.11 | 795 |
| | 1897. | | | | | | |
| 4 | Jan. 18 | B. M. Hall..... | 8 | 4.95 | 1,344 | 2.47 | 3,318 |
| 5 | Mar. 18 | .....do ..... | 91 | 5.15 | 1,417 | 3.00 | 4,257 |

*Rating table for Oconee River at Carey, Georgia.*

[This table is applicable from October 29, 1896, to March 18, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| ..... | ..... | 2.10 | 850 | 3.20 | 1,465 | 4.30 | 2,430 |
| ..... | ..... | 2.20 | 900 | 3.30 | 1,530 | 4.40 | 2,550 |
| ..... | ..... | 2.30 | 950 | 3.40 | 1,600 | 4.50 | 2,680 |
| ..... | ..... | 2.40 | 1,000 | 3.50 | 1,670 | 4.60 | 2,820 |
| ..... | ..... | 2.50 | 1,055 | 3.60 | 1,740 | 4.70 | 2,970 |
| ..... | ..... | 2.60 | 1,110 | 3.70 | 1,830 | 4.80 | 3,130 |
| 1.60 | 635 | 2.70 | 1,165 | 3.80 | 1,910 | 4.90 | 3,300 |
| 1.70 | 670 | 2.80 | 1,220 | 3.90 | 2,000 | 5.00 | 3,500 |
| 1.80 | 715 | 2.90 | 1,270 | 4.00 | 2,100 | 5.10 | 3,850 |
| 1.90 | 760 | 3.00 | 1,340 | 4.10 | 2,210 | 5.20 | 4,230 |
| 2.00 | 805 | 3.10 | 1,400 | 4.20 | 2,320 | 5.30 | 4,620 |

## MACON STATION ON OCMULGEE RIVER.

The Ocmulgee River heads as South River in the city of Atlanta. It is made up of South River, Yellow River, Alcovey River, Towaliga River, and other streams. It crosses the fall line at Macon, the head of navigation. Above this point it is a constant series of shoals, some of the largest being: 46 feet fall in 3,300 feet distance near Conyers, on Yellow River; 55 feet in 2,700 feet distance at Cedar Shoal, near Covington, on same river; 24 feet, 18 feet, 12 feet, 12 feet, 20 feet, and 16 feet at successive shoals on South River; 85 feet in 4,000 feet distance at Garners Shoal, on Alcovey River; 97 feet in 1,200 feet distance at

Highfalls, on Towaliga River, and almost a continuous shoal along the line of the Southern Railway, on the Ocmulgee River, for 40 miles above Macon. The Southern Railway and the Georgia Railroad give easy access to the water powers of the Ocmulgee system.

On September 19, 1896, Mr. Max Hall made a discharge measurement at Almon, on the Yellow River, where the Georgia Railroad crosses near Covington, Georgia, finding a discharge of only 62.4 second-feet. It is probable that this does not represent the true minimum discharge of the river, as there are impounding dams above which may have materially affected the flow at that low-water season.

The only regular station on the Ocmulgee watershed is at Macon, Georgia. Here the United States Weather Bureau kept a record of gage height during 1893, 1894, and a part of 1895. Using the same gage datum, Mr. C. C. Babb established a regular station here on October 23, 1895, and Prof. B. M. Hall has kept up regular records and measurements from that time to the present.

This station was described in Bulletin No. 140, page 74. Observations have been continued throughout the year from the gage on the Macon, Dublin and Savannah Railroad bridge in the eastern part of the town. Measurements of discharge are made from the wagon bridge a short distance above. The observer is Mr. J. P. Mercer. The length of the wire gage cable is 35.30 feet. The zero of the rod is 3.85 feet from the outside of the pulley wheel. The drainage area, as measured from county maps, is 2,425 square miles. A bench mark on the top and upper end of the triangular casting at the foot of the seventh tie rod of the first span from the south is 28.84 feet above datum of gage. The record of daily gage heights for 1893, 1894, 1895, and 1896 is given in Water-Supply and Irrigation Paper No. 11, page 21.

*List of discharge measurements made on Ocmulgee River at Macon, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second) | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 18 | C. C. Babb.... | 76 | 0.39 | 784 | 1.04 | 813 |
| 2 | Oct. 23 | .....do ..... | 76 | 0.20 | 726 | 1.06 | 767 |
| 3 | Dec. 13 | .....do ..... | 62 | 1.59 | 1,045 | 1.46 | 1,530 |
| | 1896. | | | | | | |
| 4 | Jan. 28 | B. M. Hall..... | 8 | 5.52 | 2,107 | 1.63 | 3,436 |
| 5 | June 12 | .....do ..... | 8 | —0.10 | 539 | 1.47 | 791 |
| 6 | June 30 | Max Hall..... | 8 | —0.82 | 372 | 1.19 | 442 |
| 7 | Aug. 6 | .....do ..... | 16 | 2.97 | 1,659 | 1.23 | 2,045 |
| 8 | Aug. 31 | .....do ..... | 11 | —0.13 | 837 | 0.776 | 651 |
| 9 | Oct. 16 | .....do ..... | 11 | —0.61 | 667 | 0.68 | 459 |
| | 1897. | | | | | | |
| 10 | Mar. 15 | B. M. Hall..... | 91 | 16.75 | 5,862 | 4.36 | 25,535 |

*Rating table for Ocmulgee River at Macon, Georgia.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| —0.80 | 426 | 3.30 | 2,195 | 7.40 | 5,060 | 11.50 | 11,125 |
| —0.70 | 469 | 3.40 | 2,240 | 7.50 | 5,175 | 11.60 | 11,295 |
| —0.60 | 512 | 3.50 | 2,285 | 7.60 | 5,290 | 11.70 | 11,465 |
| —0.50 | 555 | 3.60 | 2,320 | 7.70 | 5,405 | 11.80 | 11,635 |
| —0.40 | 598 | 3.70 | 2,375 | 7.80 | 5,520 | 11.90 | 11,805 |
| —0.30 | 641 | 3.80 | 2,420 | 7.90 | 5,635 | 12.00 | 11,975 |
| —0.20 | 684 | 3.90 | 2,470 | 8.00 | 5,750 | 12.10 | 12,175 |
| —0.10 | 727 | 4.00 | 2,520 | 8.10 | 5,900 | 12.20 | 12,375 |
| 0.00 | 770 | 4.10 | 2,575 | 8.20 | 6,050 | 12.30 | 12,575 |
| +0.10 | 813 | 4.20 | 2,630 | 8.30 | 6,200 | 12.40 | 12,775 |
| 0.20 | 855 | 4.30 | 2,685 | 8.40 | 6,350 | 12.50 | 12,975 |
| 0.30 | 898 | 4.40 | 2,740 | 8.50 | 6,500 | 12.60 | 13,180 |
| 0.40 | 941 | 4.50 | 2,800 | 8.60 | 6,650 | 12.70 | 13,385 |
| 0.50 | 984 | 4.60 | 2,860 | 8.70 | 6,800 | 12.80 | 13,590 |
| 0.60 | 1,027 | 4.70 | 2,915 | 8.80 | 6,950 | 12.90 | 13,795 |
| 0.70 | 1,070 | 4.80 | 2,970 | 8.90 | 7,100 | 13.00 | 14,000 |
| 0.80 | 1,113 | 4.90 | 3,030 | 9.00 | 7,250 | 13.10 | 14,275 |
| 0.90 | 1,156 | 5.00 | 3,090 | 9.10 | 7,385 | 13.20 | 14,550 |
| 1.00 | 1,200 | 5.10 | 3,150 | 9.20 | 7,520 | 13.30 | 14,825 |
| 1.10 | 1,242 | 5.20 | 3,210 | 9.30 | 7,655 | 13.40 | 15,100 |
| 1.20 | 1,285 | 5.30 | 3,270 | 9.40 | 7,790 | 13.50 | 15,375 |
| 1.30 | 1,328 | 5.40 | 3,330 | 9.50 | 7,925 | 13.60 | 15,650 |
| 1.40 | 1,371 | 5.50 | 3,390 | 9.60 | 8,065 | 13.70 | 15,925 |
| 1.50 | 1,414 | 5.60 | 3,460 | 9.70 | 8,205 | 13.80 | 16,200 |
| 1.60 | 1,457 | 5.70 | 3,530 | 9.80 | 8,345 | 13.90 | 16,475 |
| 1.70 | 1,500 | 5.80 | 3,600 | 9.90 | 8,485 | 14.00 | 16,750 |
| 1.80 | 1,543 | 5.90 | 3,675 | 10.00 | 8,625 | 14.10 | 17,050 |
| 1.90 | 1,586 | 6.00 | 3,750 | 10.10 | 8,790 | 14.20 | 17,350 |
| 2.00 | 1,629 | 6.10 | 3,825 | 10.20 | 8,955 | 14.30 | 17,650 |
| 2.10 | 1,672 | 6.20 | 3,900 | 10.30 | 9,120 | 14.40 | 17,950 |
| 2.20 | 1,715 | 6.30 | 3,985 | 10.40 | 9,285 | 14.50 | 18,250 |
| 2.30 | 1,758 | 6.40 | 4,070 | 10.50 | 9,450 | 14.60 | 18,550 |
| 2.40 | 1,801 | 6.50 | 4,155 | 10.60 | 9,620 | 14.70 | 18,850 |
| 2.50 | 1,844 | 6.60 | 4,240 | 10.70 | 9,790 | 14.80 | 19,150 |
| 2.60 | 1,887 | 6.70 | 4,335 | 10.80 | 9,960 | 14.90 | 19,450 |
| 2.70 | 1,920 | 6.80 | 4,430 | 10.90 | 10,130 | 15.00 | 19,750 |
| 2.80 | 1,963 | 6.90 | 4,515 | 11.00 | 10,300 | 15.10 | 20,075 |
| 2.90 | 2,006 | 7.00 | 4,600 | 11.10 | 10,465 | 15.20 | 20,400 |
| 3.00 | 2,050 | 7.10 | 4,715 | 11.20 | 10,630 | 15.30 | 20,725 |
| 3.10 | 2,100 | 7.20 | 4,830 | 11.30 | 10,795 | 15.40 | 21,050 |
| 3.20 | 2,150 | 7.30 | 4,945 | 11.40 | 10,960 | 15.50 | 21,375 |

*Rating table for Ocmulgee River at Macon, Georgia*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet..* | *Feet.* | *Sec. feet.* |
| 15.60 | 21,700 | 16.80 | 25,560 | 18.00 | 29,375 | 19.20 | 33,440 |
| 15.70 | 22,025 | 16.90 | 25,880 | 18.10 | 29,710 | 19.30 | 33,785 |
| 15.80 | 22,350 | 17.00 | 26,200 | 18.20 | 30,045 | 19.40 | 34,130 |
| 15.90 | 22,675 | 17.10 | 26,515 | 18.30 | 30,380 | 19.50 | 34,475 |
| 16.00 | 23,000 | 17.20 | 26,830 | 18.40 | 30,715 | 19.60 | 34,820 |
| 16.10 | 23,320 | 17.30 | 27,145 | 18.50 | 31,050 | 19.70 | 35,165 |
| 16.20 | 23,640 | 17.40 | 27,460 | 18.60 | 31,390 | 19.80 | 35,510 |
| 16.30 | 23,960 | 17.50 | 27,775 | 18.70 | 31,730 | 19.90 | 35,855 |
| 16.40 | 24,280 | 17.60 | 28,095 | 18.80 | 32,070 | 20.00 | 36,200 |
| 16.50 | 24,600 | 17.70 | 28,415 | 18.90 | 32,410 | | |
| 16.60 | 24,920 | 17.80 | 28,735 | 19.00 | 32,750 | | |
| 16.70 | 25,240 | 17.90 | 29,055 | 19.10 | 33,095 | | |

*Estimated monthly discharge of Ocmulgee River at Macon, Georgia.*

[Drainage area, 2,425 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1893. | | | | | | |
| January 21 to 31 | 4,240 | 1,887 | 2,881 | 62,854 | 0.48 | 1.19 |
| February | 18,550 | 1,328 | 5,667 | 314,729 | 2.44 | 2.34 |
| March 1 to 20, 24 to 31 | 13,385 | 1,672 | 4,438 | 246,484 | 1.90 | 1.83 |
| April | 7,250 | 1,285 | 1,938 | 115,319 | 0.89 | 0.80 |
| May | 4,830 | 855 | 1,844 | 113,384 | 0.87 | 0.76 |
| June | 8,205 | 1,200 | 2,352 | 139,953 | 1.08 | 0.97 |
| July | 3,330 | 1,113 | 1,411 | 86,760 | 0.67 | 0.58 |
| August | 15,100 | 1,242 | 2,336 | 143,636 | 1.10 | 0.96 |
| September | 10,130 | 1,371 | 2,787 | 165,838 | 1.28 | 1.15 |
| October | 5,750 | 1,328 | 1,905 | 117,135 | 0.91 | 0.79 |
| November | 2,050 | 1,414 | 1,552 | 92,350 | 0.71 | 0.64 |
| December | 2,285 | 1,414 | 1,794 | 110,309 | 0.85 | 0.74 |
| Per annum | 18,550 | 855 | 2,575 | 1,708,751 | 13.18 | 1.06 |
| 1894. | | | | | | |
| January | 4,430 | 1,457 | 2,246 | 138,102 | 1.07 | 0.93 |
| February | 15,925 | 1,629 | 4,488 | 249,251 | 1.92 | 1.85 |
| March | 9,285 | 2,050 | 3,415 | 209,982 | 1.63 | 1.41 |
| April | 4,155 | 1,629 | 2,409 | 143,345 | 1.10 | 0.99 |
| May | 2,050 | 1,285 | 1,464 | 90,018 | 0.69 | 0.60 |

*Estimated monthly discharge of Ocmulgee River at Macon, Georgia*—Continued.

[Drainage area, 2,425 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1894. | | | | | | |
| June | 2,050 | 1,113 | 1,359 | 80,866 | 0.62 | 0.56 |
| July | 5,635 | 1,285 | 2,391 | 147,018 | 1.13 | 0.98 |
| August | 17,350 | 2,050 | 3,854 | 236,975 | 1.83 | 1.59 |
| September | 10,795 | 1,200 | 2,723 | 162,029 | 1.25 | 1.12 |
| October | 20,075 | 1,113 | 2,841 | 174,687 | 1.35 | 1.17 |
| November | 4,600 | 1,200 | 1,980 | 117,818 | 0.91 | 0.82 |
| December | 14,550 | 1,156 | 2,827 | 173,827 | 1.35 | 1.17 |
| Per annum | 20,075 | 1,113 | 2,666 | 1,923,918 | 14.85 | 1.10 |
| 1895. | | | | | | |
| January | 19,750 | 1,629 | 4,698 | 288,871 | 2.24 | 1.94 |
| February | 3,750 | 2,100 | 2,610 | 144,952 | 1.13 | 1.08 |
| March | 30,715 | 2,050 | 8,187 | 503,402 | 3.90 | 3.38 |
| April | 12,975 | 2,470 | 5,040 | 299,900 | 2.32 | 2.08 |
| May | 12,975 | 2,320 | 3,244 | 199,467 | 1.54 | 1.34 |
| June | 2,800 | 2,006 | 2,322 | 138,168 | 1.07 | 0.96 |
| July | 15,100 | 2,006 | 4,360 | 268,088 | 2.08 | 1.80 |
| August | 14,000 | 1,963 | 4,529 | 278,479 | 2.16 | 1.87 |
| September | 3,090 | 2,050 | 2,502 | 148,879 | 1.15 | 1.03 |
| October | 1,629 | 842 | 1,036 | 63,702 | 0.49 | 0.43 |
| November | 1,174 | 971 | 1,016 | 60,456 | 0.47 | 0.42 |
| December | 2,776 | 941 | 1,284 | 78,951 | 0.61 | 0.53 |
| Per annum | 30,715 | 842 | 3,402 | 2,473,315 | 19.16 | 1.40 |
| 1896. | | | | | | |
| January | 13,600 | 1,178 | 3,353 | 206,167 | 1.59 | 1.38 |
| February | 14,270 | 1,801 | 3,889 | 223,697 | 1.73 | 1.60 |
| March | 4,800 | 1,586 | 2,884 | 177,329 | 1.37 | 1.19 |
| April | 2,860 | 1,049 | 1,449 | 86,222 | 0.67 | 0.60 |
| May | 1,942 | 727 | 1,001 | 61,548 | 0.47 | 0.41 |
| June | 1,586 | 405 | 888 | 52,840 | 0.41 | 0.37 |
| July | 36,200 | 380 | 7,436 | 457,222 | 3.54 | 3.07 |
| August | 2,075 | 727 | 1,150 | 70,710 | 0.54 | 0.47 |
| September | 813 | 380 | 608 | 36,178 | 0.28 | 0.25 |
| October | 727 | 380 | 487 | 29,944 | 0.23 | 0.20 |
| November | 17,950 | 706 | 3,227 | 192,019 | 1.48 | 1.33 |
| December | 13,200 | 1,070 | 3,261 | 200,511 | 1.56 | 1.35 |
| Per annum | 36,200 | 380 | 2,469 | 1,794,387 | 13.87 | 1.02 |

The minimum discharge at Macon, as established by Mr. C. C. Anderson, of the Georgia Geological Survey, by a series of measurements made in 1891 and 1892, was 2,100 second-feet. This would indicate that during those years the lowest stage reached by the water would correspond to 3.10 on the present gage. The Weather Bureau gage station was not established until 1893, and may or may not have been set on the same datum as Mr. Anderson's gage (now washed away), but it is interesting to note that the gage heights given by the Weather Bureau for 1893 and 1894 are much higher than those for 1896 taken from the same datum by the United States Geological Survey.

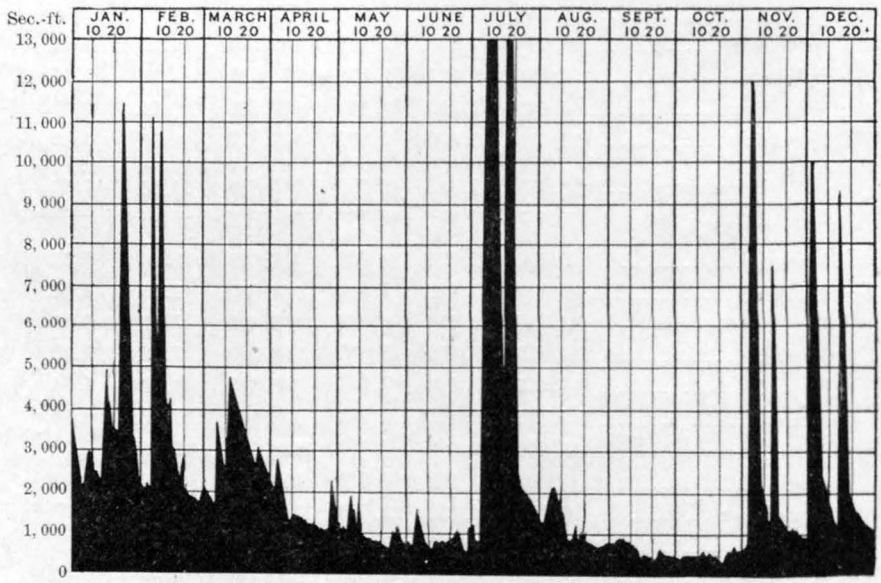



FIG. 10.—Discharge of Ocmulgee River at Macon, Georgia, 1896.

## GULF OF MEXICO WATERSHED.

### APALACHICOLA BASIN.

This basin includes the Chattahoochee and Flint rivers, which join to form the Apalachicola River at the Florida line. It has been described by Prof. George F. Swain in his report on the "Water powers of the eastern Gulf Slope," pages 21 to 34, contained in Volume XVI of the Tenth Census reports.

The Chattahoochee River rises in the northeast corner of Georgia and flows in a southwesterly direction through the State, reaching the Alabama line at West Point; thence along the Alabama line to the southwest corner of Georgia. The Georgia line is not the center of the river, however, but is high-water mark on its west bank, leaving the entire river on Georgia territory. At Columbus, Georgia, the head of navigation, the river crosses the fall line and leaves its granitic bed to enter the younger geological formations. The Chattahoochee

water-shed is a long, narrow basin, having its greatest width in the Blue Ridge Mountains, where the autumn rainfall is much greater than it is at Atlanta. Dividing the waters of the Atlantic slope from those of the Tennessee and Mobile basins, it holds a position which would naturally be expected to be occupied by a great ridge. It is, in fact, on very high ground, the river bed opposite Atlanta being 762 feet above tide. This is about 300 feet lower than the city of Atlanta, whose elevation is 1,050 feet at the union passenger depot, and about 1,100 feet at the highest point in the city.

From Gainesville to Columbus, Georgia, a distance of 214 miles, the river falls 748 feet, 362 feet of which is between West Point and Columbus, a distance of only 34 miles. This fall is not uniform, but is a succession of abrupt shoals with long stretches of navigable water between them. The largest tributaries are the Soquee River, Big Wahoo Creek, Chestatee River, Vickerys Creek, Peachtree Creek, and Sweetwater Creek. Some of the large water powers are Porter Mills Shoals, on Soquee River, with 75 feet fall; Austell Shoal, on Sweetwater Creek, with 80 feet fall; and the following on Chattahoochee River: Johnnys Ford, opposite Mount Airy, 38 feet fall; Pegg and Dunlap Shoal, in 3 miles of Gainesville, about 30 feet; Browns bridge, 9 miles from Gainesville, 17 feet, with 7 feet just above it; shoals near Buford and Suwanee, 20 feet or more; Bull Sluice, below Roswell, 13½ miles from Atlanta, 50 feet fall; Vining Shoal, 7½ miles from Atlanta, 32 feet fall; large shoals near Fairburn, Newnan, Hogansville, and Lagrange, fall unknown; from West Point to Columbus, 34 miles, fall 362 feet in successive drops, as follows: 51, 89, 20, 26, 22, 30, 10, 42, 37, 10, and 25 feet. Of this fall 120 feet is in the last 4 miles near Columbus. There are also many fine powers on the Flint River, the best being Flat Shoals or Freeman Shoal, on the line of Pike and Merriwether counties, near Neals Station on the Georgia Midland Railroad, a division of the Southern Railway.

The Piedmont Air Line of the Southern Railway closely parallels the river from Clarkesville to Atlanta, a distance of 80 miles. The Georgia Pacific Division of the Southern Railway passes Austell and shoals in vicinity; the Georgia Midland of the same system reaches Columbus. Its Atlanta and Florida and Georgia Midland divisions reach the Flint River powers. The Western and Atlantic Railroad passes within 1 mile of the Vining Shoal. The Atlanta and West Point Railroad closely parallels the river from Atlanta to West Point, and the Western Railway of Alabama is close to some of the largest shoals below West Point.

### OAKDALE STATION ON CHATTAHOOCHEE RIVER.

This station is in latitude 33° 48.8′, longitude 84° 29.5′, in the Atlanta quadrangle, 1 mile above the mouth of Proctor Creek, about 6 miles from Atlanta, near the town of Oakdale, where the Southern

Railroad bridge crosses the Chattahoochee. It is described in Bulletin 140, page 76. The bridge is decked, and consists of two spans, each 150 feet long. The current under the bridge has a moderate velocity, and measurements are made from a plank walk extending through the bridge and resting on the lower members at a height of about 30 feet above the water. The bridge itself is about 56 feet from the water. A wire gage was placed October 17, 1895, the pulley and rod being attached to the lower guard rail on the second panel of the second span from the east. The water was at that time 29 feet below the top of the upper end of the third crossbeam, on which the plank walk rests, first span from the east. This measurement was taken from the casting at

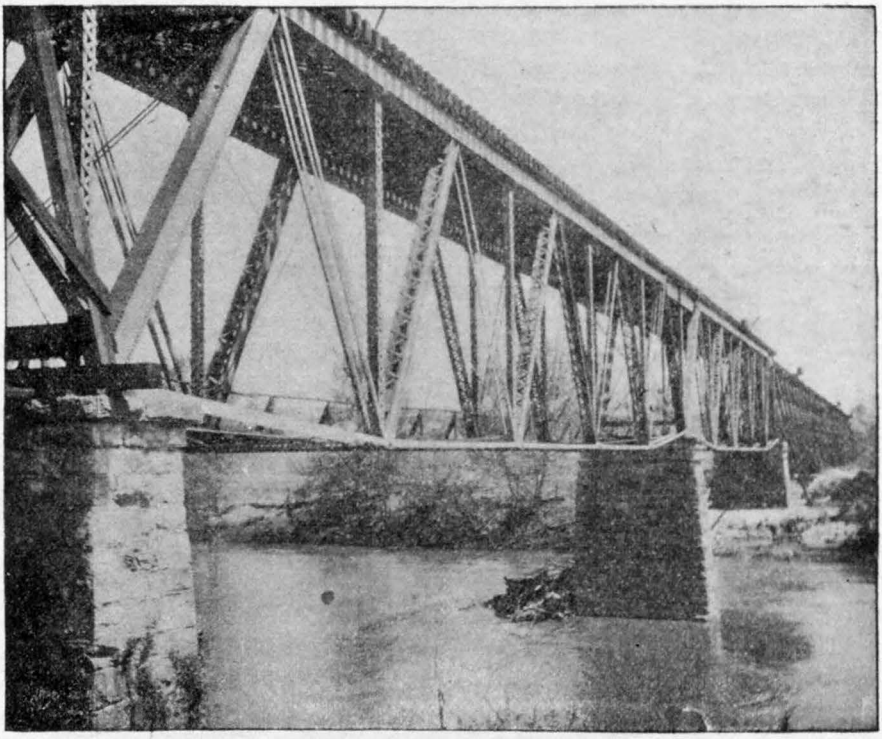


FIG. 11.—Oakdale station on Chattahoochee River.

the end of the crossbeam, close to the tie rod. The length of the wire gage is 58.85 feet. The distance from the pulley to the zero of the rod is 2.20 feet. The reading of the gage on October 17, when established, was 0.35 foot. The drainage area above this point is 1,560 square miles, and is mapped on atlas sheets Walhalla, Dahlonega, Ellijay, Suwanee, Gainesville, Marietta, and Atlanta. Mr. Hall has made an exact cross section with Y level. There have been some changes in the cross section made by the shifting sand bottom and by a raft formed recently at the center pier of the bridge; but as the gage wire is at a point considerably below the cross section, where there have been no changes of

cross section, the discharge remains practically the same for same gage height. The lowest discharge, as found by Mr. C. C. Anderson, late assistant State geologist, by a series of measurements made in 1891 and 1892, was over 2,500 second-feet, which would correspond to present gage height 2.50. The observer is J. B. Phillips. A record of daily gage height, not published, was kept at this point from October 15 to December 31, 1895; the height fluctuated from 0.20 to 2.95 feet. The record for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 24.

*List of discharge measurements made on Chattahoochee River at Oakdale, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 15 | C. C. Babb..... | 76 | 0.40 | 663 | 1.66 | 1,096 |
| 2 | Dec. 14 | .....do ..... | 62 | 0.69 | 796 | 1.73 | 1,380 |
| | 1896. | | | | | | |
| 3 | Jan. 14 | B. M. Hall..... | 8 | 0.70 | 888 | 1.53 | 1,360 |
| 4 | June 15 | .....do ..... | 8 | 0.00 | 704 | 1.40 | 985 |
| 5 | June 20 | .....do ..... | 8 | 0.33 | 792 | 1.45 | 1,153 |
| 6 | June 22 | .....do ..... | 8 | 1.01 | 952 | 1.45 | 1,380 |
| 7 | June 23 | .....do ..... | 8 | 0.55 | 841 | 1.48 | 1,250 |
| 8 | June 24 | Max Hall..... | 8 | 0.28 | 729 | 1.54 | 1,126 |
| 9 | July 9 | .....do ..... | 8 | 18.05 | 4,120 | 4.41 | 18,183 |
| 10 | July 10 | B. M. Hall..... | 8 | 12.80 | 3,132 | 3.56 | 11,137 |
| 11 | July 13 | Max Hall..... | 8 | 3.01 | 1,161 | 2.55 | 2,957 |
| 12 | July 15 | .....do ..... | 8 | 1.88 | 961 | 2.15 | 2,066 |
| 13 | July 17 | .....do ..... | 8 | 4.60 | 1,471 | 3.15 | 4,640 |
| 14 | July 24 | .....do ..... | 8 | 2.22 | 1,028 | 2.40 | 2,470 |
| 15 | Aug. 29 | .....do ..... | 11 | —0.18 | 507 | 1.88 | 958 |
| 16 | Sept. 9 | .....do ..... | 11 | —0.55 | 422 | 1.76 | 744 |
| 17 | Oct. 17 | .....do ..... | 8 | —0.50 | 420 | 1.84 | 775 |

*Rating table for Chattahoochee River at Oakdale, Georgia.*

[This table is applicable only from October 15, 1895, to December, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| —0.45 | 805 | 0.95 | 1,498 | 2.35 | 2,416 | 3.75 | 3,660 |
| —0.40 | 820 | 1.00 | 1,528 | 2.40 | 2,455 | 3.80 | 3,711 |
| —0.35 | 838 | 1.05 | 1,557 | 2.45 | 2,495 | 3.85 | 3,764 |
| —0.30 | 856 | 1.10 | 1,586 | 2.50 | 2,535 | 3.90 | 3,817 |
| —0.25 | 875 | 1.15 | 1,616 | 2.55 | 2,575 | 3.95 | 3,872 |
| —0.20 | 895 | 1.20 | 1,646 | 2.60 | 2,616 | 4.00 | 3,928 |
| —0.15 | 916 | 1.25 | 1,676 | 2.65 | 2,667 | 4.05 | 3,984 |
| —0.10 | 938 | 1.30 | 1,707 | 2.70 | 2,698 | 4.10 | 4,040 |
| —0.05 | 961 | 1.35 | 1,738 | 2.75 | 2,740 | 4.15 | 4,097 |
| 0.00 | 985 | 1.40 | 1,769 | 2.80 | 2,782 | 4.20 | 4,154 |
| +0.05 | 1,010 | 1.45 | 1,800 | 2.85 | 2,825 | 4.25 | 4,213 |
| 0.10 | 1,035 | 1.50 | 1,832 | 2.90 | 2,868 | 4.30 | 4,271 |
| 0.15 | 1,060 | 1.55 | 1,864 | 2.95 | 2,911 | 4.35 | 4,331 |
| 0.20 | 1,085 | 1.60 | 1,896 | 3.00 | 2,956 | 4.40 | 4,391 |
| 0.25 | 1,112 | 1.65 | 1,920 | 3.05 | 3,000 | 4.45 | 4,453 |
| 0.30 | 1,138 | 1.70 | 1,961 | 3.10 | 3,044 | 4.50 | 4,514 |
| 0.35 | 1,164 | 1.75 | 1,995 | 3.15 | 3,088 | 4.55 | 4,577 |
| 0.40 | 1,191 | 1.80 | 2,027 | 3.20 | 3,133 | 4.60 | 4,640 |
| 0.45 | 1,218 | 1.85 | 2,061 | 3.25 | 3,178 | 4.65 | 4,704 |
| 0.50 | 1,245 | 1.90 | 2,085 | 3.30 | 3,223 | 4.70 | 4,768 |
| 0.55 | 1,272 | 1.95 | 2,120 | 3.35 | 3,279 | 4.75 | 4,834 |
| 0.60 | 1,300 | 2.00 | 2,155 | 3.40 | 3,315 | 4.80 | 4,899 |
| 0.65 | 1,328 | 2.05 | 2,191 | 3.45 | 3,363 | 4.85 | 4,966 |
| 0.70 | 1,356 | 2.10 | 2,227 | 3.50 | 3,410 | 4.90 | 5,033 |
| 0.75 | 1,384 | 2.15 | 2,264 | 3.55 | 3,459 | 4.95 | 5,102 |
| 0.80 | 1,412 | 2.20 | 2,301 | 3.60 | 3,508 | 5.00 | 5,170 |
| 0.85 | 1,440 | 2.25 | 2,339 | 3.65 | 3,558 | | |
| 0.90 | 1,469 | 2.30 | 2,377 | 3.70 | 3,608 | | |

*Estimated monthly discharge of Chattahoochee River at Oakdale, Georgia.*

[Drainage area, 1,560 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| October 15 to 31 | 1,180 | 970 | 1,038 | 35,003 | 0.43 | 0.67 |
| November | 1,961 | 1,130 | 1,293 | 76,939 | 0.92 | 0.83 |
| December | 2,911 | 1,140 | 1,432 | 88,051 | 1.06 | 0.92 |
| 1896. | | | | | | |
| January | 12,000 | 1,356 | 2,821 | 173,458 | 2.09 | 1.81 |
| February | 7,400 | 1,707 | 2,767 | 159,160 | 1.90 | 1.77 |
| March | 2,120 | 1,586 | 1,790 | 110,063 | 1.33 | 1.15 |
| April | 2,740 | 1,328 | 1,599 | 95,147 | 1.14 | 1.02 |
| May | 3,088 | 1,060 | 1,384 | 85,099 | 1.02 | 0.89 |
| June | 2,227 | 875 | 1,272 | 75,689 | 0.91 | 0.82 |
| July | 24,600 | 821 | 3,891 | 239,250 | 2.89 | 2.50 |
| August | 1,961 | 821 | 1,075 | 66,100 | 0.79 | 0.69 |
| September | 1,300 | 745 | 850 | 50,578 | 0.60 | 0.54 |
| October | 1,469 | 775 | 913 | 56,139 | 0.67 | 0.58 |
| November | 4,640 | 1,086 | 1,608 | 95,682 | 1.15 | 1.03 |
| December | 3,133 | 1,112 | 1,454 | 89,404 | 1.07 | 0.93 |
| Per annum | 24,600 | 745 | 1,785 | 1,295,769 | 15.56 | 1.14 |

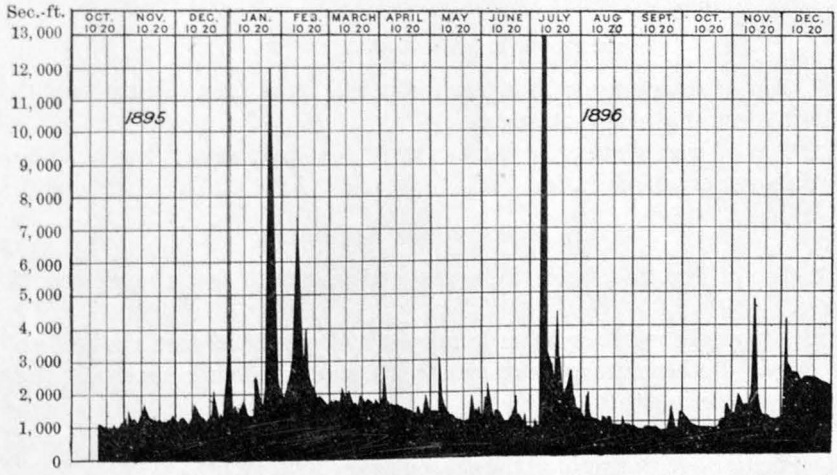



FIG. 12.—Discharge of Chattahoochee River at Oakdale, Georgia, 1895-96.

### WEST POINT STATION ON CHATTAHOOCHEE RIVER.

Drainage area, 3,300 square miles. This station is at the highway bridge in the city of West Point, about 1,200 feet from the railroad passenger depot. The bridge is of iron and is 450 feet in length, consisting of three spans of 150 feet each. At low water the stream is 400 feet wide and from 6 to 11 feet deep, making a large cross-section area and very low velocity. At extreme low water much of the section's current is less than 0.30 foot per second, and is therefore difficult of accurate measurement with a Haskell meter. At medium stage of water the current is good. Attempts were made to find a better section, but no other bridge was found where the conditions were as favorable as at this point. The important water powers between West Point and Columbus make it necessary to have a station in that vicinity, and West Point has better railroad facilities than any other place that could have been chosen.

On July 30, 1896, a wire gage was put in by Mr. Max Hall on the Atlanta and West Point Railroad bridge about 1,000 feet up the river from the highway bridge, and bench marks were established; but on August 14, 1896, it was changed to the highway bridge and put on the same datum by measuring down to the water, which was practically on the same level as at the railroad bridge. The rod of the gage on the highway bridge is nailed to the floor of the downstream footway on the outside of the iron hand rail. The center of the 3-inch pulley is at gage height 25.38 feet, 120.4 feet from the initial point of measurements, and 7.9 feet from zero point of rod. The rod is 14 feet long, divided to feet and tenths, and is toward the initial point from the pulley. The length of wire cable from bottom of weight to index mark is 33.46 feet.

#### BENCH MARKS ON RAILROAD BRIDGE.

1. Top of capstone on first pier from right bank (not the abutment) is 24.65 feet above zero of gage.
2. Top of iron stringer under the cross-ties near same pier is 28.85 feet above zero of gage.

#### BENCH MARKS ON HIGHWAY BRIDGE.

1. Top of first floor beam from west end pier 24.01 feet above zero of gage.
2. Top of second floor beam from west end pier 24.19 feet above zero of gage. Both points are at downstream ends of floor beams (not the beams under sidewalk).
3. The bench established by Mr. Cyrus C. Babb on this bridge is 27.40 feet above the zero of the present gage.

The initial point is the center of first iron post of hand rail on downstream side of bridge at right bank. The bottom is sandy and liable to change, but four discharge measurements from July 30 to September

25, 1896, show very little change. The banks of the river at the ends of the bridge seldom, if ever, overflow, but the ground between the banks and the depot is lower and does overflow at high water. The observer is Mr. C. E. Melton, who is employed at the freight depot of the Atlanta and West Point Railroad, about one-quarter of a mile from the gage. He passes it going to and from his work. The record of daily gage heights for 1896, from August 1 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 24.

*List of discharge measurements made on Chattahoochee River at West Point, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Oct. 22 | C. C. Babb..... | 76 | ..... | 2,802 | 0.51 | 1,404 |
| | 1896. | | | | | | |
| | June 29 | J. W. Jones..... | 8 | ..... | 2,293 | 0.90 | 2,067 |
| 2 | July 30 | Max Hall ..... | 16 | 2.45 | 3,249 | 0.75 | 2,430 |
| 3 | Aug. 14 | .....do ..... | 16 | 1.72 | 3,077 | 0.52 | 1,594 |
| 4 | Sept. 5 | .....do ..... | 11 | 1.20 | 2,857 | 0.35 | 1,006 |
| 5 | Sept. 25 | B. M. Hall..... | 8 | 1.15 | 2,792 | 0.37 | 1,030 |
| 6 | Oct. 28 | Max Hall ..... | 11 | 1.75 | 2,883 | 0.57 | 1,642 |

*Rating table for Chattahooche River at West Point, Georgia.*

[This table is applicable from July 30, 1896, to October 28, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 880 | 2.60 | 2,760 | 4.20 | 6,302 | 5.80 | 10,178 |
| 1.10 | 950 | 2.70 | 2,940 | 4.30 | 6,538 | 5.90 | 10,314 |
| 1.20 | 1,050 | 2.80 | 3,125 | 4.40 | 6,774 | 6.00 | 10,550 |
| 1.30 | 1,150 | 2.90 | 3,310 | 4.50 | 7,010 | 6.10 | 10,786 |
| 1.40 | 1,250 | 3.00 | 3,505 | 4.60 | 7,246 | 6.20 | 11,022 |
| 1.50 | 1,350 | 3.10 | 3,725 | 4.70 | 7,482 | 6.30 | 11,258 |
| 1.60 | 1,460 | 3.20 | 3,950 | 4.80 | 7,718 | 6.40 | 11,494 |
| 1.70 | 1,565 | 3.30 | 4,180 | 4.90 | 7,954 | 6.50 | 11,730 |
| 1.80 | 1,670 | 3.40 | 4,414 | 5.00 | 8,190 | 6.60 | 11,966 |
| 1.90 | 1,775 | 3.50 | 4,650 | 5.10 | 8,426 | 6.70 | 12,202 |
| 2.00 | 1,880 | 3.60 | 4,886 | 5.20 | 8,762 | 6.80 | 12,438 |
| 2.10 | 1,995 | 3.70 | 5,122 | 5.30 | 8,998 | 6.90 | 12,674 |
| 2.20 | 2,110 | 3.80 | 5,358 | 5.40 | 9,234 | 7.00 | 12,910 |
| 2.30 | 2,230 | 3.90 | 5,594 | 5.50 | 9,470 | 7.50 | 14,090 |
| 2.40 | 2,350 | 4.00 | 5,830 | 5.60 | 9,706 | 8.00 | 15,270 |
| 2.50 | 2,480 | 4.10 | 6,066 | 5.70 | 9,942 | | |

*Estimated monthly discharge of Chattahoochee River at West Point, Georgia.*

[Drainage area, 3,300 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 9,500 | 1,050 | 2,688 | 165,278 | 0.93 | 0.81 |
| September | 5,260 | 780 | 1,436 | 85,448 | 0.49 | 0.44 |
| October | 4,980 | 950 | 1,622 | 99,732 | 0.56 | 0.49 |
| November | 24,000 | 1,565 | 5,101 | 307,530 | 1.72 | 1.54 |
| December | 5,170 | 1,775 | 2,960 | 182,003 | 1.04 | 0.90 |

The lowest discharge found at West Point by Mr. C. C. Anderson, formerly assistant State geologist, in a series of measurements made in 1891 and 1892, was four times as great as the minimum given above.

## MISCELLANEOUS DISCHARGE MEASUREMENTS.

On September 2, 1896, Prof. B. M. Hall made a discharge measurement at Leathers Ford, on the Chestatee River, from the new highway bridge, getting a discharge of 140 second-feet. This was at minimum stage during an exceptionally dry year. Prof. D. C. Barrow, who was assistant State geologist in 1875 and 1876, found a low-water discharge at this point of 290 second-feet. The section under the bridge is not a good one for continuous measurements. On September 2, 1896, the water was 22.2 feet below top of downstream end of first iron floor beam from right-bank pier.

At Shallow Ford, on Chattahoochee River, opposite Gainesville, Georgia, measurements were made from the new iron highway bridge. This bridge has two spans of 120 feet each. No gage was put in, but measurements were made down to the top of the water from the top of the downstream end of the first iron floor beam to the right of the center pier, the elevation of which point was assumed as gage height 26.0. The first measurement, that on March 26, 1896, was made by Prof. B. M. Hall, hydrographer. The gage height was 1.20 feet; area, 362 square feet; mean velocity, 2,016, and discharge, 730 second-feet. The second measurement was on September 2, 1896, by Prof. B. M. Hall, hydrographer. The gage height was 0.40 foot; area, 182 square feet; mean velocity, 1.95 feet per second, and discharge, 356 second-feet.[1] Prof. D. C. Barrow, assistant State geologist, in 1875 and 1876 found low-water discharge at this point 929 second-feet.

On September 4, 1896, Prof. B. M. Hall made a discharge measurement of Sweetwater Creek at Strickland's bridge, near Austell, Georgia,

[1] See evidence that September, 1896, was lowest water for many years, page 77.

just above the Austell Shoal and about 15 miles from Atlanta. Area, 120 square feet; mean velocity, 0.45 foot per second; discharge, 54.5 second-feet. As estimated by Professor Hall from previous measurements, rainfall tables, and the watershed area of 250 square miles, the discharge at this point could not have been less at any time from 1870 to 1895, inclusive, than 100 second-feet.

On September 25, 1896, Prof. B. M. Hall visited Columbus, Georgia, in order to find, if possible, a proper section for continuous discharge measurements. He found two railroad bridges very high above the water and the sections under them not suitable for measurements. He found also two highway bridges completely housed in, so that water can not be seen from the bridge. So far no really good bridge section has been found below Oakdale Station on the Chattahoochee. There are many good sections at ferries, one of which will probably be used in 1897.

## MOBILE BASIN.

This is the largest drainage basin in Georgia and Alabama, and is designated the Mobile Basin because its waters all enter the Gulf through the Mobile River at Mobile, Alabama. It is formed as follows: Beginning at the headwaters, the Cartecay and Ellijay rivers unite at Ellijay, Georgia, to form the Coosawattee River. Just above Resaca, Georgia, this unites with the Conasauga to form the Oostanaula River. At Rome, Georgia, the Oostanaula and Etowah unite to form the Coosa River. Just above Montgomery, Alabama, the Coosa and Tallapoosa unite to form the Alabama River; and not far from the coast the Tombigbee unites with the Alabama to form the Mobile River, which flows into Mobile Bay, an arm of the Gulf of Mexico.

All of the important water powers in this basin in Georgia are either in the crystalline region or at the western fall line between this region and the Paleozoic. This fall line in Georgia passes through Carters, on the Coosawattee River, and Cartersville, on the Etowah River. Continuing in a southwesterly course it crosses the Coosa River near Marble Valley, Alabama; not as a fall line, because in this case the river passes from the Paleozoic back into the crystalline region.

The great southern fall line of Georgia, dividing the crystalline rocks from the Cretaceous and younger formations, and passing through Augusta, Milledgeville, Macon, and Columbus, extends westward into the Mobile Basin, making the great falls at Tallassee, Alabama, on the Tallapoosa River, and the shoals at Wetumpka, Alabama, on the Coosa River. The head of navigation on the Coosawattee River is at Carters, Georgia. Above this point there are many large water powers on the stream and its tributaries.

The largest water power on the Etowah River proper is at Cartersville, Georgia, where there is a fall of 80 feet; but the river has good shoals all the way down to Rome, Georgia, and all the way up to its head. On its headwaters, near Dahlonega, Georgia, it has a fall of 100

feet in a distance of half a mile. The Amicalola River is the most important tributary of the Etowah. Amicalola Falls, on Amicalola River, makes a leap of 625 feet in a half mile; Heard Shoal, on Amicalola River, in Dawson County, near its mouth, has a fall of 234 feet.

The Tallapoosa River heads in Georgia and flows in a southwesterly course among the crystalline and semicrystalline rocks to Tallassee, Alabama. It has a rapid current and many shoals. The largest are Tallassee Falls. The shoals of the Coosa and Black Warrior rivers have had for years the attention of the United States Army Engineers, and are fully described in their reports. Railroads that reach the water powers of the Mobile Basin are: The Atlanta, Knoxville and Northern Railroad, Western and Atlanta Railroad, Southern Railway, Atlanta and West Point, and Western Railway of Alabama.

After making examinations at Carters, Resaca, Calhoun, Canton, Cartersville, Ladds, and Rome, Georgia; Riverside, Montgomery, and Milstead, Alabama, and other points, stations have been established and measurements made at the following points:

### CANTON STATION ON ETOWAH RIVER.

This station is on the Suwanee quadrangle one-half mile above the mouth of Canton Creek, in latitude 34° 14.4′, longitude 84° 29.5′. It is located at the iron highway bridge over Etowah River, about 1,000 feet north of and upstream from the Atlanta, Knoxville and Northern Railroad depot, Canton, Georgia.

The bridge clears the channel with a single span, 116 feet, resting on stone masonry piers at each bank of the stream. The approaches to this span are 70 feet at right bank, or west side, and 79 feet at left bank, or east side. The United States Weather Bureau gage rod of 6 by 8 heart pine, divided to feet and tenths 27.3 feet above zero and 1 foot below zero, is fastened by iron bolts on the upstream side of the left-bank pier. This rod has been used for the past four years, giving accurate daily records of gage heights, which have been sent to this office and will be used for future computations.

Discharge measurements were made on April 29, July 7, September 9, and October 28, 1896, by Prof. B. M. Hall. On September 9, 1896, Mr. James A. Low, agent and telegraph operator at the Atlanta, Knoxville and Northern Railroad depot, about 1,000 feet south of the bridge, was employed as observer. He has also been the Weather Bureau observer for years.

The bench mark is on the left-bank pier. The iron bridge rests on four pieces of railroad track iron, forming a cap; measuring from the end toward the river on one of these on the upstream side of the bridge, its top is 23.3 feet above the datum of the gage.

Up to 3 feet gage height the river is only 116 feet wide, and flows between the piers on its lower banks. Up to about 14 feet it is confined between its upper banks, which are the abutments at outer end

of approaches. Above this stage it begins to overflow the bottom lands, which have a width of about 1,200 feet on west side, or right bank, and 200 feet on east side. The initial point is top of right-bank pier, at its edge toward the river. The drainage area is 573 square miles, and is mapped on the Ellijay, Dahlonega, and Suwanee atlas sheets.

The record of daily gage heights for 1892, 1893, 1894, 1895, and 1896 is given in Water-Supply and Irrigation Paper No. 11, pages 25–27.

*List of discharge measurements made on Etowah River at Canton, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Apr. 29 | B. M. Hall ..... | 8 | 0.05 | 459 | 1.28 | 590 |
| 2 | July 7 | .....do ..... | 8 | 0.59 | 536 | 1.607 | 862 |
| 3 | Sept. 9 | .....do ..... | 8 | —0.65 | 390 | 0.56 | 218 |
| 4 | Oct. 28 | .....do ..... | 8 | 0.45 | 523 | 1.40 | 733 |
| 5 | Oct. 28 | .....do ..... | 8 | 2.25 | 715 | 3.25 | 2,327 |
| 6 | Nov. 27 | .....do ..... | 8 | —0.05 | 453 | 0.991 | 449 |

*Rating table for Etowah River at Canton, Georgia.*

[This table is applicable from April 29, 1896, to November 27, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| —0.75 | 200 | 0.70 | 950 | 2.20 | 2,260 | 3.70 | 4,100 |
| —0.70 | 210 | 0.80 | 1,025 | 2.30 | 2,370 | 3.80 | 4,225 |
| —0.60 | 240 | 0.90 | 1,110 | 2.40 | 2,480 | 3.90 | 4,350 |
| —0.50 | 270 | 1.00 | 1,180 | 2.50 | 2,590 | 4.00 | 4,475 |
| —0.40 | 320 | 1.10 | 1,250 | 2.60 | 2,700 | 4.10 | 4,600 |
| —0.30 | 360 | 1 20 | 1,340 | 2.70 | 2,830 | 4.20 | 4,725 |
| —0.20 | 410 | 1.30 | 1,430 | 2.80 | 2,960 | 4.30 | 4,850 |
| —0.10 | 470 | 1.40 | 1,520 | 2.90 | 3,100 | 4.40 | 4,975 |
| 0.00 | 510 | 1.50 | 1,610 | 3.00 | 3,225 | 4.50 | 5,100 |
| 0.10 | 565 | 1.60 | 1,700 | 3.10 | 3,350 | 4.60 | 5,225 |
| 0.20 | 625 | 1.70 | 1,790 | 3.20 | 3,475 | 4.70 | 5,350 |
| 0.30 | 680 | 1.80 | 1,880 | 3.30 | 3,600 | 4.80 | 5,475 |
| 0.40 | 750 | 1.90 | 1,970 | 3.40 | 3,725 | 4.90 | 5,600 |
| 0.50 | 810 | 2.00 | 2,060 | 3.50 | 3,850 | 5.00 | 5,725 |
| 0.60 | 870 | 2.10 | 2,160 | 3.60 | 3,975 | | |

*Estimated monthly discharge of Etowah River at Canton, Georgia.*

[Drainage area, 573 square miles.]

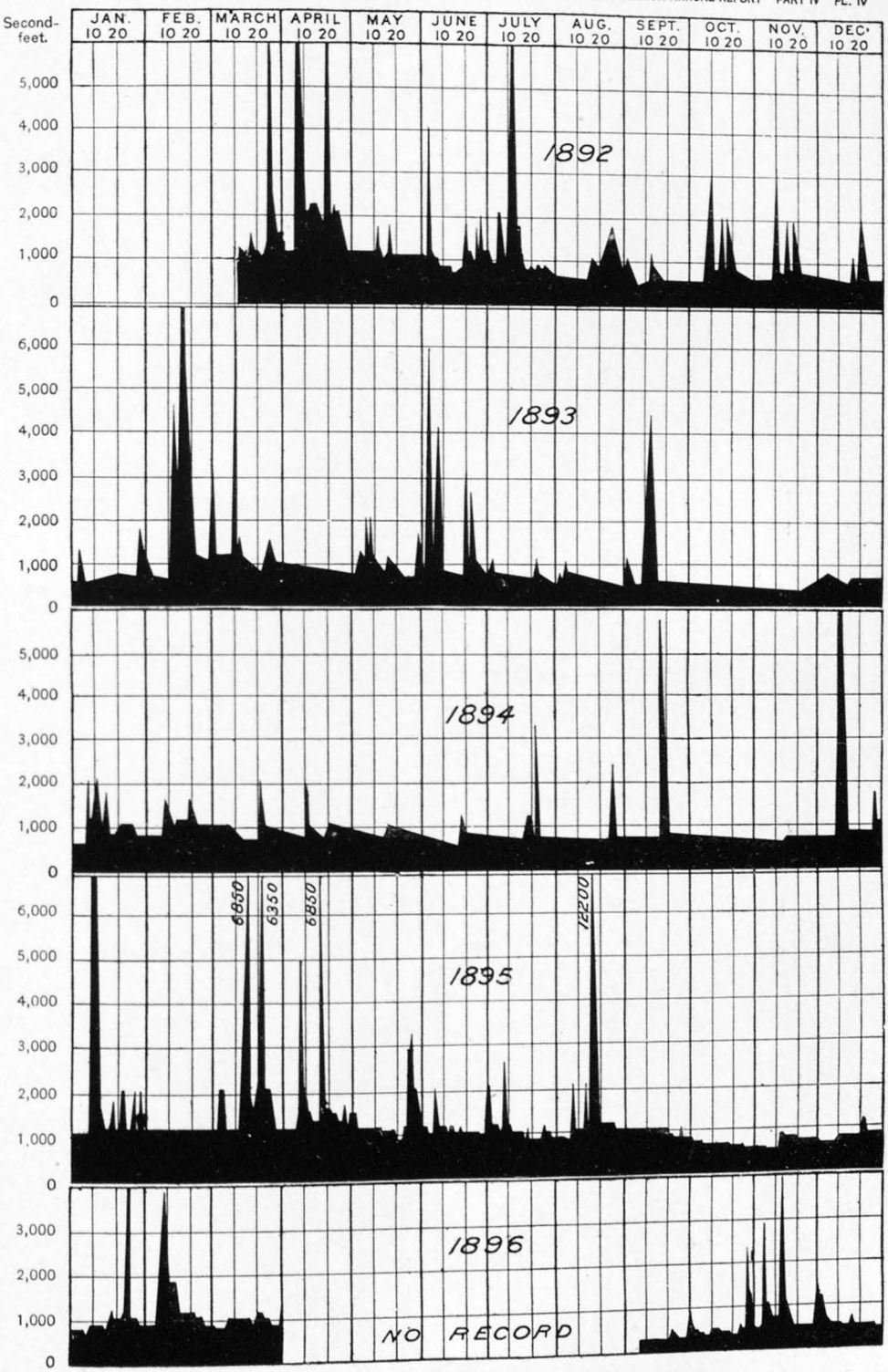
| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | a19,000 | 1,025 | 2,520 | 154,950 | 5.08 | 4.40 |
| February | 1,180 | 1,180 | 1,180 | 65,534 | 2.14 | 2.06 |
| March | a6,850 | 1,180 | 2,161 | 132,876 | 4.35 | 3.77 |
| April | a6,850 | 1,180 | 1,790 | 106,512 | 3.48 | 3 12 |
| May | 3,225 | 950 | 1,388 | 85,345 | 2.79 | 2.42 |
| June | 2,060 | 950 | 1,138 | 67,716 | 2.22 | 1.99 |
| July | 2,590 | 870 | 1,132 | 69,604 | 2.28 | 1.98 |
| August | a12,200 | 810 | 1,611 | 99,057 | 3.24 | 2.81 |
| September | 1,025 | 810 | 982 | 58,433 | 1.91 | 1.71 |
| October | 750 | 565 | 655 | 40,275 | 1.31 | 1.14 |
| November | 810 | 510 | 691 | 41,117 | 1.35 | 1.21 |
| December | 1,180 | 680 | 816 | 50,174 | 1.64 | 1.42 |
| Per annum | a19,000 | 510 | 1,339 | 971,593 | 31.79 | 2.34 |
| 1896. | | | | | | |
| September 9 to 30 | 950 | 200 | 280 | 12,210 | 0.40 | 0.49 |
| October | 2,320 | 270 | 476 | 29,268 | 0.95 | 0.83 |
| November | 3,940 | 500 | 906 | 53,911 | 1.76 | 1.58 |
| December | 1,180 | 470 | 598 | 36,771 | 1.21 | 1.05 |

*a* Estimated.

## CARTERS STATION ON COOSAWATTEE RIVER.

The drainage area above this point is 532 square miles, of which 150 square miles is on Talking Rock Creek, which enters the river one-half mile above. The basin is mapped on atlas sheets Dalton, Ellijay, Cartersville, and Suwanee.

The station is at the iron highway bridge at Carter's store and post-office, Murray County, Georgia, about 20 miles northeast of Calhoun, the most convenient railroad station. It is in the Dalton quadrangle, in latitude 34° 36.2′, longitude 84° 41.7′. It is also about 20 miles from Resaca, on the Oostanaula River, which is formed by the Coosawattee and Conasauga rivers. Carters is the head of navigation, small boats running to it from Rome, Georgia, and the Coosa River below. It is at the foot of the great shoals made by this stream in cutting through the Cohutta Mountains, the last of which is Carters Shoal, a short distance above the bridge, with a fall of over 50 feet.




DISCHARGE OF ETOWAH RIVER AT CANTON, GEORGIA, 1892–1896.

The bridge is a single span, 140 feet long, supported on double cylindrical iron piers at each bank, and has approaches on each end about 50 feet in length. At low water the stream is 113 feet wide and from 2 to 3 feet deep. The current is not uniform, being broken by a gravel bar above, but is a fairly good section for measurement. The bed is gravel and not very apt to change. The banks are high, but are sometimes overflowed. The bridge is over 30 feet above low water, and the highest floods do not get up to it.

On August 15, 1896, a station was established and a wire gage put in by Mr. Max Hall. The rod of the gage is nailed to the outside of the guard timber on downstream side of the bridge. Center of 3-inch pulley is 20 feet from initial point and is 32.05 feet above datum. The zero point of rod is 5 feet from center of pulley and beyond the pulley from the initial point. The rod is 24 feet long, divided to feet and tenths. The length of wire cable from bottom of weight to index marker is 37.24 feet.

The initial point is on the downstream side of the bridge—top of iron pier, right bank, edge of pier toward the bank, away from river. The pulley of the gage is 20 feet from the initial point, the zero of rod 25 feet, and the farther end of rod 49 feet from the initial point. The top of the cylindrical iron pier at the right-bank, downstream corner of bridge is 30.35 feet above datum, or at gage height 30.35. The observer is Col. S. M. Carter.

On October 10, 1896, when the gage height was 0.55 and discharge 228, the discharge of Talking Rock Creek at its mouth was 35 second-feet, leaving 193 second-feet as the minimum discharge of the Coosawattee River above the mouth of Talking Rock. The record of daily gage heights for 1896, from August 17 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 27.

*List of discharge measurements made on Coosawattee River at Carters, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 15 | Max Hall | 16 | 0.90 | 244 | 1.31 | 320 |
| 2 | Aug. 17 | do | 16 | 0.95 | 240 | 1.32 | 319 |
| 3 | Oct. 10 | do | 11 | 0.55 | 197 | 1.15 | 228 |

*Rating table for Coosawattee River at Carters, Georgia.*

[This table is applicable from August 15, 1896, to October 10, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.50 | 219 | 0.90 | 320 | 1.30 | 460 | 1.70 | 632 |
| 0.60 | 240 | 1.00 | 350 | 1.40 | 500 | 1.80 | 677 |
| 0.70 | 265 | 1.10 | 379 | 1.50 | 544 | 1.90 | 726 |
| 0.80 | 290 | 1.20 | 424 | 1.60 | 588 | 2.00 | 780 |

RESACA STATION ON OOSTANAULA RIVER.

This station is in the Dalton quadrangle, in latitude 34° 34.5′, longitude 84° 56.4′. The drainage area is 1,527 square miles and is mapped on atlas sheets Cleveland, Ellijay, Dalton, Cartersville, and Suwanee. The Oostanaula River is formed about 3 miles above Resaca by the junction of the Coosawattee and Conasauga rivers, the former having a drainage area of 875 and the latter of 648 square miles, while there are 4 square miles between the junction and Resaca.

The station is the iron railroad bridge of the Western and Atlantic Railroad, in the town of Resaca, 1,000 feet from the depot. This has been a Weather Bureau station for years, and the past records of gage heights can probably be employed in computations of discharge. The Weather Bureau gage rod is a large timber about 6 by 8 inches, bolted securely to downstream side of center pier and divided to feet and tenths, the top of which is 40.12 feet above zero point. At low water the stream is about 150 feet wide, including the center pier, and from 3 to 10 feet deep. The river bed is probably soft and liable to change. Current sluggish near center pier.

On July 27, 1896, a discharge measurement was made by Mr. Max Hall and a station established, using the Weather Bureau gage. On August 19 another measurement was made and a wire gage put in, the old gage being taken out and repainted. Both gages are on the same datum. The initial point is the first pin of bottom link cord at right-bank end of bridge, downstream side. The rod of the wire gage is nailed to the outside of the guard rail on the downstream side. The center of the 3-inch pulley is on the downstream side of the bridge, 61.50 feet from initial point, and at 40.20 feet gage height. The end or zero point of the rod is 3 feet from the center of the pulley. The rod is 14 feet long, divided to feet and tenths. The length from bottom of weight to index of gage cable is 43.40 feet. The first bench mark is on the top of capstone of center pier at 36.12 feet gage height The second is the top of cross-tie near center at 40.12 feet gage height. The observer is Mr. S. M. Barnett, railroad agent at depot, who is also the observer for the Weather Bureau. The record of daily gage heights

for 1892, 1893, 1894, 1895, and 1896 is given in Water-Supply and Irrigration Paper No. 11, pages 28–30.

*List of discharge measurements made on Oostanaula River at Resaca, Georgia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | July 27 | Max Hall..... | 16 | 2.90 | 919 | 1.23 | 1,133 |
| 2 | Aug. 19 | .....do ..... | 16 | 1.47 | 700 | 0.70 | 492 |
| 3 | Oct. 13 | .....do ..... | 11 | 1.70 | 724 | 0.83 | 601 |

*Rating table for Oostanaula River at Resaca, Georgia.*

[This table is applicable from July 27, 1896, to October 13, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec.feet.* | *Feet.* | *Sec.feet.* | *Feet.* | *Sec.feet.* | *Feet.* | *Sec.feet.* |
| 0.90 | 240 | 1.70 | 602 | 2.50 | 970 | 3.30 | 1,338 |
| 1.00 | 280 | 1 80 | 648 | 2.60 | 1,016 | 3.40 | 1,384 |
| 1.10 | 326 | 1.90 | 694 | 2.70 | 1,062 | 3.50 | 1,430 |
| 1.20 | 372 | 2.00 | 740 | 2.80 | 1,108 | 3.60 | 1,476 |
| 1.30 | 418 | 2.10 | 786 | 2.90 | 1,154 | 3.70 | 1,522 |
| 1.40 | 464 | 2.20 | 832 | 3.00 | 1,200 | 3.80 | 1,568 |
| 1.50 | 510 | 2.30 | 878 | 3.10 | 1,246 | 3.90 | 1,614 |
| 1.60 | 556 | 2.40 | 924 | 3.20 | 1,292 | 4.00 | 1,660 |

## RIVERSIDE STATION ON COOSA RIVER.

This station is at Riverside, Alabama, in the Springville quadrangle, in latitude 33° 37′ and longitude 85° 12′, at the bridge of the Southern Railway, Georgia Pacific Division, across the Coosa River. The river here flows in a southerly direction, the railroad running from east to west. The town of Riverside is on the right or west bank of the river, and the railroad depot is about 1,000 feet west of the bridge, which is of iron and about 30 feet above low water. Beginning at the left bank, there are two spans of 154 feet each; then a drawbridge 220 feet, revolving on a large center pier; then a stationary span, 80 feet in length, to west or right bank abutment. There is no running water at low stages under the last-named span.

At low water the flowing river is 480 feet wide, including three piers, and is from 4 to 10 feet deep. Very little of the current is too slow to turn any meter. It is somewhat irregular, as there are shoals and some old cribs just above the bridge, but for all stages it is probably the

best section that can be found on the river at a bridge and easy of access.

On September 8, 1896, a discharge measurement was made by Prof. B. M. Hall, and two bench marks were established. On September 25, 1896, another discharge measurement was made, a wire gage was put in, and Mr. J. W. Foster, sawyer at large sawmill about 300 feet distant, on right bank of river, below the bridge, was employed as observer.

The initial point is top of left abutment at the edge toward the river, on the downstream side of the bridge, from which side soundings and meter measurements are made. The rod of wire gage is nailed to outside of guard rail, downstream side, next to the last panel of stationary bridge before reaching the pier at end of draw span. The center of the 3-inch pulley is 5 feet east of zero end of rod, and is 33 feet above gage datum. The rod is 14 feet long and divided to feet and tenths. The length of wire cable from bottom of weight to index of wire is 38.20 feet. The first bench mark is the top of capstone on the large circular center pier of turn span. It is 26.80 feet above datum of gage at downstream side of pier. The top of the first iron floor beam on stationary part east of the draw, near gage, downstream end, is 30.80 feet above gage datum.

The drainage area is 6,850 square miles, and is mapped on atlas sheets Springville, Anniston, Gadsden, Fort Payne, Rome, Tallapoosa, Marietta, Cartersville, Suwanee, Ellijay, Dalton, Cleveland, Ringgold, and Stevenson. The record of daily gage heights for 1896, from September 27 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 30.

*List of discharge measurements made on Coosa River at Riverside, Alabama.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Sept. 8 | B. M. Hall..... | 8 | 0.70 | 2,520 | 0.65 | 1,630 |
| 2 | Sept. 25 | Max Hall..... | 11 | 0.50 | 2,426 | 0.58 | 1,403 |
| 3 | Oct. 30 | B. M. Hall..... | 8 | 0.88 | 2,605 | 0.76 | 1,986 |
| 4 | Dec. 21 | .....do ..... | 8 | 1.57 | 2,867 | 1.14 | 3,272 |
| | 1897. | | | | | | |
| 5 | Mar. 31 | B. M. Hall..... | 91 | 4.53 | 4,544 | 2.53 | 12,515 |

*Rating table for Coosa River at Riverside, Alabama.*

[This table is applicable from September 27, 1896, to March 31, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.50 | 1,400 | 1.70 | 3,560 | 2.90 | 7,010 | 4.10 | 11,030 |
| 0.60 | 1,500 | 1.80 | 3,820 | 3.00 | 7,320 | 4.20 | 11,390 |
| 0.70 | 1,630 | 1.90 | 4,080 | 3.10 | 7,640 | 4.30 | 11,750 |
| 0.80 | 1,780 | 2.00 | 4,360 | 3.20 | 7,970 | 4.40 | 12,110 |
| 0.90 | 1,930 | 2.10 | 4,630 | 3.30 | 8,300 | 4.50 | 12,470 |
| 1.00 | 2,100 | 2.20 | 4,920 | 3.40 | 8,630 | 4.60 | 12,840 |
| 1.10 | 2,280 | 2.30 | 5,200 | 3.50 | 8,960 | 4.70 | 13,210 |
| 1.20 | 2,480 | 2 40 | 5,500 | 3.60 | 9,300 | 4.80 | 13,580 |
| 1.30 | 2,680 | 2.50 | 5,800 | 3.70 | 9,640 | 4.90 | 13,950 |
| 1.40 | 2,880 | 2.60 | 6,100 | 3.80 | 9,980 | 5.00 | 14,330 |
| 1.50 | 3,090 | 2.70 | 6,400 | 3.90 | 10,330 | 5.10 | 14,710 |
| 1.60 | 3,320 | 2.80 | 6,700 | 4.00 | 10,680 | 5.20 | 15,100 |

*Estimated monthly discharge of Coosa River at Riverside, Alabama.*

[Drainage area, 6,850 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches | Second-feet per square mile. |
| 1896. | | | | | | |
| September 27 to 30.... | 1,400 | 1,350 | 1,363 | 10,812 | 0.03 | 0.20 |
| October..... | 7,640 | 1,450 | 2,218 | 136,380 | 0.37 | 0.32 |
| November..... | 15,100 | 2,190 | 4,637 | 275,921 | 0.75 | 0.68 |
| December..... | 12,110 | 2,280 | 4,125 | 253,636 | 0.69 | 0.60 |

## LOCK No. 5 ON COOSA RIVER.

In March, April, and May, 1893, when Mr. D. M. Andrews, United States Assistant Engineer, was engaged in improvement of Coosa River, he made 24 discharge measurements near Lock No. 5, one-half mile above Birmingham and Atlantic Railroad crossing, about 20 miles below the gaging station at Riverside, embracing gage heights from 2 feet to 19 feet. His areas of cross section were obtained by making eleven parallel cross sections, 10 feet apart, and thus covering 100 feet in length of river bed. His velocities were measured by long rod-floats, reaching from top of water to near the bottom. Mr. Andrews has plotted the discharges and velocities in two curves, showing their relation to gage height. The diagram thus formed is here reproduced,

showing the discharges from which it is plotted. (See fig. 13.) These curves of velocity and discharge are applicable only to gage height from 2 to 19, inclusive. From the discharge measurements as shown in the diagram a rating table has been prepared, which is given below. The values given below gage height of 2 feet are estimated from those measured above that point, and are, of course, subject to considerable error. Mr. Andrews has furnished the table of gage heights here appended for the years 1892 to 1896, inclusive, and by applying the rating table to them a fair approximation may be obtained of the discharge at any point above 1 foot. This leaves a large part of the record of gage height unprovided with rating, but it should be noted that a record for the autumn of 1896 on this river is given for the Riverside station, 20 miles above this point, showing a minimum of 1,350 cubic feet per second, while the table of gage heights shows the month of August, 1896, to be the lowest stage of the river on record. The record of daily gage heights for 1892, 1893, 1894, 1895, and 1896 are given in Water-Supply and Irrigation Paper No. 11, pages 34–36; also Lock No. 4 from 1890 to 1896, pages 31–34.

*Rating table for Coosa River at Lock No. 5, Alabama.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 6,000 | 3.20 | 14,800 | 5.40 | 23,600 | 7.60 | 35,000 |
| 1.10 | 6,400 | 3.30 | 15,200 | 5.50 | 24,000 | 7.70 | 35,500 |
| 1.20 | 6,800 | 3.40 | 15,600 | 5.60 | 24,400 | 7.80 | 36,000 |
| 1.30 | 7,200 | 3.50 | 16,000 | 5.70 | 24,800 | 7.90 | 36,500 |
| 1.40 | 7,600 | 3.60 | 16,400 | 5.80 | 25,200 | 8.00 | 37,000 |
| 1.50 | 8,000 | 3.70 | 16,800 | 5.90 | 25,600 | 8.10 | 37,500 |
| 1.60 | 8,400 | 3.80 | 17,200 | 6.00 | 27,000 | 8.20 | 38,000 |
| 1.70 | 8,800 | 3.90 | 17,600 | 6.10 | 27,500 | 8.30 | 38,500 |
| 1.80 | 9,200 | 4.00 | 18,000 | 6.20 | 28,000 | 8.40 | 39,000 |
| 1.90 | 9,600 | 4.10 | 18,400 | 6.30 | 28,500 | 8.50 | 39,500 |
| 2.00 | 10,000 | 4.20 | 18,800 | 6.40 | 29,000 | 8.60 | 40,000 |
| 2.10 | 10,400 | 4.30 | 19,200 | 6.50 | 29,500 | 8.70 | 40,500 |
| 2.20 | 10,800 | 4.40 | 19,600 | 6.60 | 30,000 | 8.80 | 41,000 |
| 2.30 | 11,200 | 4.50 | 20,000 | 6.70 | 30,500 | 8.90 | 41,500 |
| 2.40 | 11,600 | 4.60 | 20,400 | 6.80 | 31,000 | 9.00 | 42,000 |
| 2.50 | 12,000 | 4.70 | 20,800 | 6.90 | 31,500 | 9.10 | 42,600 |
| 2.60 | 12,400 | 4.80 | 21,200 | 7.00 | 32,000 | 9.20 | 43,200 |
| 2.70 | 12,800 | 4.90 | 21,600 | 7.10 | 32,500 | 9.30 | 43,800 |
| 2.80 | 13,200 | 5.00 | 22,000 | 7.20 | 33,000 | 9.40 | 44,400 |
| 2.90 | 13,600 | 5.10 | 22,400 | 7.30 | 33,500 | 9.50 | 45,000 |
| 3.00 | 14,000 | 5.20 | 22,800 | 7.40 | 34,000 | 9.60 | 45,600 |
| 3.10 | 14,400 | 5.30 | 23,200 | 7.50 | 34,500 | 9.70 | 46,200 |

*Rating table for Coosa River at Lock No. 5, Alabama*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 9.80 | 46,800 | 12.20 | 64,000 | 14.50 | 81,250 | 16.80 | 98,500 |
| 9.90 | 47,400 | 12.30 | 64,750 | 14.60 | 82,000 | 16.90 | 99,250 |
| 10.00 | 48,000 | 12.40 | 65,500 | 14.70 | 82,750 | 17.00 | 100,000 |
| 10.10 | 48,700 | 12.50 | 66,250 | 14.80 | 83,500 | 17.10 | 100,750 |
| 10.20 | 49,400 | 12.60 | 67,000 | 14.90 | 84,250 | 17.20 | 101,500 |
| 10.30 | 50,100 | 12.70 | 67,750 | 15.00 | 85,000 | 17.30 | 102,250 |
| 10.40 | 50,800 | 12.80 | 68,500 | 15.10 | 85,750 | 17.40 | 103,000 |
| 10.50 | 51,500 | 12.90 | 69,250 | 15.20 | 86,500 | 17.50 | 103,750 |
| 10.60 | 52,200 | 13.00 | 70,000 | 15.30 | 87,250 | 17.60 | 104,500 |
| 10.70 | 52,900 | 13.10 | 70,750 | 15.40 | 88,000 | 17.70 | 105,250 |
| 10.80 | 53,600 | 13.20 | 71,500 | 15.50 | 88,750 | 17.80 | 106,000 |
| 10.90 | 54,300 | 13.30 | 72,250 | 15.60 | 89,500 | 17.90 | 106,750 |
| 11.00 | 55,000 | 13.40 | 73,000 | 15.70 | 90,250 | 18.00 | 107,500 |
| 11.10 | 55,750 | 13.50 | 73,750 | 15.80 | 91,000 | 18.10 | 108,250 |
| 11.20 | 56,500 | 13.60 | 74,500 | 15.90 | 91,750 | 18.20 | 109,000 |
| 11.30 | 57,250 | 13.70 | 75,250 | 16.00 | 92,500 | 18.30 | 109,750 |
| 11.40 | 58,000 | 13.80 | 76,000 | 16.10 | 93,250 | 18.40 | 110,500 |
| 11.50 | 58,750 | 13.90 | 76,750 | 16.20 | 94,000 | 18.50 | 111,250 |
| 11.60 | 59,500 | 14.00 | 77,500 | 16.30 | 94,750 | 18.60 | 112,000 |
| 11.70 | 60,250 | 14.10 | 78,250 | 16.40 | 95,500 | 18.70 | 112,750 |
| 11.80 | 61,000 | 14.20 | 79,000 | 16.50 | 96,250 | 18.80 | 113,500 |
| 11.90 | 61,750 | 14.30 | 79,750 | 16.60 | 97,000 | 18.90 | 114,250 |
| 12.00 | 62,500 | 14.40 | 80,500 | 16.70 | 97,750 | 19.00 | 115,000 |
| 12.10 | 63,250 | | | | | | |

TUSCALOOSA STATION ON BLACK WARRIOR RIVER, ALABAMA.

This gage was placed in position by the United States Corps of Engineers in 1888. It is about three-fourths of a mile from the business center of Tuscaloosa, Alabama, and is reached by passing down Bridge street to the river, thence down the east bank 1,800 feet to the gage. It consists of an inclined timber, 2 by 6 inches, supported on posts and graduated by means of notches placed 1 foot vertically apart. The observer is W. S. Wyman, jr., Tuscaloosa, Alabama. Mr. Wyman is observer for the Corps of Engineers, and has been kind enough to send weekly reports to Professor Hall for this office. Observations are taken daily at 7 a. m. The area draining past this point is 4,900 square miles.

The bench marks are fixed, one on a willow 10 feet west of gage 97.84 feet above Mobile datum, the other on a small hackberry 30 feet south of the upper end of the gage and 139.36 feet above Mobile datum. The

current here is rather sluggish, being almost imperceptible at low stages. Both banks are of earth and subject to overflow. The bed of the stream is composed of sand and gravel. Observations of gage height have been obtained through the courtesy of Mr. R. C. McCallo, jr., of the United States Engineers in charge of the Black Warrior River, from the time the gage was established until December 31, 1896. A

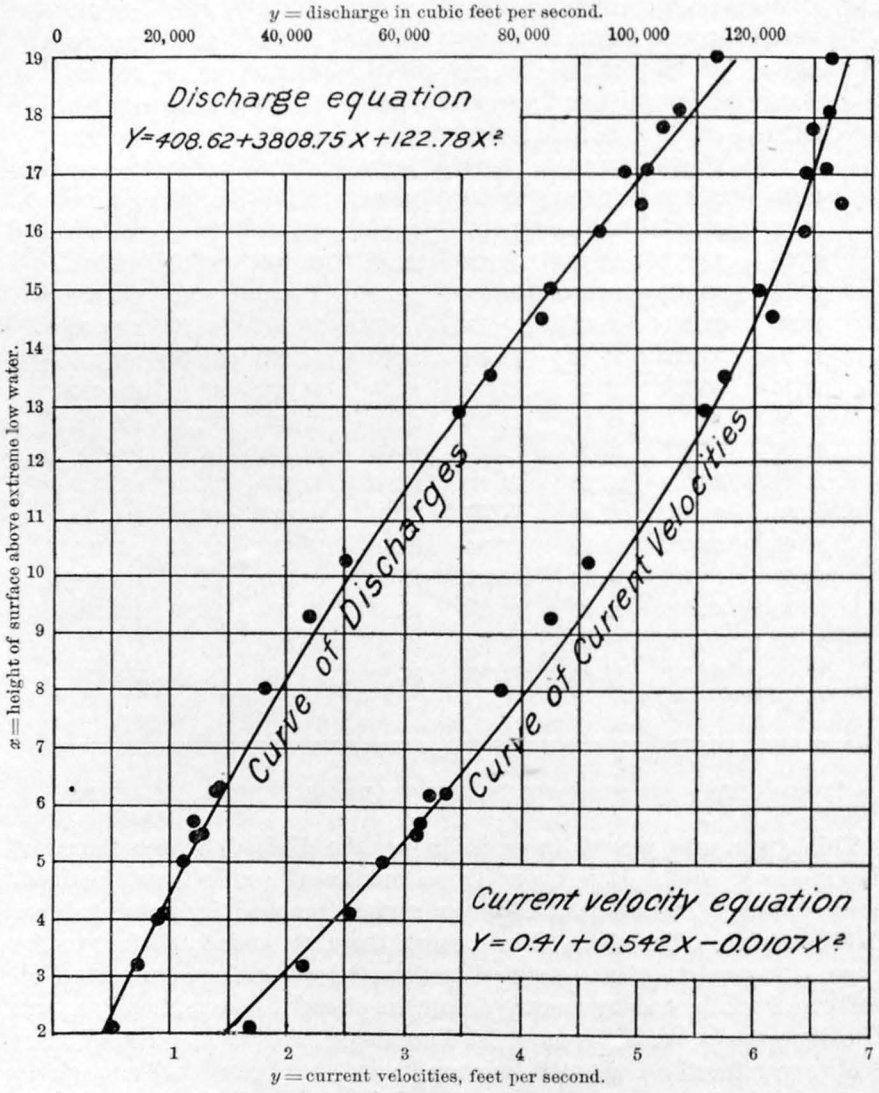



FIG. 13.—Curves of current velocity and discharge of Coosa River at Lock No. 5, Georgia. Constructed by Mr. D. M. Andrews, U. S. assistant engineer.

measurement made by Mr. McCallo September 14, 1896, showed a gage height of —0.60 foot, area 1,022 square feet, mean velocity 0.16, discharge 164 second-feet.

The following list of measurements at the same place has been furnished by Mr. Horace Harding, C. E., United States assistant engi-

neer, 2016 Quinlan avenue, Birmingham, Alabama. Velocities were obtained by means of rod floats reaching from the water surface to near the bottom. The highest flood occurred on April 8, 1892. The gage height was 62.5, the sectional area 33,600 square feet, and the estimated mean velocity 4.5 feet per second. This gave a discharge of 151,200 cubic feet per second. From this estimate and the following list of measurements a curve has been plotted and a rating table constructed, and this rating table applied to all gage heights observed. The estimates of discharge thus obtained are shown in diagrammatic form in Plate V. The highest discharges are merely approximations, but the discharges shown by the diagrams serve as a basis for comparison of the state of the river during the various years. The record of daily gage heights from 1889 to 1896, inclusive, is given in Water-Supply and Irrigation Paper No. 11, pages 37–40.

*List of discharge measurements made on Black Warrior River at Tuscaloosa, Alabama.*

| No. | Date. | Gage height. | Discharge. | Remarks. |
|---|---|---|---|---|
| | 1895. | *Feet.* | *Sec. feet.* | |
| 1 | Dec. 17 | 1.10 | 617 | Stationary. |
| 2 | Dec. 21 | 2.61 | 1,344 | Do. |
| 3 | Dec. 24 | 3.60 | 1,733 | Rising slowly. |
| | 1896. | | | |
| 4 | Jan. 30 | 9.99 | 5,073 | Falling 0.05 per hour. |
| 5 | Jan. 31 | 8.65 | 4,363 | Do. |
| 6 | Feb. 26 | 8.25 | 4,360 | Falling 0.01 per hour. |
| 7 | Feb. 28 | 7.27 | 3,657 | Falling 0.02 per hour. |
| 8 | Feb. 29 | 6.92 | 3,522 | Stationary. |
| 9 | Mar. 2 | 7.67 | 4,211 | Do. |
| 10 | Mar. 3 | 7.28 | 3,632 | Falling 0.03 per hour. |
| 11 | Mar. 6 | 6.94 | 4,558 | Rising 0.15 per hour. |
| 12 | Mar. 24 | 24.85 | 13,550 | Falling 0.12 per hour. |
| 13 | Apr. 10 | 9.71 | 5,331 | Falling. |
| 14 | Apr. 11 | 8.89 | 4,755 | Do. |
| 15 | Apr. 14 | 8.25 | 4,675 | Rising. |
| 16 | Apr. 20 | 7.55 | 3,862 | Falling. |
| 17 | Apr. 21 | 6.65 | 3,388 | Do. |
| 18 | Apr. 22 | 5.96 | 2,940 | Do. |
| 19 | Apr. 23 | 5.46 | 2,704 | Do. |
| 20 | Apr. 24 | 5.88 | 3,158 | Rising. |
| 21 | Apr. 27 | 5.68 | 3,049 | Do. |

*Rating table for Black Warrior River at Tuscaloosa, Alabama.*

[This table is applicable only from January 1, 1895, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| —1.00 | 90 | 3.00 | 1,470 | 7.00 | 3,665 | 11.00 | 5,885 |
| —0.90 | 105 | 3.10 | 1,520 | 7.10 | 3,715 | 11.10 | 5,935 |
| —0.80 | 120 | 3.20 | 1,570 | 7.20 | 3,765 | 11.20 | 5,985 |
| —0.70 | 140 | 3.30 | 1,620 | 7.30 | 3,815 | 11.30 | 6,035 |
| —0.60 | 160 | 3.40 | 1,670 | 7.40 | 3,865 | 11.40 | 6,085 |
| —0.50 | 180 | 3.50 | 1,725 | 7.50 | 3,925 | 11.50 | 6,145 |
| —0.40 | 200 | 3.60 | 1,780 | 7.60 | 3,985 | 11.60 | 6,205 |
| —0.30 | 220 | 3.70 | 1,835 | 7.70 | 4,045 | 11.70 | 6,265 |
| —0.20 | 240 | 3.80 | 1,890 | 7.80 | 4,105 | 11.80 | 6,325 |
| —0.10 | 260 | 3.90 | 1,945 | 7.90 | 4,165 | 11.90 | 6,385 |
| 0.00 | 280 | 4.00 | 2,000 | 8.00 | 4,220 | 12.00 | 6,440 |
| 0.10 | 310 | 4.10 | 2,055 | 8.10 | 4,270 | 12.10 | 6,490 |
| 0.20 | 340 | 4.20 | 2,111 | 8.20 | 4,320 | 12.20 | 6,540 |
| 0.30 | 370 | 4.30 | 2,166 | 8.30 | 4,370 | 12.30 | 6,590 |
| 0.40 | 400 | 4.40 | 2,222 | 8.40 | 4,420 | 12.40 | 6,640 |
| 0.50 | 430 | 4.50 | 2,277 | 8.50 | 4,480 | 12.50 | 6,700 |
| 0.60 | 460 | 4.60 | 2,333 | 8.60 | 4,540 | 12.60 | 6,760 |
| 0.70 | 490 | 4.70 | 2,388 | 8.70 | 4,600 | 12.70 | 6,820 |
| 0.80 | 530 | 4.80 | 2,444 | 8.80 | 4,660 | 12.80 | 6,880 |
| 0.90 | 565 | 4.90 | 2,500 | 8.90 | 4,720 | 12.90 | 6,940 |
| 1.00 | 600 | 5.00 | 2,555 | 9.00 | 4,775 | 13.00 | 6,995 |
| 1.10 | 635 | 5.10 | 2,610 | 9.10 | 4,825 | 13.10 | 7,045 |
| 1.20 | 670 | 5.20 | 2,666 | 9.20 | 4,875 | 13.20 | 7,095 |
| 1.30 | 710 | 5.30 | 2,721 | 9.30 | 4,925 | 13.30 | 7,145 |
| 1.40 | 750 | 5.40 | 2,777 | 9.40 | 4,975 | 13.40 | 7,195 |
| 1.50 | 790 | 5.50 | 2,832 | 9.50 | 5,035 | 13.50 | 7,255 |
| 1.60 | 830 | 5.60 | 2,888 | 9.60 | 5,095 | 13.60 | 7,315 |
| 1.70 | 870 | 5.70 | 2,943 | 9.70 | 5,155 | 13.70 | 7,375 |
| 1.80 | 910 | 5.80 | 3,000 | 9.80 | 5,215 | 13.80 | 7,435 |
| 1.90 | 955 | 5.90 | 3,054 | 9.90 | 5,275 | 13.90 | 7,495 |
| 2.00 | 1,000 | 6.00 | 3,110 | 10.00 | 5,330 | 14.00 | 7,550 |
| 2.10 | 1,045 | 6.10 | 3,160 | 10.10 | 5,380 | 14.10 | 7,600 |
| 2.20 | 1,090 | 6.20 | 3,210 | 10.20 | 5,430 | 14.20 | 7,650 |
| 2.30 | 1,135 | 6.30 | 3,260 | 10.30 | 5,480 | 14.30 | 7,700 |
| 2.40 | 1,180 | 6.40 | 3,310 | 10.40 | 5,530 | 14.40 | 7,750 |
| 2.50 | 1,225 | 6.50 | 3,370 | 10.50 | 5,590 | 14.50 | 7,810 |
| 2.60 | 1,270 | 6.60 | 3,430 | 10.60 | 5,650 | 14.60 | 7,870 |
| 2.70 | 1,320 | 6.70 | 3,490 | 10.70 | 5,710 | 14.70 | 7,930 |
| 2.80 | 1,370 | 6.80 | 3,550 | 10.80 | 5,770 | 14.80 | 7,990 |
| 2.90 | 1,420 | 6.90 | 3,610 | 10.90 | 5,830 | 14.90 | 8,050 |

*Rating table for Black Warrior River at Tuscaloosa, Alabama*—Continued.

[This table is applicable only from January 1, 1895, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 15.00 | 8,105 | 17.60 | 9,535 | 20.10 | 10,950 | 22.60 | 13,100 |
| 15.10 | 8,155 | 17.70 | 9,595 | 20.20 | 11,020 | 22.70 | 13,200 |
| 15.20 | 8,205 | 17.80 | 9,655 | 20.30 | 11,090 | 22.80 | 13,300 |
| 15.30 | 8,255 | 17.90 | 9,715 | 20.40 | 11,160 | 22.90 | 13,400 |
| 15.40 | 8,305 | 18.00 | 9,770 | 20.50 | 11,230 | 23.00 | 13,500 |
| 15.50 | 8,365 | 18.10 | 9,820 | 20.60 | 11,305 | 23.10 | 13,620 |
| 15.60 | 8,425 | 18.20 | 9,870 | 20.70 | 11,380 | 23.20 | 13,740 |
| 15.70 | 8,485 | 18.30 | 9,920 | 20.80 | 11,455 | 23.30 | 13,860 |
| 15.80 | 8,545 | 18.40 | 9,970 | 20.90 | 11,530 | 23.40 | 13,980 |
| 15.90 | 8,605 | 18.50 | 10,030 | 21.00 | 11,600 | 23.50 | 14,100 |
| 16.00 | 8,660 | 18.60 | 10,090 | 21.10 | 11,690 | 23.60 | 14,220 |
| 16.10 | 8,710 | 18.70 | 10,150 | 21.20 | 11,780 | 23.70 | 14,340 |
| 16.20 | 8,760 | 18.80 | 10,210 | 21.30 | 11,870 | 23.80 | 14,460 |
| 16.30 | 8,810 | 18.90 | 10,270 | 21.40 | 11,960 | 23.90 | 14,580 |
| 16.40 | 8,860 | 19.00 | 10,325 | 21.50 | 12,050 | 24.00 | 14,700 |
| 16.50 | 8,920 | 19.10 | 10,375 | 21.60 | 12,140 | 24.10 | 14,830 |
| 16.60 | 8,980 | 19.20 | 10,425 | 21.70 | 12,230 | 24.20 | 14,960 |
| 16.70 | 9,040 | 19.30 | 10,475 | 21.80 | 12,320 | 24.30 | 15,090 |
| 16.80 | 9,100 | 19.40 | 10,525 | 21.90 | 12,410 | 24.40 | 15,200 |
| 16.90 | 9,160 | 19.50 | 10,585 | 22.00 | 12,500 | 24.50 | 15,350 |
| 17.00 | 9,215 | 19.60 | 10,645 | 22.10 | 12,600 | 24.60 | 15,480 |
| 17.10 | 9,265 | 19.70 | 10,705 | 22.20 | 12,700 | 24.70 | 15,610 |
| 17.20 | 9,315 | 19.80 | 10,765 | 22.30 | 12,800 | 24.80 | 15,740 |
| 17.30 | 9,365 | 19.90 | 10,825 | 22.40 | 12,900 | 24.90 | 15,870 |
| 17.40 | 9,415 | 20.00 | 10,880 | 22.50 | 13,000 | 25.00 | 16,000 |
| 17.50 | 9,475 | | | | | | |

*Estimated monthly discharge of Black Warrior River at Tuscaloosa, Alabama.*

[Drainage area, 4,900 square miles.]

| Month. | Discharge in second feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 103,400 | 2,777 | 25,464 | 1,565,720 | 6.00 | 5.20 |
| February | 14,830 | 4,775 | 7,603 | 422,249 | 1.61 | 1.55 |
| March | 109,000 | 4,540 | 39,977 | 2,458,106 | 9.42 | 8.16 |
| April | 14,700 | 3,665 | 6,895 | 410,280 | 1.57 | 1.41 |
| May | 13,860 | 2,000 | 5,511 | 338,860 | 1.29 | 1.12 |
| June | 3,665 | 1,000 | 2,133 | 126,922 | 0.49 | 0.44 |
| July | 9,970 | 1,000 | 3,581 | 220,189 | 0.84 | 0.73 |
| August | 2,500 | 565 | 1,098 | 67,514 | 0.25 | 0.22 |
| September | 1,835 | 310 | 883 | 52,542 | 0.20 | 0.18 |
| October | 310 | 140 | 233 | 14,327 | 0.06 | 0.05 |
| November | 750 | 280 | 488 | 29,038 | 0.11 | 0.10 |
| December | 11,600 | 530 | 2,021 | 124,267 | 0.47 | 0.41 |
| Per annum | 109,000 | 140 | 7,991 | 5,830,014 | 22.31 | 1.63 |
| 1896. | | | | | | |
| January | 24,610 | 2,444 | 5,981 | 367,757 | 1.41 | 1.22 |
| February | 47,000 | 3,665 | 19,161 | 1,102,153 | 4.22 | 3.91 |
| March | 52,600 | 3,160 | 12,996 | 799,093 | 3.06 | 2.65 |
| April | 14,100 | 2,721 | 6,072 | 361,309 | 1.38 | 1.24 |
| May | 49,800 | 1,370 | 7,420 | 456,238 | 1.74 | 1.51 |
| June | 9,970 | 1,090 | 2,910 | 173,157 | 0.65 | 0.59 |
| July | 4,420 | 460 | 1,232 | 75,753 | 0.29 | 0.25 |
| August | 750 | 310 | 478 | 29,391 | 0.12 | 0.10 |
| September | 400 | 120 | 201 | 11,960 | 0.04 | 0.04 |
| October | 260 | 120 | 157 | 9,654 | 0.03 | 0.03 |
| November | 600 | 120 | 307 | 18,268 | 0.07 | 0.06 |
| December | 4,045 | 430 | 955 | 58,721 | 0.22 | 0.19 |
| Per annum | 52,600 | 120 | 4,823 | 3,463,454 | 13.23 | 0.98 |

## MISCELLANEOUS MEASUREMENTS.

Measurements of discharge were made on the Oostanaula and Etowah rivers at Rome, Georgia. The area of the watershed above Rome, on the Etowah, is 1,770 square miles; while above Rome, on the Oostanaula River, the area is 2,114 square miles. A regular hydrographic station was not established here, as each river is influenced by the stage of the other to such an extent that its gage height changes materially, without corresponding change in discharge. The measurements, however, are considered useful in connection with the gage heights at Canton and

DISCHARGE OF BLACK WARRIOR RIVER AT

FEB.
10 20
MAR.
10 20
APRIL
10 20
MAY
10 20
JUNE
10 20
JULY
10 20
AUG.
10 20
SEPT
10 20
OCT.
10 20
NOV.
10 20
DEC.
10 20
1895
1892
1894
1896

Resaca, especially at extreme low water, in showing the characteristics of the lower watersheds of these two rivers. For instance, on September 24, 1896, the Etowah River at Rome measured 834 second-feet when the gage height at Canton, Georgia, was —0.30 and the discharge 360 second-feet. On the same day the Oostanaula at Rome measured only 375 second-feet, when at Resaca it had a gage height of 1.55 and a discharge of 533 second-feet.

An explanation of these seeming discrepancies may be found in the different formations through which these two rivers run in the Paleozoic region. From Cartersville to Rome the Etowah River is fed by great limestone springs that show very little change in the dryest season, and these springs seem to form the lowest outlet for ground water. On the other hand, the Oostanaula River from Resaca to Rome passes through a belt of pervious shales, underlain in many places by deep limestone caverns. At ordinary seasons, and even at low water during ordinary years, these caverns are full to overflowing and the shales are saturated; but in an extreme dry season, like the past summer and autumn, when the supply of ground water has been decreasing for a series of years, the normal water level in the caverns has become lowered and the shales are thoroughly drained. Under such conditions it is easy to conceive of an actual leakage from the river into these shales as an explanation of the discharge measurements above referred to. In corroboration of this theory, it may be stated that nearly all of the small streams tributary to the Oostanaula become dry in summer. It is to be remembered that this is not a water-power stream, and that none of the Georgia water powers are in similar regions or have such a watershed above them.

*List of discharge measurements made on the Etowah and Oostanaula rivers at Rome, Georgia.*

| No. | Date. | Hydrographer. | Name of stream. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | | |
| 1 | Sept. 24 | Max Hall.... | Oostananla *b*. | 8 | 0.20 | 726 | 0.52 | 375 |
| 1 | Sept. 24 | Max Hall.... | Etowah ..... | 8 | 0.50 | 609 | 1.37 | 834 |
| 1 | Oct. 15 | .....do ..... | Oostanaula *a*. | 11 | 0.35 | 766 | 0.77 | 591 |
| 2 | Oct. 15 | .....do ..... | .....do. *b*..... | 11 | 0.35 | 741 | 0.77 | 572 |

*a* Made from Second avenue bridge. *b* Made from Fifth avenue bridge.

On August 22 Mr. Max Hall made a discharge measurement at Ladds Station, on the Etowah River, from the East and West Railroad bridge, 3 miles below Cartersville, Georgia, with meter No. 16. The initial point of soundings is the end of the iron bridge at right bank, downstream side of bridge. The bench mark is at 40 feet from initial point on the top of the iron chord on which cross-ties rest, and is 32.10 feet above water. The area of cross section was 317 square feet, mean velocity was 1.40 feet per second, and discharge was 444 second-feet. The

1890
1892
1894
1896

Resaca, especially at extreme low water, in showing the characteristics of the lower watersheds of these two rivers. For instance, on September 24, 1896, the Etowah River at Rome measured 834 second-feet when the gage height at Canton, Georgia, was —0.30 and the discharge 360 second-feet. On the same day the Oostanaula at Rome measured only 375 second-feet, when at Resaca it had a gage height of 1.55 and a discharge of 533 second-feet.

An explanation of these seeming discrepancies may be found in the different formations through which these two rivers run in the Paleozoic region. From Cartersville to Rome the Etowah River is fed by great limestone springs that show very little change in the dryest season, and these springs seem to form the lowest outlet for ground water. On the other hand, the Oostanaula River from Resaca to Rome passes through a belt of pervious shales, underlain in many places by deep limestone caverns. At ordinary seasons, and even at low water during ordinary years, these caverns are full to overflowing and the shales are saturated; but in an extreme dry season, like the past summer and autumn, when the supply of ground water has been decreasing for a series of years, the normal water level in the caverns has become lowered and the shales are thoroughly drained. Under such conditions it is easy to conceive of an actual leakage from the river into these shales as an explanation of the discharge measurements above referred to. In corroboration of this theory, it may be stated that nearly all of the small streams tributary to the Oostanaula become dry in summer. It is to be remembered that this is not a water-power stream, and that none of the Georgia water powers are in similar regions or have such a watershed above them.

*List of discharge measurements made on the Etowah and Oostanaula rivers at Rome, Georgia.*

| No. | Date. | Hydrographer. | Name of stream. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | | |
| 1 | Sept. 24 | Max Hall.... | Oostananla *b*. | 8 | 0.20 | 726 | 0.52 | 375 |
| 1 | Sept. 24 | Max Hall.... | Etowah ..... | 8 | 0.50 | 609 | 1.37 | 834 |
| 1 | Oct. 15 | .....do ..... | Oostanaula *a*. | 11 | 0.35 | 766 | 0.77 | 591 |
| 2 | Oct. 15 | .....do ..... | .....do. *b*..... | 11 | 0.35 | 741 | 0.77 | 572 |

*a* Made from Second avenue bridge. *b* Made from Fifth avenue bridge.

On August 22 Mr. Max Hall made a discharge measurement at Ladds Station, on the Etowah River, from the East and West Railroad bridge, 3 miles below Cartersville, Georgia, with meter No. 16. The initial point of soundings is the end of the iron bridge at right bank, downstream side of bridge. The bench mark is at 40 feet from initial point on the top of the iron chord on which cross-ties rest, and is 32.10 feet above water. The area of cross section was 317 square feet, mean velocity was 1.40 feet per second, and discharge was 444 second-feet. The

drainage area is about 1,183 square miles. The section is not a good one for continuous measurements. On August 4, 1896, Professor Hall examined the Alabama River at Montgomery, Alabama. The nearest bridge is the Louisville and Nashville Railroad bridge, 3 miles up the river. Finding this point inconvenient and expensive to reach for continuous measurements, it was decided not to establish a station there.

On September 16, 1896, Mr. Max Hall made a discharge measurement on Tallapoosa River at Milstead, Alabama, with meter No. 11, from the bridge of the Tallassee Railroad. The stage of water was 59.45 feet below the top of second iron crossbeam from south end of bridge. He assumed this point as gage height 60.00, thus making gage height of river 0.55. The area of section was 849 square feet, the mean velocity 0.393 foot per second, and the discharge was 335 second-feet. The current was too sluggish at this stage for accurate measurement with the Haskell meter.

On October 10, 1896, Mr. Max Hall measured Talking Rock Creek at its mouth where it enters the Coosawattee River just above Carters. The gage on Coosawattee River at Carters read 0.55 foot, the area was 28 square feet, the mean velocity was 1.25 feet per second, and the discharge was 35 second-feet. The area of watershed above the point of measurement is 150 square miles.

## TEXAS STREAMS.

Measurements in Texas were made by Mr. Cyrus C. Babb in November and December, 1896, chiefly on streams measured in 1895, and described in Bulletin 140, pages 82 to 85. The results are given in the following table:

*List of discharge measurements made on Texas rivers.*

| Date. | Stream. | Location. | Meter number. | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Nov. 28 | Del Rio *a* | Del Rio | 63 | 35 | 2.06 | 72 |
| Nov. 28 | Canal | do | 63 | 19 | 0.90 | 17 |
| Nov. 30 | San Antonio *b* | San Antonio | 63 | 67 | 0.37 | 25 |
| Nov. 30 | Upper Labor ditch | do | 63 | 3.5 | 1.0 | 3.5 |
| Nov. 30 | Alamo ditch | do | 63 | | | 0.5 |
| Nov. 30 | San Pedro Canal | do | 63 | 7 | 1.25 | 8.8 |
| Nov. 30 | San Pedro River *c* | do | 63 | 3.8 | 0.77 | 2.9 |
| Dec. 1 | Comal | New Braunfels | 63 | 101 | 3.86 | 390 |
| Dec. 1 | Guadalupe | do | 63 | 167 | 2.62 | 438 |
| Dec. 2 | San Marcos | San Marcos | 63 | 218 | 0.86 | 186 |
| Dec. 3 | Colorado | Austin | 63 | 525 | 1.14 | 598 |
| Dec. 3 | Barton | do | 63 | 27 | 1.78 | 48 |

*a* The measurement was made below the point of diversion of the canal. The total flow is thus the sum of the discharges, or 97 second-feet.

*b* Total flow, adding ditches, is 29 second-feet. *c* Total flow, including canal, is 11.7 second-feet.

## OHIO RIVER TRIBUTARIES.

The stations maintained in this basin were described in Bulletin 140, pages 77 and 78.

### KANAWHA BASIN.

#### ALDERSON STATION ON GREENBRIER RIVER.

This station is in the Hinton quadrangle, one-half mile above the mouth of Muddy Creek, in latitude 37° 43.4′ and longitude 80° 38.5′. Its drainage basin is in the Hinton, Beverly, Monterey, Huntersville, and Lewisburg quadrangles, and has an area of 1,344 square miles. On July 30, 1895, a wire gage was established on the county bridge at Alderson, West Virginia, 21 miles above Hinton. It is placed on the third panel of the second span, lower side, and the edge of the pulley over which the wire passes is 0.75 foot south of the second vertical strut. The zero of the gage is 2 feet from the edge of the pulley. The distance from the end of the weight to the wire marker is 28.37 feet. When the reading of water is 1.88 feet, the distance from the surface of the water to the top of the floor beam at the end of the third panel is 20.59 feet. The bridge consists of 4 spans, each 108 feet long and with 7 panels to a span, making a total width of 432 feet. At ordinary stages the water flows in two channels, there being an island 600 feet long and 75 feet in width between them. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 41.

*List of discharge measurements made on Greenbrier River at Alderson, West Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 30 | C. C. Babb..... | 29 h. | 1.89 | 385 | 1.18 | 457 |
| 2 | Sept. 4 | D. C. Humphreys | W. & L. U. | 1.36 | 82 | 1.27 | 106 |
| | 1896. | | | | | | |
| 3 | June 10 | D. C. Humphreys | W. B., 1 A | 2.30 | 402 | 1.77 | 714 |
| 4 | July 22 | .....do ..... | W. B., 1 A | 2.07 | 465 | 1.43 | 665 |
| 5 | Aug. 13 | .....do ..... | W. B., 1 A | 1.95 | 402 | 1.31 | 529 |
| 6 | Dec. 18 | .....do ..... | W. B., 1 A | 2.80 | 639 | 2.32 | 1,480 |
| | 1897. | | | | | | |
| 7 | Mar. 30 | D. C. Humphreys | W. B., 1 A | 2.75 | 672 | 2.44 | 1,638 |
| 8 | May 3 | F. H. Anschutz.. | Floats .... | 4.88 | 1,567 | 3.94 | 6,181 |
| 9 | May 4 | .....do ..... | W. B., 1 A | 4.38 | 1,349 | 4.04 | 5,450 |
| 10 | May 4 | .....do ..... | Floats .... | 4.29 | 1,326 | 3.75 | 4,963 |
| 11 | May 6 | .....do ..... | W. B., 1 A | 3.56 | 1,031 | 3.06 | 3,158 |
| 12 | May 13 | .....do ..... | W. B., 1 A | 12.30 | 4,756 | 6.85 | 32,563 |
| 13 | May 14 | .....do ..... | Floats .... | 12.32 | 4,769 | 6.93 | 33,033 |
| 14 | May 14 | .....do ..... | W. B., 1 A | 9.52 | 3,580 | 5.79 | 20,722 |

*Rating table for Greenbrier River at Alderson, West Virginia.*

[This table is applicable from August 1, 1895, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.30 | 86 | 3.50 | 3,000 | 5.70 | 8,600 | 8.80 | 18,320 |
| 1.35 | 105 | 3.55 | 3,120 | 5.75 | 8,750 | 8.90 | 18,660 |
| 1.40 | 125 | 3.60 | 3,240 | 5.80 | 8,900 | 9.00 | 19,000 |
| 1.45 | 145 | 3.65 | 3,360 | 5.85 | 9,050 | 9.10 | 19,340 |
| 1.50 | 170 | 3.70 | 3,480 | 5.90 | 9,200 | 9.20 | 19,680 |
| 1.55 | 200 | 3.75 | 3,600 | 5.95 | 9,350 | 9.30 | 20,020 |
| 1.60 | 230 | 3.80 | 3,720 | 6.00 | 9,500 | 9.40 | 20,360 |
| 1.65 | 265 | 3.85 | 3,840 | 6.05 | 9,650 | 9.50 | 20,700 |
| 1.70 | 300 | 3.90 | 3,960 | 6.10 | 9,800 | 9.60 | 21,050 |
| 1.75 | 335 | 3.95 | 4,080 | 6.15 | 9,950 | 9.70 | 21,410 |
| 1.80 | 375 | 4.00 | 4,200 | 6.20 | 10,100 | 9.80 | 21,770 |
| 1.85 | 415 | 4.05 | 4,320 | 6.25 | 10,250 | 9.90 | 22,130 |
| 1.90 | 460 | 4.10 | 4,440 | 6.30 | 10,400 | 10.00 | 22,500 |
| 1.95 | 505 | 4.15 | 4,560 | 6.35 | 10,550 | 10.10 | 22,870 |
| 2.00 | 550 | 4.20 | 4,680 | 6.40 | 10,700 | 10.20 | 23,240 |
| 2.05 | 595 | 4.25 | 4,800 | 6.45 | 10,850 | 10.30 | 23,620 |
| 2.10 | 645 | 4.30 | 4,920 | 6.50 | 11,000 | 10.40 | 24,000 |
| 2.15 | 695 | 4.35 | 5,040 | 6.55 | 11,150 | 10.50 | 24,400 |
| 2.20 | 745 | 4.40 | 5,160 | 6.60 | 11,300 | 10.60 | 24,810 |
| 2.25 | 795 | 4.45 | 5,280 | 6.65 | 11,450 | 10.70 | 25,230 |
| 2.30 | 855 | 4.50 | 5,400 | 6.70 | 11,600 | 10.80 | 25,650 |
| 2.35 | 915 | 4.55 | 5,530 | 6.75 | 11,750 | 10.90 | 26,070 |
| 2.40 | 975 | 4.60 | 5,660 | 6.80 | 11,900 | 11.00 | 26,500 |
| 2.45 | 1,035 | 4.65 | 5,790 | 6.85 | 12,050 | 11.10 | 26,930 |
| 2.50 | 1,100 | 4.70 | 5,920 | 6.90 | 12,200 | 11.20 | 27,360 |
| 2.55 | 1,165 | 4.75 | 6,050 | 6.95 | 12,350 | 11.30 | 27,800 |
| 2.60 | 1,230 | 4.80 | 6,180 | 7.00 | 12,500 | 11.40 | 28,240 |
| 2.65 | 1,300 | 4.85 | 6,310 | 7.10 | 12,800 | 11.50 | 28,700 |
| 2.70 | 1,380 | 4.90 | 6,440 | 7.20 | 13,100 | 11.60 | 29,200 |
| 2.75 | 1,460 | 4.95 | 6,570 | 7.30 | 13,400 | 11.70 | 29,700 |
| 2.80 | 1,540 | 5.00 | 6,700 | 7.40 | 13,700 | 11.80 | 30,200 |
| 2.85 | 1,620 | 5.05 | 6,830 | 7.50 | 14,000 | 11.90 | 30,700 |
| 2.90 | 1,710 | 5.10 | 6,960 | 7.60 | 14,300 | 12.00 | 31,200 |
| 2.95 | 1,805 | 5.15 | 7,090 | 7.70 | 14,620 | 12.10 | 31,700 |
| 3.00 | 1,900 | 5.20 | 7,220 | 7.80 | 14,940 | 12.20 | 32,200 |
| 3.05 | 2,000 | 5.25 | 7,350 | 7.90 | 15,260 | 12.30 | 32,700 |
| 3.10 | 2,110 | 5.30 | 7,480 | 8.00 | 15,600 | 12.40 | 33,200 |
| 3.15 | 2,220 | 5.35 | 7,610 | 8.10 | 15,940 | 12.50 | 33,700 |
| 3.20 | 2,330 | 5.40 | 7,740 | 8.20 | 16,280 | 12.60 | 34,200 |
| 3.25 | 2,440 | 5.45 | 7,870 | 8.30 | 16,620 | 12.70 | 34,700 |
| 3.30 | 2,550 | 5.50 | 8,000 | 8.40 | 16,960 | 12.80 | 35,200 |
| 3.35 | 2,660 | 5.55 | 8,150 | 8.50 | 17,300 | 12.90 | 35,700 |
| 3.40 | 2,770 | 5.60 | 8,300 | 8.60 | 17,640 | | |
| 3.45 | 2,880 | 5.65 | 8,450 | 8.70 | 17,980 | | |

*Estimated monthly discharge of Greenbrier River at Alderson, West Virginia.*

[Drainage area, 1,344 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| August | 422 | 125 | 268 | 16,479 | 0.23 | 0.20 |
| September | 886 | 71 | 168 | 9,997 | 0.13 | 0.12 |
| October | 91 | 60 | 73 | 4,489 | 0.06 | 0.05 |
| November | 250 | 91 | 153 | 9,104 | 0.12 | 0.11 |
| December | 3,120 | 137 | 486 | 29,883 | 0.41 | 0.36 |
| 1896. | | | | | | |
| January | 4,680 | 300 | 1,051 | 64,623 | 0.90 | 0.78 |
| February | 8,900 | 220 | 2,975 | 171,181 | 2.38 | 2.21 |
| March | 24,400 | 855 | 3,558 | 218,773 | 3.05 | 2.65 |
| April | 12,500 | 915 | 2,723 | 162,030 | 2.26 | 2.03 |
| May | 5,660 | 595 | 1,531 | 91,101 | 1.31 | 1.14 |
| June | 3,600 | 415 | 903 | 53,732 | 0.74 | 0.67 |
| July | 12,350 | 615 | 2,361 | 145,172 | 2.03 | 1.76 |
| August | 5,400 | 265 | 1,079 | 66,345 | 0.92 | 0.80 |
| September | 6,516 | 188 | 456 | 27,134 | 0.39 | 0.34 |
| October | 11,300 | 300 | 1,067 | 65,607 | 0.91 | 0.79 |
| November | 20,700 | 279 | 2,421 | 144,060 | 2.01 | 1.80 |
| December | 6,050 | 125 | 1,417 | 87,128 | 1.21 | 1.05 |

FAYETTE STATION ON NEW RIVER.

This station is in the Kanawha Falls quadrangle, just below the mouth of Wolf Creek, in latitude 38° 4′, longitude 81° 5′. Its drainage area is 6,200 square miles, in the Kanawha Falls, Nicholas, Hinton, Beverly, Monterey, Huntersville, Lewisburg, Raleigh, Christiansburg, Dublin, Pocahontas, Abingdon, Wytheville, Hillsville, Yadkinville, Wilkesboro, and Cranberry quadrangles. The station was described in Bulletin 140, page 79. It is at a highway bridge of one span, having a total length of 261 feet. A wire gage was established here July 29, 1895, and a measurement of discharge subsequently made. The zero of the gage is opposite the south edge of the second vertical strut from the north end of the bridge, and is 5.20 feet from the pulley. The distance vertically from the zero to the bottom plate of the girder at the end of the first panel on the lower side is 55.13 feet. Bench marks: Top of coping of first pier from left bank to zero of gage, 21.75 feet; upper end of bridge seat left bank abutment to zero of gage, 21.61 feet; top of stone foundation of water tank Chesapeake and Ohio Railway to

zero of gage, 23.48 feet. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, p. 41.

*List of discharge measurements made on New River at Fayette, West Virginia.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 29 | C. C. Babb..... | 29, h. | 4.07 | 2,805 | 2.54 | 7,128 |
| 2 | Sept. 4 | D. C. Humphreys | W. B., 1 A | 1.71 | 2,116 | 1.43 | 3,030 |
| | 1896. | | | | | | |
| 3 | June 10 | D. C. Humphreys | W. B., 1 A | 4.05 | 2,557 | 2.08 | 5,308 |
| 4 | July 23 | .....do ..... | W. B., 1 A | 4.25 | 2,474 | 2.05 | 5,076 |
| 5 | Aug. 13 | .....do ..... | W. B., 1 A | 2.32 | 2,219 | 1.56 | 3,454 |
| 6 | Dec. 18 | .....do ..... | W. B., 1 A | 7.48 | 3,260 | 4.20 | 13,685 |
| | 1897. | | | | | | |
| 7 | Mar. 31 | D. C. Humphreys | W. B., 1 A | 5.50 | 3,082 | ..... | 9,587 |
| 8 | May 5 | F. H. Anschutz .. | W. B., 1 A | 8.50 | 3,797 | ..... | 15,931 |
| 9 | May 15 | .....do ..... | W. B., 1 A | 13.98 | 5,231 | ..... | 35,195 |

*Rating table for New River at Fayette, West Virginia.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.50 | 2,565 | 2.40 | 3,500 | 4.30 | 5,340 | 6.20 | 9,060 |
| 0.60 | 2,590 | 2.50 | 3,570 | 4.40 | 5,480 | 6.30 | 9,360 |
| 0.70 | 2,615 | 2.60 | 3,640 | 4.50 | 5,620 | 6.40 | 9,660 |
| 0.80 | 2,640 | 2.70 | 3,720 | 4.60 | 5,760 | 6.50 | 9,970 |
| 0.90 | 2,670 | 2.80 | 3,800 | 4.70 | 5,920 | 7.00 | 11,570 |
| 1.00 | 2,700 | 2.90 | 3,880 | 4.80 | 6,080 | 7.50 | 13,220 |
| 1.10 | 2,740 | 3.00 | 3,960 | 4.90 | 6,240 | 8.00 | 14,900 |
| 1.20 | 2,780 | 3.10 | 4,050 | 5.00 | 6,400 | 8.50 | 16,550 |
| 1.30 | 2,820 | 3.20 | 4,140 | 5.10 | 6,580 | 9.00 | 18,200 |
| 1.40 | 2,870 | 3.30 | 4,240 | 5.20 | 6,760 | 9.50 | 19,900 |
| 1.50 | 2,920 | 3.40 | 4,340 | 5.30 | 6,960 | 10.00 | 21,600 |
| 1.60 | 2,970 | 3.50 | 4,440 | 5.40 | 7,160 | 11.00 | 25,000 |
| 1.70 | 3,030 | 3.60 | 4,540 | 5.50 | 7,380 | 12.00 | 28,400 |
| 1.80 | 3,090 | 3.70 | 4,650 | 5.60 | 7,600 | 13.00 | 31,800 |
| 1.90 | 3,150 | 3.80 | 4,760 | 5.70 | 7,820 | 14.00 | 35,200 |
| 2.00 | 3,220 | 3.90 | 4,870 | 5.80 | 8,040 | 15.00 | 38,600 |
| 2.10 | 3,290 | 4.00 | 4,980 | 5.90 | 8,270 | 16.00 | 42,000 |
| 2.20 | 3,360 | 4.10 | 5,100 | 6.00 | 8,500 | 17.00 | 45,500 |
| 2.30 | 3,430 | 4.20 | 5,220 | 6.10 | 8,780 | 18.00 | 49,000 |

*Estimated monthly discharge of New River at Fayette, West Virginia.*

[Drainage area, 6,200 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895 | | | | | | |
| August | 10,125 | 2,900 | 4,197 | 258,065 | 0.78 | 0.68 |
| September | 4,450 | 2,538 | 2,906 | 172,919 | 0.53 | 0.47 |
| October | 2,600 | 2,450 | 2,532 | 155,688 | 0.47 | 0.41 |
| November | 3,575 | 2,575 | 2,812 | 167,325 | 0.50 | 0.45 |
| December | 20,750 | 2,550 | 4,370 | 268,703 | 0.81 | 0.70 |
| 1896. | | | | | | |
| January | 21,600 | 2,780 | 5,433 | 334,064 | 1.01 | 0.88 |
| February | 30,100 | 3,430 | 11,560 | 664,939 | 2.01 | 1.86 |
| March | 67,900 | 3,360 | 17,051 | 1,048,432 | 3.17 | 2.75 |
| April | 68,600 | 5,220 | 16,974 | 1,010,021 | 3.05 | 2.74 |
| May | 12,560 | 4,005 | 6,318 | 388,482 | 1.18 | 1.02 |
| June | 17,870 | 3,560 | 5,809 | 345,659 | 1.04 | 0.94 |
| July | 74,200 | 3,800 | 13,373 | 822,279 | 2.41 | 2.16 |
| August | 6,580 | 2,800 | 3,961 | 243,554 | 0.74 | 0.64 |
| September | 3,570 | 2,615 | 2,793 | 166,195 | 0.50 | 0.45 |
| October | 38,260 | 2,545 | 5,064 | 311,375 | 0.94 | 0.82 |
| November | 45,850 | 2,700 | 7,912 | 470,796 | 1.48 | 1.28 |
| December (20 days) | 31,120 | 3,570 | 7,807 | 480,037 | 0.93 | 1.26 |
| Per annum | 74,200 | 2,615 | 8,671 | 6,285,833 | 18.46 | 1.40 |

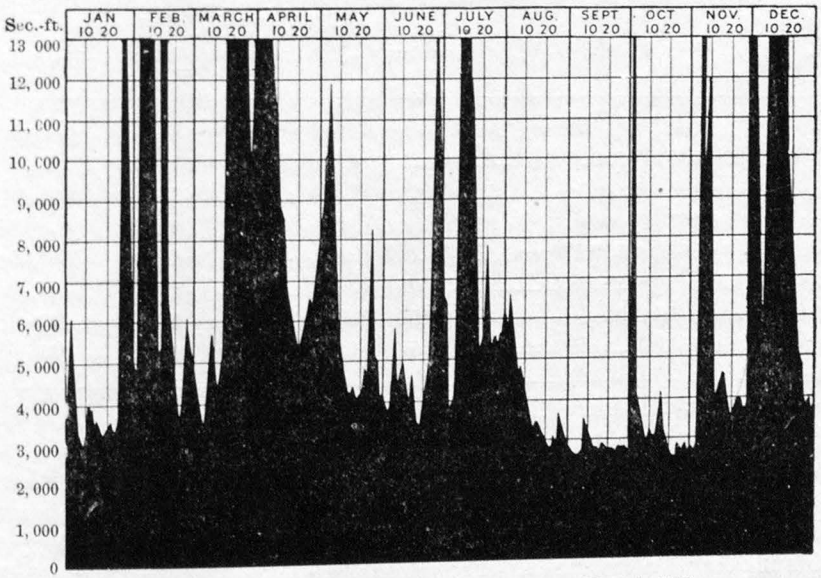



FIG. 14.—Discharge of New River at Fayette, West Virginia, 1896.

## TENNESSEE BASIN.

### ASHEVILLE STATION ON FRENCH BROAD RIVER.

This station is in the Asheville quadrangle, 3 miles below the mouth of the Swanannoa River, in latitude 35° 36.7′, longitude 82° 34.4′. The area drained is 987 square miles, and is mapped on the Asheville, Mount Mitchell, Pisgah, and Saluda atlas sheets.

This station was established by Cyrus C. Babb on September 17, 1895. It is at the Bingham School iron highway bridge, 3 miles west of Asheville, and is reached by electric-car line. The gage is a wire one. The zero of the rod is opposite the east edge of the fifth upright, first span from east, upper side. The outside edge of the pulley is 3 feet from the end of the rod, and the length of the wire cable from the end of the weight to the index marker is 26.03 feet. When the gage height is 3.22 the water surface is 17.16 feet below top of the lower end of the second floor beam, first span from the east.

The initial point for soundings is on the right bank, at the end of the first span of the bridge. Both banks may overflow in very high water. The current is swift and the channel is rocky and reasonably permanent. The observer is J. M. Taylor, a carpenter of Asheville, North Carolina. Observations were taken throughout the year, except during the first half of March. The discharge measurements are not sufficiently comprehensive to justify the construction of a rating table for this station. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, p. 42.

*List of discharge measurements made on French Broad River at Asheville, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 2 | C. C. Babb..... | 29 | 4.30 | 650 | 1.84 | 1,192 |
| 2 | Sept. 17 | .....do ..... | 29 | 3.22 | 585 | 1.72 | 1,006 |
| | 1896. | | | | | | |
| 3 | Apr. 18 | E. W. Myers..... | 21 | 2.90 | 538 | 1.22 | 659 |
| 4 | June 19 | .....do ..... | 21 | 3.42 | 685 | 2.18 | 1,495 |
| 5 | Aug. 16 | .....do ..... | 2,154 | 3.25 | 543 | 2.00 | 1,089 |
| 6 | Sept. 19 | .....do ..... | 2,154 | 2.50 | 438 | 1.58 | 694 |

### BRYSON STATION ON TUCKASEEGEE RIVER.

This station is in the Cowee quadrangle, 2 miles below the mouth of Newtons Mill Creek, in latitude 35° 26′, longitude 83° 24′. The drainage area is 609 square miles, and is mapped on the Cowee, Pisgah, and Mount Guyot atlas sheets. The gage is located on the Southern Rail-

way bridge about 3 miles above Bryson and just below Governor Island post-office, and was put in June 26, 1896. The zero of the gage rod is 20 feet from the end of the second span from the south end of the bridge. The outer rim of the pulley is 1 foot from the zero of the gage, and from the end of the weight to the marker on the wire is 26.75 feet, the gage reading zero when the weight touches bottom. The bottom is rocky and not easily changed and the banks are high; but the section is not a good one, as there are two bad pier obstructions and the bridge is across a bend of the river, the greater portion of the current being thrown toward the west bank. The observer is A. J. Sutton, Governor Island, North Carolina. The discharge measurements are not sufficiently comprehensive to justify the construction of a rating table for this station. The record of daily gage heights for 1896, from July 1 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 42.

*List of discharge measurements made on Tuckaseegee River, 3 miles above Bryson, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 *a* | June 22 | E. W. Myers..... | 21 | ..... | 1,100 | 0.81 | 892 |
| 2 | June 26 | .....do ..... | 21 | 2.26 | 272 | 3.03 | 821 |
| 3 | Aug. 12 | .....do ..... | 2154 | 2.42 | 207 | 3.90 | 809 |
| 4 | Sept. 21 | .....do ..... | 2154 | 1.84 | 238 | 2.48 | 593 |

*a* Measurement made at Bryson City.

## JUDSON STATION ON LITTLE TENNESSEE RIVER.

This station is in the Nantahala quadrangle, below the mouth of Sawyer Branch, in latitude 35° 25′ and longitude 83° 33.7′. The area drained is 682 square miles, and is mapped on the Nantahala, Cowee, and Walhalla atlas sheets. The gage is located on the Southern Railway bridge about one-fourth of a mile from Judson, North Carolina, and was established June 25, 1896. The zero of the gage rod is 25 feet west of the east end of the second span from the east. The outer rim of the pulley wheel is 2 feet from the zero of the gage rod, and the distance from the end of the weight to the marker on the wire rope is 26.25 feet. The gage reads zero when the weight touches the bottom of the stream. On the west side of the stream the bottom is rocky, on the east side sandy, and the current is very swift. The river is straight for several hundred yards above and below the station. The section is not a very good one, as there are two bad pier obstructions. The observer is R. C. Sawyer, Judson, North Carolina. The discharge measurements are not sufficiently comprehensive to justify

the construction of a rating table for this station. The record of daily gage heights for 1896, from July 1 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 42.

*List of discharge measurements made on Little Tennessee River at Judson, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 25 | E. W. Myers..... | 21 | 2.76 | 345 | 2.69 | 929 |
| 2 | Sept. 23 | .....do ..... | 2154 | 3.00 | 286 | 2.71 | 775 |

MURPHY STATION ON HIWASSEE RIVER.

This station is in the Murphy quadrangle, one-half mile above Valley River, in latitude 35° 5.2′, and longitude 84° 2.3′. The area drained is 410 square miles, and is mapped on the Murphy, Nantahala, and Dahlonega atlas sheets. The gage was established June 26, 1896, on the highway bridge crossing the river at Murphy, North Carolina. The zero of the gage rod is 8 feet north of the center of the second full-length compression member from the north end and on the downstream side of bridge. The outer rim of the pulley wheel is 2 feet from the zero of the gage rod, and the distance from the end of the weight to the marker on the wire is 29.1 feet. The reading of the gage is zero when the weight touches the bottom of the river. The section here is a fairly good one, though somewhat obstructed by the remains of two old piers directly under the present bridge. The course of the stream is straight for several hundred yards above and below the bridge and the current fairly rapid. The bottom is hard and rocky and is not subject to any decided change by high water. The banks are high and are not subject to overflow except in very high water. The observer here is M. L. Brittain, who lives about 50 yards from the bridge. The discharge measurements are not sufficiently comprehensive to justify the construction of a rating table for this station. The record of daily gage heights for 1896, from July 1 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 43.

*List of discharge measurements made on Hiwassee River at Murphy, North Carolina.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 23 | E. W. Myers..... | 21 | 3.82 | 311 | 1.17 | 366 |
| 2 | Aug. 10 | .....do ..... | 2154 | 3.95 | 278 | 1.37 | 382 |
| 3 | Sept. 22 | .....do ..... | 2154 | 4.01 | 353 | 1.46 | 517 |

## CHATTANOOGA STATION ON TENNESSEE RIVER.

This station is located on the Tennessee River at the city of Chattanooga, in the Chattanooga quadrangle. A gage was established at this point by the Signal Corps of the United States Army in 1879, and has been in charge of the Weather Bureau since July 1, 1891. A record of gage heights from January 1, 1890, to December 31, 1896, is published in Water-Supply and Irrigation Paper No. 11, pages 43–46.

The gage is vertical for about 20 feet in its lower portion, and the graduation is continued on an inclined railroad iron up the bank from the top of the vertical portion. It is located at the foot of Lookout street, just below Chattanooga Island. The zero of the gage is 630.64 feet above sea level. Measurements are made from the Hamilton County steel highway bridge at the foot of Walnut street a short distance below the gage. Nine discharge measurements were made by Mr. L. M. Pindell with large Haskell meter No. 2 in the spring of 1893, embracing gage heights from 5 to 26 feet. From these observations a rating curve has been plotted and a rating table computed, and the gage readings from 1890 to 1895 inclusive have been interpreted in terms of discharge in cubic feet per second. The lowest stage of water known at this point was in September, 1839, when the water surface stood at zero of the present gage. The highest water record was on March 11, 1867, showing a gage height of 58.05 feet. The drainage area above this station is 21,382 square miles, and has all been contoured by the United States Geological Survey, It is included in the quadrangles of Morristown, Greenville, Roan Mountain, Loudon, Knoxville, Mount Guyot, Asheville, Murphy, Briceville, Standing Stone, Wartburg, Pikeville, Maynardville, Cumberland Gap, Jonesville, Estillville, Bristol, Whitesburg, Grundy, Abingdon, Tazewell, Pocahontas, Wytheville, Cranberry, Morganton, Mount Mitchell, Saluda, Pisgah, Como, Nantahala, Walhalla, Dahlonega, Ellijay, Dalton, Cleveland, Ringgold, Kingston, and Chattanooga.

*List of discharge measurements made on Tennessee River at Chattanooga, Tennessee.*[1]

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 1 | Mar. 15 | L. M. Pindell.... | 2 | 10.3 | 17,971 | ..... | 63,039 |
| 2 | Mar. 16 | .....do ..... | 2 | 9.2 | 16,847 | ..... | 58,310 |
| 3 | Apr. 3 | .....do ..... | 2 | 5.1 | 12,427 | ..... | 32,629 |
| 4 | Apr. 4 | .....do ..... | 2 | 5.1 | 12,427 | ..... | 32,643 |
| 5 | May 5 | .....do ..... | 2 | 26.0 | 36,648 | 3.93 | 156,187 |
| 6 | May 8 | .....do ..... | 2 | 26.0 | 36,825 | 3.73 | 151,660 |
| 7 | May 9 | .....do ..... | 2 | 16.0 | 24,913 | 3.75 | 96,979 |
| 8 | May 17 | .....do ..... | 2 | 9.9 | 17,971 | 3.39 | 65,867 |
| 9 | May 18 | .....do ..... | 2 | 10.4 | 18,539 | 3.29 | 67,883 |

[1] Meter submerged at one-half depth.

*Rating table for Tennessee River at Chattanooga, Tennessee.*

[This table is applicable from January 1, 1890, to December 31, 1895.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 16,360 | 11.00 | 66,850 | 22.50 | 133,665 | 34.00 | 293,820 |
| 0.80 | 16,560 | 11.50 | 69,755 | 23.00 | 136,570 | 34.50 | 302,720 |
| 0.90 | 16,780 | 12.00 | 72,660 | 23.50 | 139,475 | 35.00 | 311,620 |
| 1.00 | 17,000 | 12.50 | 75,565 | 24.00 | 142,380 | 35.50 | 320,520 |
| 1.50 | 18,160 | 13.00 | 78,470 | 24.50 | 145,285 | 36.00 | 329,420 |
| 2.00 | 19,500 | 13.50 | 81,375 | 25.00 | 148,190 | 36.50 | 338,320 |
| 2.50 | 21,100 | 14.00 | 84,280 | 25.50 | 151,095 | 37.00 | 347,220 |
| 3.00 | 23,000 | 14.50 | 87,185 | 26.00 | 154,000 | 37.50 | 356,120 |
| 3.50 | 25,090 | 15.00 | 90,090 | 26.50 | 162,500 | 38.00 | 365,020 |
| 4.00 | 27,300 | 15.50 | 92,995 | 27.00 | 171,000 | 38.50 | 373,920 |
| 4.50 | 29,660 | 16.00 | 95,900 | 27.50 | 179,900 | 39.00 | 382,820 |
| 5.00 | 32,200 | 16.50 | 98,805 | 28.00 | 188,800 | 39.50 | 391,720 |
| 5.50 | 34,895 | 17.00 | 101,710 | 28.50 | 197,700 | 40.00 | 400,620 |
| 6.00 | 37,800 | 17.50 | 104,615 | 29.00 | 206,600 | 40.50 | 409,520 |
| 6.50 | 40,705 | 18.00 | 107,520 | 29.50 | 215,500 | 41.00 | 418,420 |
| 7.00 | 43,610 | 18.50 | 110,425 | 30.00 | 224,400 | 41.50 | 427,320 |
| 7.50 | 46,515 | 19.00 | 113,330 | 30.50 | 233,300 | 42.00 | 436,220 |
| 8.00 | 49,420 | 19.50 | 116,235 | 31.00 | 242,200 | 42.50 | 445,120 |
| 8.50 | 52,325 | 20.00 | 119,140 | 31.50 | 251,100 | 43.00 | 454,020 |
| 9.00 | 55,230 | 20.50 | 122,045 | 32.00 | 260,000 | 43.50 | 462,920 |
| 9.50 | 58,135 | 21.00 | 124,950 | 32.50 | 268,900 | 44.00 | 471,820 |
| 10.00 | 61,040 | 21.50 | 127,855 | 33.00 | 276,020 | 44.50 | 480,720 |
| 10.50 | 63,945 | 22.00 | 130,760 | 33.50 | 284,920 | | |

*Estimated monthly discharge of Tennessee River at Chattanooga, Tennessee.*

[Drainage area, 21,382 square miles.]

| Month. | Discharge in second-feet. | | | Total for month in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1890. | | | | | | |
| January | 78,470 | 30,150 | 42,749 | 2,628,551 | 2.31 | 2.00 |
| February | 308,060 | 44,191 | 76,081 | 4,225,310 | 3.72 | 3.56 |
| March | 445,120 | 52,906 | 129,093 | 7,937,670 | 6.96 | 6.03 |
| April | 121,464 | 43,029 | 64,855 | 3,859,132 | 3.38 | 3.03 |
| May | 72,079 | 41,286 | 51,200 | 3,148,186 | 2.76 | 2.39 |
| June | 41,286 | 23,400 | 29,102 | 1,731,685 | 1.52 | 1.36 |
| July | 47,677 | 19,500 | 27,036 | 1,662,390 | 1.45 | 1.26 |
| August | 46,515 | 21,100 | 30,881 | 1,898,810 | 1.66 | 1.44 |

*Estimated monthly discharge of Tennessee River at Chattanooga, Tennessee*—Continued.

[Drainage area, 21,382 square miles.]

| Month. | Discharge in second-feet. | | | Total for month in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1890. | | | | | | |
| September | 47,096 | 22,200 | 27,843 | 1,656,770 | 1.45 | 1.30 |
| October | 58,135 | 25,950 | 37,982 | 2,335,437 | 2.04 | 1.77 |
| November | 42,448 | 20,700 | 26,394 | 1,570,549 | 1.37 | 1.23 |
| December | 77,889 | 20,400 | 36,088 | 2,218,980 | 1.95 | 1.69 |
| Per annum | 445,120 | 19,500 | 48,275 | 34,873,470 | 30.57 | 2.26 |
| 1891. | | | | | | |
| January | 92,995 | 39,543 | 59,484 | 3,657,552 | 3.21 | 2.78 |
| February | 356,120 | 59,878 | 154,822 | 8,598,380 | 7.53 | 7.23 |
| March | 381,040 | 63,364 | 135,160 | 8,310,718 | 7.30 | 6.32 |
| April | 97,643 | 38,962 | 61,873 | 3,681,690 | 3.22 | 2.89 |
| May | 37,219 | 26,380 | 30,215 | 1,857,860 | 1.63 | 1.41 |
| June | 47,096 | 26,840 | 36,276 | 2,158,567 | 1.90 | 1.70 |
| July | 36,057 | 21,800 | 26,429 | 1,625,066 | 1.43 | 1.24 |
| August | 98,224 | 23,000 | 40,402 | 2,484,238 | 2.18 | 1.89 |
| September | 36,638 | 19,200 | 25,777 | 1,533,835 | 1.34 | 1.20 |
| October | 19,200 | 17,910 | 18,461 | 1,135,130 | .99 | .86 |
| November | 41,867 | 17,440 | 23,510 | 1,398,939 | 1.23 | 1.10 |
| December | 66,269 | 22,200 | 39,299 | 2,416,417 | 2.12 | 1.84 |
| Per annum | 381,040 | 17,440 | 54,309 | 38,858,392 | 34.08 | 2.54 |
| 1892. | | | | | | |
| January | 363,240 | 41,286 | 103,453 | 6,361,118 | 5.57 | 4.83 |
| February | 69,755 | 33,733 | 46,755 | 2,689,348 | 2.43 | 2.25 |
| March | 64,526 | 31,680 | 45,769 | 2,814,244 | 2.47 | 2.14 |
| April | 299,160 | 40,705 | 101,287 | 6,026,982 | 5.27 | 4.73 |
| May | 53,487 | 31,160 | 39,772 | 2,445,501 | 2.14 | 1.86 |
| June | 56,972 | 28,680 | 43,265 | 2,574,447 | 2.25 | 2.02 |
| July | 71,498 | 26,380 | 44,520 | 2,737,446 | 2.40 | 2.08 |
| August | 31,680 | 21,800 | 25,121 | 1,544,640 | 1.35 | 1.17 |
| September | 29,660 | 17,660 | 21,403 | 1,273,564 | 1.11 | 1.00 |
| October | 19,800 | 17,220 | 17,952 | 1,103,833 | .97 | .84 |
| November | 43,610 | 17,220 | 27,924 | 1,661,590 | 1.45 | 1.30 |
| December | 56,972 | 21,450 | 32,793 | 2,016,376 | 1.76 | 1.53 |
| Per annum | 363,240 | 17,220 | 45,835 | 33,249,089 | 29.17 | 2.15 |
| 1893. | | | | | | |
| January | 44,191 | 22,600 | 26,812 | 1,648,616 | 1.44 | 1.25 |
| February | 283,140 | 38,381 | 105,921 | 5,882,535 | 5.15 | 4.95 |
| March | 72,660 | 33,057 | 50,320 | 3,094,076 | 2.71 | 2.35 |

*Estimated monthly discharge of Tennessee River at Chattanooga, Tennessee*—Continued.

[Drainage area, 21,382 square miles.]

| Month. | Discharge in second-feet. | | | Total for month in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1893. | | | | | | |
| April | 73,241 | 31,160 | 42,137 | 2,507,326 | 2.20 | 1.97 |
| May | 224,400 | 30,150 | 71,525 | 4,397,929 | 3.85 | 3.34 |
| June | 123,207 | 27,760 | 49,679 | 2,956,099 | 2.59 | 2.32 |
| July | 34,895 | 21,450 | 25,741 | 1,582,763 | 1.38 | 1.20 |
| August | 33,152 | 18,410 | 23,477 | 1,443,554 | 1.27 | 1.10 |
| September | 76,727 | 20,750 | 33,933 | 2,019,149 | 1.77 | 1.59 |
| October | 58,716 | 18,660 | 25,550 | 1,571,018 | 1.37 | 1.19 |
| November | 31,160 | 20,400 | 22,263 | 1,324,738 | 1.16 | 1.04 |
| December | 30,640 | 21,100 | 24,970 | 1,535,355 | 1.35 | 1.17 |
| Per annum | 283,140 | 18,410 | 41,861 | 29,963,158 | 26.24 | 1.96 |
| 1894. | | | | | | |
| January | 56,972 | 22,600 | 37,389 | 2,298,975 | 2.02 | 1.75 |
| February | 151,095 | 31,680 | 70,893 | 3,937,185 | 3.45 | 3.31 |
| March | 59,297 | 33,152 | 46,796 | 2,877,392 | 2.53 | 2.19 |
| April | 52,325 | 27,300 | 36,287 | 2,159,222 | 1.90 | 1.70 |
| May | 44,191 | 23,800 | 31,137 | 1,914,552 | 1.68 | 1.46 |
| June | 28,680 | 19,500 | 21,983 | 1,308,076 | 1.15 | 1.03 |
| July | 29,170 | 18,910 | 24,486 | 1,505,595 | 1.31 | 1.14 |
| August | 30,150 | 18,910 | 22,971 | 1,412,441 | 1.23 | 1.07 |
| September | 27,300 | 16,560 | 19,160 | 1,140,097 | 1.00 | .90 |
| October | 20,750 | 16,360 | 17,445 | 1,072,658 | .94 | .82 |
| November | 20,400 | 16,360 | 17,330 | 1,031,204 | .90 | .81 |
| December | 68,012 | 16,780 | 30,862 | 1,897,643 | 1.66 | 1.44 |
| Per annum | 151,095 | 16,360 | 31,395 | 22,555,040 | 19.77 | 1.53 |
| 1895. | | | | | | |
| January | 261,780 | 23,400 | 76,446 | 4,700,512 | 4.12 | 3.57 |
| February | 47,096 | 24,200 | 35,787 | 1,987,503 | 1.74 | 1.67 |
| March | 134,827 | 42,448 | 72,341 | 4,448,103 | 3.90 | 3.38 |
| April | 78,470 | 37,219 | 51,047 | 3,037,501 | 2.67 | 2.39 |
| May | 58,135 | 34,314 | 43,929 | 2,701,106 | 2.37 | 2.05 |
| June | 35,476 | 21,100 | 26,417 | 1,651,917 | 1.37 | 1.23 |
| July | 63,364 | 20,750 | 29,638 | 1,822,381 | 1.60 | 1.39 |
| August | 38,381 | 21,800 | 26,927 | 1,655,687 | 1.45 | 1.26 |
| September | 24,660 | 16,780 | 20,316 | 1,208,883 | 1.05 | .95 |
| October | 17,000 | 16,360 | 16,665 | 1,024,698 | .90 | .78 |
| November | 20,750 | 17,220 | 18,162 | 1,080,714 | .94 | .85 |
| December | 33,152 | 17,660 | 21,561 | 1,325,743 | 1.16 | 1.01 |
| Per annum | 261,780 | 16,360 | 36,603 | 26,564,748 | 23.27 | 1.71 |

MISCELLANEOUS MEASUREMENTS.

*Measurements made by Mr. E. W. Myers.*

| Date. | Stream. | Locality. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| June 27 | Swannanoa. | Biltmore, N. C. | 21 | 2.84 | 57 | 1.30 | 74 |
| July 10 | Valley ..... | Murphy, N. C.. | 2154 | ..... | 292 | 0.46 | 135 |

On October 15, 1896, Prof. B. M. Hall made measurement at Mineral Bluff, Georgia, on the Toccoa River, known as Ocoee River after it crosses the line into the State of Tennessee. The bench mark is on the top of downstream end of second iron floor beam (crossbeam) and is 22.7 feet above water. A measurement was made with meter No. 8, which gave a mean velocity of 0.443 foot per second; the area was 33.2 square feet, and the discharge 148 second-feet.

## UPPER MISSOURI BASIN.

The drainage basin of the Missouri River has been described briefly in the Thirteenth Annual Report, Part III, Irrigation, beginning on page 34. In the early part of the year 1896 the work in this region was under the supervision of Prof. A. M. Ryan, and after his removal from Montana in July, the work was placed in charge of Prof. Frank Beach, of the agricultural experiment station, Bozeman, Montana.

### TOWNSEND STATION ON MISSOURI RIVER.

This locality is described in Bulletin No. 131, page 22, and mentioned in Bulletin No. 140, page 93. The Missouri River Commission has continued observations of river height at this point, and a copy of the record has been obtained from Capt. J. C. Sanford. By adding the constant 3,300 to each gage reading, the actual height of the surface of the water in the river above sea level may be obtained. No discharge measurements were made at this point during 1896. This station is in the Fort Logan quadrangle. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 47.

*List of discharge measurements made on Missouri River at Townsend, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Nov. 18 | A. P. Davis | 24 | 89.00 | 1,546 | 2.44 | 3,766 |
| | 1895. | | | | | | |
| 2 | June 29 | P. Sieh | 20 | 91.05 | 2,290 | 4.67 | 10,699 |
| | 1896. | | | | | | |
| 3 | June 4 | P. Sieh | 20 | 93.55 | 3,798 | 6.43 | 24,448 |
| 4 | July 14 | .....do | 20 | 90.15 | 2,592 | 3.70 | 9,602 |
| 5 | Aug. 25 | H. Shaw | 60 | 88.70 | 1,754 | 1.93 | 3,390 |
| 6 | Sept. 16 | C. C. Babb | 63 | 89.10 | 1,596 | 1.90 | 3,031 |

## GALLATIN RIVER.

The Gallatin River rises in the high mountains in the northwestern corner of the Yellowstone National Park and in the range north of this. The course of the river is in general northerly for a distance of about 50 miles through narrow valleys and canyons, finally entering the Gallatin Valley, one of the finest agricultural areas in the Northwest. An extended description of this stream, its basin, and its tributaries is given in the Thirteenth Annual Report, Geological Survey, Part III, Irrigation, beginning on page 41.

### SALESVILLE STATION ON WEST GALLATIN RIVER.

This station is described in Bulletin No. 140, page 86. It is about 16 miles southwest of Bozeman and near the highway bridge crossing the stream about 5 miles south of Salesville, Montana, in the Three Forks quadrangle, latitude 45° 30′, longitude 111° 16′. A gage rod was erected in July, 1895, and observations were begun on August 1 by Ira T. Williams, a ranchman living about 600 feet away. The gage is spiked to a tree, and is not liable to be washed out. The bench mark consists of a 6-inch spike driven in the top of a stump 5 feet north of the gage post. It is 6.71 feet above the zero of the gage as lowered 5 feet from the original position. A second bench mark consists of a 6-inch spike driven into the east bridge abutment. This is 3.26 feet above the zero of the gage. On September 13, 1896, a wire gage was placed on the bridge and nailed to upper side. The pulley was fastened to the end of the rod opposite the 0.15 foot mark. The distance of the end of the weight to the index marker is 15.50 feet. The two gages were made to read the same. The record of daily gage heights for 1896 from January 1 to March 7 and from April 10 to November 30 is given in Water-Supply and Irrigation Paper No. 11, page 47.

*List of discharge measurements made on West Gallatin River, near Salesville, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 22 | A. M. Ryon | 60 | 3.40 | 256 | 4.50 | 1,153 |
| 2 | Nov. 29 | do | 60 | 3.05 | 171 | 2.33 | 398 |
| | 1896. | | | | | | |
| 3 | May 31 | A. M. Ryon | 60 | 4.90 | 376 | 6.50 | 2,479 |
| 4 | June 13 | P. Sieh | 60 | 6.85 | 699 | 11.28 | 7,889 |
| 5 | July 3 | do | 60 | 5.18 | 495 | 7.46 | 3,693 |
| 6 | July 10 | do | 60 | 4.70 | 398 | 6.04 | 2,403 |
| 7 | July 20 | do | 60 | 4.10 | 311 | 4.42 | 1,377 |
| 8 | July 30 | do | 60 | 3.95 | 304 | 4.28 | 1,301 |
| 9 | Aug. 8 | do | 60 | 3.73 | 259 | 3.45 | 892 |
| 10 | Aug. 20 | do | 60 | 3.45 | 256 | 2.71 | 695 |
| 11 | Aug. 28 | Frank Beach | 60 | 3.30 | 260 | 2.88 | 749 |
| 12 | Sept. 13 | C. C. Babb | 63 | 3.40 | 220 | 2.46 | 543 |
| 13 | Oct. 7 | Frank Beach | 60 | 3.30 | 242 | 2.23 | 538 |

*Rating table for West Gallatin River at Salesville, Montana, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.10 | 360 | 4.40 | 1,810 | 5.70 | 5,220 | 7.00 | 8,375 |
| 3.20 | 450 | 4.50 | 1,970 | 5.80 | 5,465 | 7.10 | 8,615 |
| 3.30 | 560 | 4.60 | 2,160 | 5.90 | 5,715 | 7.20 | 8,860 |
| 3.40 | 645 | 4.70 | 2,345 | 6.00 | 5,960 | 7.30 | 9,100 |
| 3.50 | 740 | 4.80 | 2,590 | 6.10 | 6,200 | 7.40 | 9,540 |
| 3.60 | 835 | 4.90 | 3,040 | 6.20 | 6,440 | 7.50 | 9,785 |
| 3.70 | 925 | 5.00 | 3,430 | 6.30 | 6,680 | 7.60 | 10,025 |
| 3.80 | 1,020 | 5.10 | 3,720 | 6.40 | 6,920 | 7.70 | 10,265 |
| 3.90 | 1,125 | 5.20 | 3,970 | 6.50 | 7,165 | 7.80 | 10,510 |
| 4.00 | 1,230 | 5.30 | 4,230 | 6.60 | 7,405 | 7.90 | 10,750 |
| 4.10 | 1,350 | 5.40 | 4,470 | 6.70 | 7,645 | 8.00 | 10,870 |
| 4.20 | 1,500 | 5.50 | 4,730 | 6.80 | 7,900 | | |
| 4.30 | 1,665 | 5.60 | 4,980 | 6.90 | 8,145 | | |

*Estimated monthly discharge of West Gallatin River near Salesville, Montana.*

[Drainage area, 860 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 360 | 210 | 250 | 15,372 | 0.33 | 0.29 |
| February | 360 | 100 | 250 | 14,380 | 0.31 | 0.29 |
| March | ..... | ..... | *a* 250 | 15,372 | 0.33 | 0.29 |
| April | 560 | 210 | 313 | 18,625 | 0.40 | 0.36 |
| May | 3,040 | 450 | 950 | 58,414 | 1.16 | 1.01 |
| June | 10,750 | 3,040 | 7,011 | 417,184 | 9.06 | 8.15 |
| July | 4,855 | 835 | 2,168 | 133,305 | 2.91 | 2.52 |
| August | 1,020 | 560 | 755 | 56,423 | 1.01 | 0.88 |
| September | 692 | 560 | 624 | 37,130 | 0.81 | 0.73 |
| October | 645 | 360 | 527 | 32,403 | 0.70 | 0.61 |
| November | 450 | 100 | 336 | 19,993 | 0.44 | 0.39 |
| December | ..... | ..... | *a* 150 | 9,223 | 0.20 | 0.17 |
| Per annum | 10,750 | 100 | 1,132 | 817,824 | 17.66 | 1.31 |

*a* Estimated.

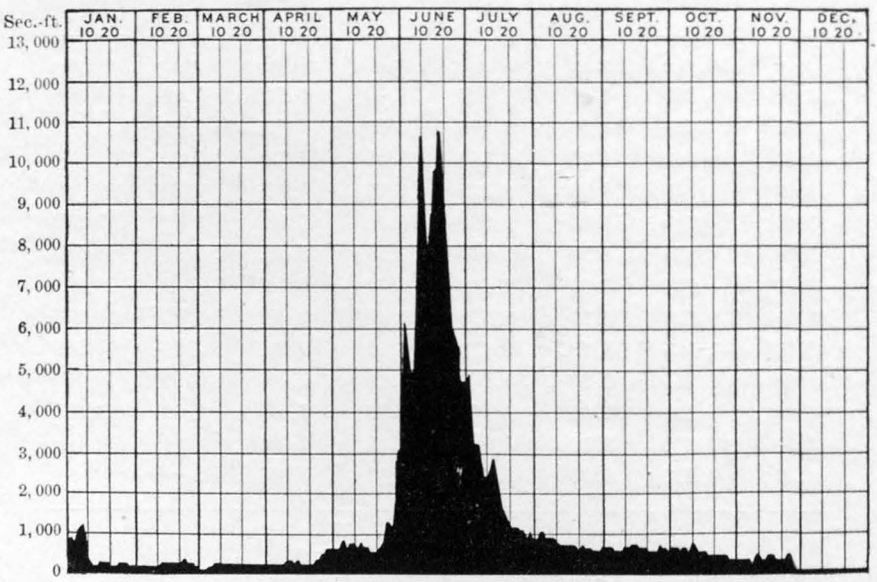



FIG. 15.—Discharge of West Gallatin River near Salesville, Montana, 1896.

## BOZEMAN STATION ON MIDDLE CREEK.

This station was described in Bulletin No. 140, page 88. It is located in Middle Creek Canyon, 9 miles from Bozeman and one-eighth of a mile above the old sawmill dam on the road from Bozeman, in the Three Forks quadrangle, latitude 45° 34′, longitude 111° 2′. The drainage area is 55 square miles, and is mapped on the Three Forks and Livingston sheets. The gage is about half a mile upstream from the point of discharge measurement. The observer is H. S. McElroy, a ranchman, living about 2 miles away. He notes the height of water only once a week. A small footbridge has been placed across the stream for convenience of making discharge measurements. The gage consists of a vertical post, 4 inches square, secured to a tree stump and protected by the latter from the full force of the current. The bench mark consists of a spike driven horizontally into a stump 5 feet high, about 80 feet east of the gage rod. The middle of this spike is at an elevation of 7.03 feet of the gage. Another bench mark consists of an 8-inch bridge spike driven horizontally into a charred stump about 25 feet northeast of the gage. The top of the spike is at an elevation of 3.58 feet. The record of daily gage heights for 1896, from April 4 to October 17, is given in Water-Supply and Irrigation Paper No. 11, page 48.

*List of discharge measurements made on Middle Creek near Bozeman, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 3 | A. M. Ryon | 60 | 0.45 | 36 | 2.32 | 84 |
| 2 | Sept. 8 | do | 60 | 0.22 | 32 | 1.53 | 49 |
| 3 | Oct. 6 | do | 60 | 0.28 | 36 | 1.40 | 53 |
| | 1896. | | | | | | |
| 4 | Apr. 4 | A. M. Ryon | 60 | 0.10 | 27 | 1.05 | 29 |
| 5 | May 30 | do | 60 | 1.80 | 61 | 4.00 | 245 |
| 6 | June 12 | P. Sieh | 60 | 1.20 | 71 | 6.10 | 433 |
| 7 | July 1 | do | 60 | 1.00 | 56 | 4.19 | 233 |
| 8 | July 11 | do | 60 | 0.83 | 49 | 3.41 | 168 |
| 9 | July 21 | do | 60 | 0.55 | 44 | 2.11 | 93 |
| 10 | July 27 | do | 60 | 0.45 | 42 | 1.90 | 80 |
| 11 | Aug. 5 | do | 60 | 0.38 | 40 | 1.25 | 50 |
| 12 | Aug. 21 | do | 60 | 0.28 | 34 | 1.30 | 45 |
| 13 | Sept. 14 | C. C. Babb | 63 | 0.27 | 30 | 1.43 | 43 |
| 14 | Oct. 17 | Frank Beach | 60 | 0.21 | 36 | 1.30 | 45 |

*Rating table for Middle Creek near Bozeman, Montana.*

[This table is applicable from January 1, 1896, to January 1, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.10 | 28.7 | 0.50 | 82 | 1.00 | 233 |
| 0.20 | 37 | 0.60 | 103 | 1.10 | 300 |
| 0.25 | 42 | 0.70 | 129 | 1.20 | 433 |
| 0.30 | 47 | 0.80 | 159 | 1.30 | 610 |
| 0.40 | 68 | 0.90 | 193 | | |

*Estimated monthly discharge of Middle Creek River, near Bozeman, Montana.*

[Drainage area, 55 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April | 37 | 29 | 33 | 1,964 | 0.68 | 0.61 |
| May | 203 | 42 | 96 | 5,903 | 2.01 | 1.74 |
| June | 610 | 193 | 381 | 22,672 | 7.72 | 6.92 |
| July | 267 | 71 | 164 | 10,084 | 3.44 | 2.98 |
| August | 52 | 39 | 44 | 2,705 | 0.92 | 0.80 |
| September | 44 | 37 | 40 | 2,380 | 0.80 | 0.72 |
| October | 38 | 38 | 38 | 2,337 | 0.79 | 0.69 |

## LOGAN STATION ON GALLATIN RIVER.

This station has been described in Bulletin No. 131, page 16, and in Bulletin No. 140, page 89. It is in the Three Forks quadrangle, in latitude 45° 54′ longitude 111° 26′. The drainage area is 1,620 square miles, and is mapped on the Three Forks, Livingston, and Gallatin atlas sheets.

The old gage was under the northeast corner of the railroad bridge of the main line of the Northern Pacific Railroad crossing the Gallatin River. A cable was placed by Mr. A. P. Davis across the stream, about 300 feet above the railroad bridge. The lower portion of the gage is inclined, and is graduated from 0.6 to 7.1 feet. The vertical portion from 7 to 12.3 feet is spiked to piles. The bench mark consists of the head of a bridge spike driven vertically into the top of the pile stump, to which the lower end of the inclined gage is fastened. This is 0.38 foot below the 2-foot mark on the gage. A second bench mark is the head of a bridge spike driven horizontally into the north end of the pier. It is 7.32 feet above the 2-foot mark. On September 16, 1896, a

wire gage was placed in the east span and fastened to the guard rail on the upper side. Both gages were made to read the same on that date. The distance from the outside edge of the pulley to the end of the rod was 1 foot; from the end of the weight to the index marker 18.40 feet. The record of daily gage heights for 1896 from January 1 to February 29 and from April 9 to December 26 is given in Water-Supply and Irrigation Paper No. 11, page 48.

*List of discharge measurements made on Gallatin River at Logan, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Nov. 17 | A. P. Davis | 24 | 1.11 | ..... | 1.82 | 772 |
| | 1895. | | | | | | |
| 2 | Apr. 28 | A. M. Ryon | 20 | 2.00 | 533 | 2.74 | 1,461 |
| 3 | May 11 | P. Sieh | 20 | 2.60 | 630 | 3.37 | 2,113 |
| 4 | June 26 | .....do | 20 | 3.45 | 790 | 4.17 | 3,289 |
| 5 | July 29 | A. M. Ryon | 20 | 0.80 | 346 | 1.37 | 477 |
| 6 | Sept. 28 | P. Sieh | 20 | 1.20 | 404 | 1.83 | 741 |
| | 1896. | | | | | | |
| 7 | May 13 | P. Sieh | 20 | 1.45 | 434 | 2.22 | 963 |
| 8 | Jan. 7 | .....do | 20 | 3.80 | 894 | 4.32 | 3,862 |
| 9 | July 7 | .....do | 20 | 2.05 | 556 | 2.97 | 1,655 |
| 10 | July 25 | .....do | 20 | 1.10 | 424 | 1.80 | 767 |
| 11 | Sept. 10 | Frank Beach | 60 | 1.00 | 435 | 1.77 | 770 |
| 12 | Sept. 19 | C. C. Babb | 63 | 1.00 | 392 | 1.55 | 609 |
| 13 | Oct. 12 | Frank Beach | 60 | 1.00 | ..... | ..... | 689 |

*Rating table for Gallatin River at Logan, Montana, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.60 | 485 | 1.90 | 1,400 | 3.20 | 3,050 | 4.50 | 4,900 |
| 0.70 | 530 | 2.00 | 1,523 | 3.30 | 3,180 | 4.60 | 5,050 |
| 0.80 | 575 | 2.10 | 1,648 | 3.40 | 3,310 | 4.70 | 5,200 |
| 0.90 | 630 | 2.20 | 1,775 | 3.50 | 3,440 | 4.80 | 5,350 |
| 1.00 | 680 | 2.30 | 1,902 | 3.60 | 3,580 | 4.90 | 5,500 |
| 1.10 | 730 | 2.40 | 2,029 | 3.70 | 3,720 | 5.00 | 5,650 |
| 1.20 | 800 | 2.50 | 2,151 | 3.80 | 3,860 | 5.10 | 5,800 |
| 1.30 | 870 | 2.60 | 2,284 | 3.90 | 4,000 | 5.20 | 5,950 |
| 1.40 | 940 | 2.70 | 2,411 | 4.00 | 4,150 | 5.30 | 6,100 |
| 1.50 | 1,020 | 2.80 | 2,539 | 4.10 | 4,300 | 5.40 | 6,250 |
| 1.60 | 1,100 | 2.90 | 2,666 | 4.20 | 4,450 | 5.50 | 6,400 |
| 1.70 | 1,190 | 3.00 | 2,793 | 4.30 | 4,600 | 5.60 | 6,550 |
| 1.80 | 1,290 | 3.10 | 2,920 | 4.40 | 4,750 | | |

*Estimated monthly discharge of Gallatin River at Logan, Montana.*

[Drainage area, 1,620 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | ..... | ..... | *a* 680 | 41,812 | 0.48 | 0.42 |
| February | 730 | 630 | 662 | 38,079 | 0.44 | 0.41 |
| March | ..... | ..... | *a* 700 | 43,041 | 0.49 | 0.43 |
| April | 800 | 680 | 712 | 42,379 | 0.49 | 0.44 |
| May | 2,411 | 800 | 1,098 | 67,514 | 0.77 | 0.67 |
| June | 6,550 | 2,793 | 4,500 | 267,769 | 3.11 | 2.79 |
| July | 2,539 | 730 | 1,220 | 75,015 | 0.86 | 0.75 |
| August | 800 | 680 | 697 | 42,857 | 0.49 | 0.43 |
| September | 730 | 630 | 682 | 40,582 | 0.47 | 0.42 |
| October | 730 | 655 | 680 | 41,812 | 0.48 | 0.42 |
| November | 680 | 680 | 680 | 40,463 | 0.47 | 0.42 |
| December | 730 | 680 | 705 | 43,349 | 0.51 | 0.44 |
| Per annum | 6,550 | 630 | 1,085 | 784,672 | 9.06 | 0.67 |

*a* Estimated.

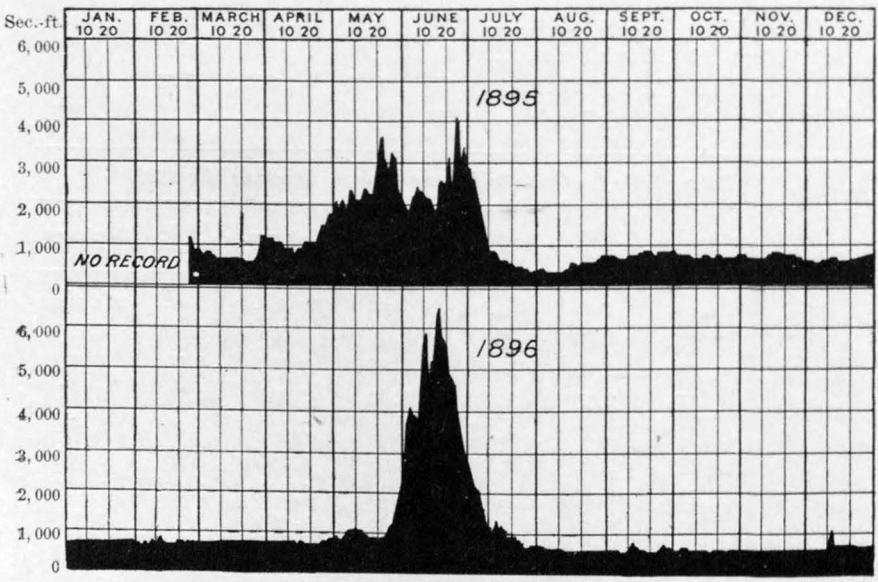



FIG. 16.—Discharge of Gallatin River at Logan, Montana, 1895–96.

*List of discharge measurements made in Montana on East Gallatin River and tributaries by H. Shaw.*

| Date. | Stream. | Meter number. | Area of section (square feet). | Mean velocity (feet, per second). | Discharge (second-feet). |
|---|---|---|---|---|---|
| Sept. 2 | East Gallatin | 60 | 10.9 | 3.03 | 33.1 |
| Sept. 3 | Rus Creek | 60 | 14.87 | 0.73 | 10.9 |
| Sept. 3 | Spring Creek | 60 | | | 3.0 |
| Sept. 3 | Ross Creek | 60 | 12.27 | 1.23 | 15.1 |
| Sept. 3 | Swamp Creek | 60 | 25.22 | 0.63 | 15.8 |
| Sept. 4 | East Gallatin | 60 | 119.3 | 1.55 | 184.4 |
| Sept. 4 | Post-Office Creek | 60 | 18.14 | 0.64 | 11.5 |
| Sept. 4 | Bull Run | 60 | 2.98 | 1.20 | 3.54 |
| Sept. 5 | South Creek | 60 | 14.34 | 0.40 | 5.84 |
| Sept. 5 | South Creek No. 2 | 60 | 4.80 | 0.51 | 2.45 |
| Sept. 5 | East Gallatin | 60 | 96.84 | 2.06 | 200 |
| Sept. 5 | Dry Creek | 60 | 4.82 | 1.70 | 8.2 |
| Sept. 5 | Nelson's Ditch | | | | 2.0 |
| Sept. 5 | Ditch No. 1 | | | | 0.66 |
| Sept. 5 | Ditch No. 2 | | | | 1.50 |
| Sept. 5 | Ditch No. 3 | | | | 1 |

## MADISON RIVER.

The Madison River rises in the Yellowstone National Park, southeast of the source of the West Gallatin. Its course is in general westerly and northwesterly for about 40 miles. It then turns toward the north and soon enters Madison Valley, a long narrow opening, bounded at both ends by canyons through which the river flows. An extended description of this river and its basin is given in the Thirteenth Annual Report, Geological Survey, Part III, Irrigation, beginning on page 46.

### THREE FORKS STATION ON MADISON RIVER.

A description of this station was given in Bulletin No. 131, page 20, and in Bulletin No. 140, page 91. It is in the Three Forks quadrangle, in latitude 45° 55′, longitude 111° 31′. The gage is at the bridge of the Northern Pacific Railroad Company, one-half mile from the town of Threeforks. The greater part of the discharge of the river flows under this bridge, but there are a number of small side channels, branching off at points above, through which some water flows, especially in time of flood. The gage is inclined, the zero being 14.11 feet below the top of the rail on the east end of the bridge. The record of daily gage heights for 1896, from January 1 to February 29 and from April 8 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 49.

*List of discharge measurements made on Madison River at Three Forks, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 1 | Aug. 24 | F. H. Newell..... | 24 | 0.30 | 582 | 2.15 | 1,251 |
| | 1894. | | | | | | |
| 2 | Nov. 4 | A. P. Davis ..... | 24 | 0.57 | 751 | 1.99 | 1,494 |
| | 1895. | | | | | | |
| 3 | May 12 | P. Sieh..... | 20 | 0.80 | 964 | 3.28 | 3,114 |
| 4 | June 27 | .....do ..... | 20 | 1.00 | 941 | 3.49 | 3,287 |
| 5 | July 30 | A. M. Ryon ..... | 20 | 0.10 | 780 | 2.18 | 1,693 |
| 6 | July 30 | P. Sieh..... | 20 | 0.10 | 780 | 2.18 | 1,695 |
| 7 | Sept. 29 | .....do ..... | 20 | —0.10 | 723 | 1.99 | 1,440 |
| | 1896. | | | | | | |
| 8 | May 12 | P. Sieh..... | 20 | 0.40 | 778 | 2.58 | 1,914 |
| 9 | July 8 | .....do ..... | 20 | 1.55 | 956 | 3.35 | 3,207 |
| 10 | July 16 | .....do ..... | 20 | 1.30 | 800 | 3.19 | 2,552 |
| 11 | July 24 | .....do ..... | 20 | 0.83 | 794 | 2.63 | 2,041 |
| 12 | Sept. 10 | Frank Beach..... | 60 | ..... | 618 | 2.66 | 1,642 |
| 13 | Sept. 19 | C. C. Babb..... | 63 | 0.48 | 642 | 2.09 | 1,343 |
| 14 | Oct. 12 | Frank Beach ..... | 60 | 0.45 | 720 | 1.84 | 1,425 |

*Rating table for Madison River at Three Forks, Montana.*

[This table is applicable from January 1, 1896, to May 31, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Foot.* | *Sec. feet.* | *Foot.* | *Sec. feet.* | *Foot.* | *Sec. feet.* | *Foot.* | *Sec. feet.* |
| 0.00 | 1,560 | 0.30 | 1,980 | 0.60 | 2,490 | 0.90 | 3,080 |
| 0.10 | 1,690 | 0.40 | 2,140 | 0.70 | 2,680 | 1.00 | 3,280 |
| 0.20 | 1,830 | 0.50 | 2,310 | 0.80 | 2,880 | | |

*Rating table for Madison River at Three Forks, Montana.*

[This table is applicable from June 1, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 1,055 | 0.90 | 1,945 | 1.80 | 3,960 | 2.70 | 6,570 |
| 0.10 | 1,130 | 1.00 | 2,085 | 1.90 | 4,250 | 2.80 | 6,860 |
| 0.20 | 1,210 | 1.10 | 2,255 | 2.00 | 4,540 | 2.90 | 7,150 |
| 0.30 | 1,295 | 1.20 | 2,430 | 2.10 | 4,830 | 3.00 | 7,440 |
| 0.40 | 1,385 | 1.30 | 2,620 | 2.20 | 5,120 | 3.10 | 7,730 |
| 0.50 | 1,475 | 1.40 | 2,830 | 2.30 | 5,410 | 3.20 | 8,020 |
| 0.60 | 1,575 | 1.50 | 3,090 | 2.40 | 5,700 | | |
| 0.70 | 1,690 | 1.60 | 3,375 | 2.50 | 5,990 | | |
| 0.80 | 1,815 | 1.70 | 3,675 | 2.60 | 6,280 | | |

*Estimated monthly discharge of Madison River at Three Forks, Montana.*

[Drainage area, 2,420 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | ..... | ..... | *a* 1,500 | 92,231 | 0.71 | 0.62 |
| February | ..... | ..... | *a* 1,500 | 86,281 | 0.67 | 0.62 |
| March | ..... | ..... | *a* 1,600 | 98,380 | 0.76 | 0.66 |
| April | 1,980 | 1,690 | 1,818 | 108,178 | 0.83 | 0.75 |
| May | 3,680 | 1,830 | 2,222 | 136,626 | 1.06 | 0.92 |
| June | 8,175 | 4,425 | 6,363 | 378,624 | 2.93 | 2.63 |
| July | 4,725 | 1,690 | 2,723 | 167,431 | 1.29 | 1.12 |
| August | 1,815 | 1,385 | 1,513 | 93,031 | 0.71 | 0.62 |
| September | 1,525 | 1,427 | 1,469 | 87,412 | 0.68 | 0.61 |
| October | 1,475 | 1,385 | 1,432 | 88,051 | 0.68 | 0.59 |
| November | ..... | ..... | *a* 1,400 | 83,306 | 0.64 | 0.58 |
| December | ..... | ..... | *a* 1,400 | 86,083 | 0.67 | 0.58 |
| Per annum | 8,175 | 1,385 | 2,078 | 1,505,634 | 11.63 | 0.86 |

*a* Estimated.

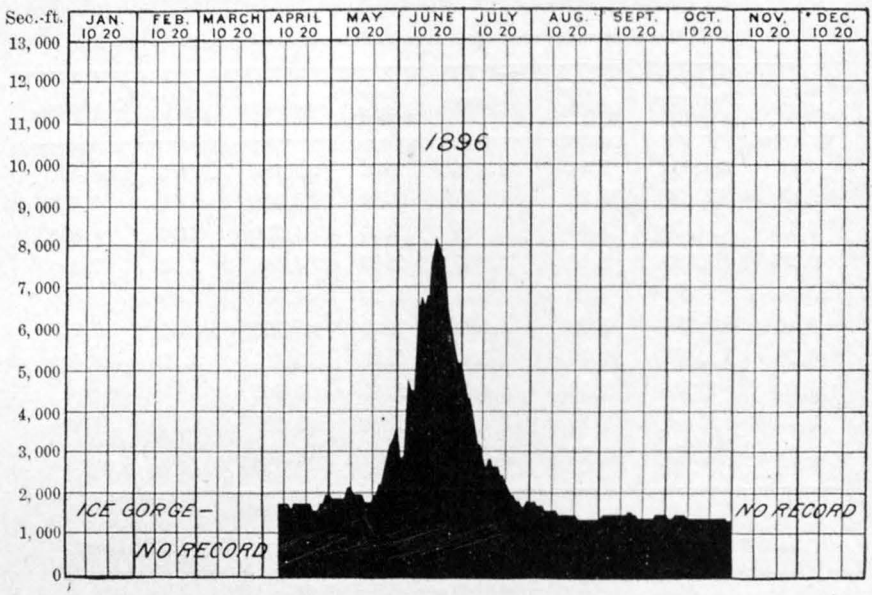



FIG. 17.—Discharge of Madison River at Three Forks, Montana, 1896.

## JEFFERSON RIVER.

The drainage basin of Jefferson River lies west of that of the Madison and includes the area bounded on the south and west by the great bend in the Continental Divide. The main stream is formed by the union of Big Hole River coming from the West and the Beaverhead from the south. From this point the river flows in a general northeasterly course for a distance of 60 miles to its junction with the Madison and Gallatin, forming the Missouri River. Of these three streams the Jefferson has by far the largest drainage area and run-off. An extended description of this stream and its basin is given in the Thirteenth Annual Report, Geological Survey, Part III, Irrigation, beginning on page 49.

### SAPPINGTON STATION ON JEFFERSON RIVER.

This station is described in Bulletin No. 131, page 22, and in Bulletin No. 140, page 92. The old gage was vertical and fastened to the crib work forming the middle pier of the Northern Pacific Railroad bridge, one-fourth of a mile north of Sappington Station. One bench mark consists of a 6-inch wire nail driven horizontally in the east side of the blocking which forms the south abutment of the railroad bridge. It is level with the 6.9-foot mark of the gage. The second bench mark is a 6-inch wire nail driven horizontally into a telegraph pole about 30 feet south and east of the south abutment of the bridge. This nail is at the elevation of the 7-foot mark.

During the spring floods the cable, located about 600 feet above the bridge, and from which discharge measurements were made, was car-

ried away. It was replaced on September 17. On the same date a wire gage was placed on the east span of the bridge. It is fastened to the guard rail on the upper side. The outside edge of the pulley is 1 foot from the end of the rod. The distance from the end of the weight to the index marker is 16 feet. Sappington Station is in the Three Forks quadrangle, in latitude 45° 48′, and longitude 111° 48′. The drainage area is 8,984 square miles, and is partly mapped on the Three Forks, Dillon, Helena, and Fort Logan atlas sheets. The record of daily gage heights for 1896, from January 1 to 25, and from September 10 to December 24, is given in Water-Supply and Irrigation Paper No. 11, page 49.

*List of discharge measurements made on Jefferson River at Sappington, Montana.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 1 | Aug. 24 | F. H. Newell..... | 24 | ..... | 442 | 1.83 | 808 |
| | 1894. | | | | | | |
| 2 | Nov. 14 | A. P. Davis..... | 24 | 1.08 | 732 | 2.67 | 1,952 |
| | 1895. | | | | | | |
| 3 | July 31 | P. Sieh..... | 20 | 0.80 | 558 | 2.02 | 1,028 |
| 4 | Nov. 30 | .....do..... | 20 | 0.95 | 602 | 1.99 | 1,200 |
| | 1896. | | | | | | |
| 5 | May 10 | P. Sieh..... | 20 | 2.15 | 956 | 3.61 | 3,454 |
| 6 | July 31 | .....do..... | 20 | 0.80 | 558 | 2.02 | 1,028 |
| 7 | Sept. 18 | C. C. Babb..... | 63 | 0.94 | 589 | 2.08 | 1,229 |
| 8 | Oct. 24 | Frank Beach..... | 60 | 0.88 | 625 | 2.09 | 1,309 |

*Rating table for Jefferson River at Sappington, Montana, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 1,155 | 1.10 | 1,555 | 1.50 | 2,080 | 1.90 | 2,800 |
| 0.80 | 1,245 | 1.20 | 1,675 | 1.60 | 2,240 | 2.00 | 3,050 |
| 0.90 | 1,335 | 1.30 | 1,800 | 1.70 | 2,410 | 2.10 | 3,300 |
| 1.00 | 1,435 | 1.40 | 1,935 | 1.80 | 2,600 | 2.20 | 3,560 |

*Estimated monthly discharge of Jefferson River at Sappington, Montana.*

[Drainage area, 8,984 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| September | 1,480 | 1,227 | 1,342 | 79,854 | 0.17 | 0.15 |
| October | 1,375 | 1,299 | 1,327 | 81,594 | 0.17 | 0.15 |
| November | 1,675 | 1,254 | 1,499 | 89,200 | 0.19 | 0.17 |
| December | ..... | ..... | 1,650 | 101,454 | 0.21 | 0.18 |

## YELLOWSTONE RIVER.

This basin is described in the Thirteenth Annual Report of this Survey, Part III, Irrigation, page 63. No measurements have recently been made on the Yellowstone proper, but observations have been maintained on Goose Creek and Clear Creek, tributaries of the Yellowstone, in the State of Wyoming.

### SHERIDAN STATION ON LITTLE GOOSE CREEK.

This station is located at Broadway bridge in the town of Sheridan, Wyoming, and about 1,000 feet above the mouth of the creek. The gage rod is firmly fastened to the piles of the bridge. The channel is shifting, being composed of clay and gravel. The observer is Mr. Felix O'Connor. The record of daily gage heights for 1896 from May 1 to July 31 is given in Water-Supply and Irrigation Paper No. 11, page 49.

*Rating table for Little Goose Creek at Sheridan, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.7 | 0.0 | 1.2 | 16.0 | 1.7 | 47.0 | 2.2 | 94.0 |
| 0.8 | 2.5 | 1.3 | 20.0 | 1.8 | 54.0 | 2.3 | 105.0 |
| 0.9 | 4.0 | 1.4 | 26.0 | 1.9 | 62.0 | 2.4 | 116.0 |
| 1.0 | 7.5 | 1.5 | 33.0 | 2.0 | 72.0 | 2.5 | 130.0 |
| 1.1 | 12.0 | 1.6 | 40.0 | 2.1 | 83.0 | 2.6 | 144.0 |

*Estimated monthly discharge of Little Goose Creek at Sheridan, Wyoming.*

[Drainage area, 128 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| May | 130 | 20 | 58 | 3,566 | 0.52 | 0.45 |
| June | 130 | 0 | 33 | 1,964 | 0.29 | 0.26 |
| July | 4 | 0 | 2 | 123 | 0.02 | 0.02 |

## SHERIDAN STATION ON BIG GOOSE CREEK.

This station is described in Bulletin No. 140, page 94. It is located in the northern part of Sheridan, Wyoming, at the Fifth avenue bridge crossing. The rod is securely fastened to the bridge piles and protected from injury by driftwood and ice. The channel is shifting, composed of clay and gravel. The station is below the mouth of Little Goose Creek. The observer is Mr. Felix O'Connor. The record of daily gage heights for 1896 from April 10 to September 30 is given in Water-Supply and Irrigation Paper No. 11, page 50.

*Rating table for Big Goose Creek, at Sheridan, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0 5 | 0 | 1.7 | 27 | 2.9 | 127 | 4.1 | 357 |
| 0.6 | 2 | 1.8 | 31 | 3.0 | 137 | 4.2 | 382 |
| 0.7 | 3 | 1.9 | 36 | 3.1 | 154 | 4.3 | 403 |
| 0.8 | 4 | 2 0 | 40 | 3.2 | 172 | 4.4 | 430 |
| 0.9 | 6 | 2.1 | 45 | 3.3 | 186 | 4.5 | 455 |
| 1.0 | 8 | 2.2 | 50 | 3.4 | 205 | 4.6 | 480 |
| 1.1 | 9 | 2.3 | 60 | 3.5 | 225 | 4.7 | 510 |
| 1.2 | 11 | 2.4 | 67 | 3.6 | 245 | 4.8 | 526 |
| 1.3 | 14 | 2.5 | 75 | 3.7 | 267 | 4.9 | 565 |
| 1.4 | 17 | 2.6 | 86 | 3.8 | 286 | 5.0 | 595 |
| 1.5 | 20 | 2.7 | 95 | 3.9 | 307 | 5.1 | 630 |
| 1.6 | 24 | 2.8 | 105 | 4.0 | 330 | 5.2 | 680 |

*Estimated monthly discharge of Big Goose Creek at Sheridan, Wyoming.*

[Drainage area, 320 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 10 to 30 | 132 | 71 | 89 | 3,717 | 0.21 | 0.28 |
| May | 526 | 40 | 187 | 11,498 | 0.67 | 0.58 |
| June | 630 | 43 | 241 | 14,340 | 0.83 | 0.75 |
| July | 100 | 40 | 60 | 3,689 | 0.22 | 0.19 |
| August | 55 | 27 | 39 | 2,398 | 0.14 | 0.12 |
| September | 31 | 14 | 21 | 1,250 | 0.08 | 0.07 |

BUFFALO STATION ON CLEAR CREEK.

Clear Creek, with its tributaries, irrigates more land than any other stream rising in the Big Horn Mountains. The volume of its water supply is, therefore, a matter of considerable importance, and it was the first stream in northern Wyoming to be measured by the irrigation authorities of the State. The gaging station is located about 4 miles west of the city of Buffalo, the county seat of Johnson County, on what was formerly the Fort McKinney Military Reservation. The observer is Mr. Fred Bond. Clear Creek, like all the other streams of the Big Horn Mountains, receives several important tributaries below where irrigation begins. It is thus impossible to establish a station which will give the entire water supply of this drainage system. Piney Creek, the most important tributary, does not join the main stream until near the lower end of the irrigated district, and as irrigation begins at the edge of the foothills and the diversion of water at near the source of each of these streams, any station which might be established would give a very incomplete record of the total water supply.

The station established is at an elevation of between 5,500 and 6,000 feet above sea level and above all the ditches which distribute water directly to irrigators from the main stream, but below two ditches which divert water from Clear Creek across a low divide into French Creek, one of its tributaries. Measurements were begun in 1889, in which year a substantial measuring flume was placed in the channel of the stream. This flume is 24 feet long, 30 feet wide, with sides 7 feet high, and with wings at the sides and a pitched apron at the upper end 12 feet long. The floor is set level in all directions, the upstream edge being even with the grade of the creek channel, and the lower 3 or 4 inches above. It cost $300, and although subjected to rough usage through the practice of floating cordwood and timber down the stream, it is still uninjured, and permits of more accurate measurements than can be obtained at any other gaging station in the State.

These measurements have their origin in a controversy over water rights, which the shortage of 1889 made acute and which could only be adjusted by a series of measurements which would show the actual volume of the stream's flow. The flume was built to secure these measurements and was paid for at first by the city of Buffalo and the county of Johnson, each contributing one-half of the expense; but in 1890 the legislature reimbursed these parties for their outlay and the station became the property of the State. In one respect it is an inconvenient point for observations, as the nearest observer lives nearly 4 miles away. This makes daily observations out of the question, and for the past two seasons a Carpenter water register, which keeps an automatic record and requires attention only once a week, has been used with fairly satisfactory results.

The water-right controversy which led to the establishment of this station grew out of the diversion of water from Clear Creek into French Creek by two ditches which head in the northern branch of Clear Creek at an elevation of about 9,000 feet, or near timber line. None of the water thus diverted returns to the stream until the mouth of French Creek is reached, a distance of about 18 miles from the place where turned out. In this distance there are eight important ditches watering several thousand acres of land, the city of Buffalo, and, before its abandonment, Fort McKinney. In 1889 so much water was turned out of the stream that Clear Creek practically ran dry before reaching the city of Buffalo. As there had been no adjudication of rights there was no means of enforcing priorities, and as the claims of the parties owning these ditches aggregated 336 cubic feet per second, or nearly three times the mean discharge of the stream during the irrigating season, the parties thus threatened with the total loss of their water supply felt impelled to secure some legal protection for their rights and as a preliminary step inaugurated the measurements of discharge before referred to.

Since its establishment, the value of this station has largely diminished. Since Wyoming's admission to statehood the rights to water from this stream have been adjudicated and under the more rigorous requirements of the State law the claims of the diverting ditches were largely reduced, one being rejected altogether, so that the amount which can be diverted does not now seriously threaten the rights of those appropriators located along the stream above where the water so diverted begins to return as seepage.

The volume allowed by the adjudication was 517 cubic feet. The mean monthly discharge for the season of 1896 was as follows: May, 139 second-feet; June, 251 second-feet; July, 115 second-feet, and August, 66 second-feet. The basis for the allotments made at the adjudication was 1 second-foot for each 70 acres shown to be irrigated. As there was no scarcity of water during the season just closed it is manifest that this was either an excessive allotment or that the acreage irrigated

at the time of the adjudication was in excess of that watered during this year, probably both causes have operated to produce this result. The record of daily gage heights for 1896, from May 2 to October 19, is given in Water-Supply and Irrigation Paper No. 11, page 50.

*Rating table for Clear Creek near Buffalo, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.05 | 2 | 0.70 | 64 | 1.35 | 266 | 2.00 | 558 |
| 0.10 | 4 | 0.75 | 73 | 1.40 | 286 | 2.05 | 582 |
| 0.15 | 6 | 0.80 | 82 | 1.45 | 303 | 2.10 | 607 |
| 0.20 | 9 | 0.85 | 92 | 1.50 | 323 | 2.15 | 632 |
| 0.25 | 13 | 0.90 | 104 | 1.55 | 344 | 2.20 | 657 |
| 0.30 | 17 | 0.95 | 118 | 1.60 | 365 | 2.25 | 680 |
| 0.35 | 20 | 1.00 | 134 | 1.65 | 385 | 2.30 | 705 |
| 0.40 | 25 | 1.05 | 150 | 1.70 | 406 | 2.35 | 720 |
| 0.45 | 29 | 1.10 | 169 | 1.75 | 426 | 2.40 | 752 |
| 0.50 | 33 | 1.15 | 189 | 1.80 | 447 | 2.45 | 778 |
| 0.55 | 39 | 1.20 | 209 | 1.85 | 475 | 2.50 | 803 |
| 0.60 | 46 | 1.25 | 228 | 1.90 | 504 | | |
| 0.65 | 55 | 1.30 | 246 | 1.95 | 529 | | |

*Estimated monthly discharge of Clear Creek near Buffalo, Wyoming.*

[Drainage area, 118 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| May | 406 | 64 | 139 | 8,547 | 1.36 | 1.18 |
| June | 504 | 82 | 251 | 14,936 | 2.37 | 2.13 |
| July | 323 | 64 | 115 | 7,071 | 1.12 | 0.97 |
| August | 134 | 40 | 66 | 4,058 | 0.64 | 0.56 |
| September | 56 | 40 | 46 | 2,737 | 0.44 | 0.39 |
| October 8 to 19 | 38 | 29 | 32 | 756 | 0.12 | 0.27 |

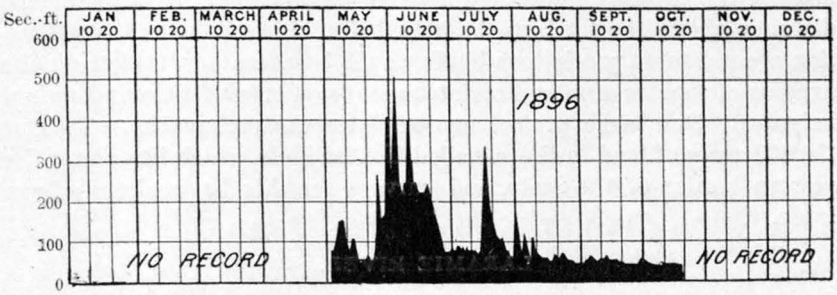



FIG. 18.—Discharge of Clear Creek near Buffalo, Wyoming, 1896.

## PLATTE BASIN.

A general discussion and map of this basin is given in the Thirteenth Annual Report of this Survey, Part III, Irrigation, pages 73 to 91. Reference to it may also be found in Bulletin 140, page 95. The general descriptions given below relating to Wyoming streams are from the manuscript report of Prof. Elwood Mead, State engineer, cooperating with the Division of Hydrography.

### NORTH PLATTE RIVER.

The North Platte River, from its location with reference to transportation facilities, its large drainage area, and the very large amount of contiguous irrigable land, occupies a very important position in the irrigation development of Wyoming. Aside from the area already reclaimed on this stream and its tributaries in the upper Platte Valley south of the Union Pacific Railway, very little use is made of its waters for this purpose and there yet remains a very large amount of excellent land unreclaimed.

The North Platte River, after it crosses the Union Pacific Railway, flows northerly for a distance of about 80 or 90 miles, and at Casper, Wyoming, turns easterly, maintaining this direction until it leaves the State at its eastern boundary. From the railroad to near Casper the course of the stream is through canyons almost all the way, there being little or no irrigable land bordering it or upon which its waters could be diverted. From a few miles above Casper—which is the present terminus of the Fremont, Elkhorn and Missouri Valley Railway—the river enters the so-called lower Platte Valley. The climatic conditions, the favorable altitude, and the transportation facilities along this portion of the river attach a peculiar value to this district and render its future cultivation a certainty. Several causes have hitherto restricted and limited the reclamation of these lands. The valley is comparatively narrow and is bordered by bluffs which abut perpendicularly upon the river at points where it swings in its course from one side of the valley to the other. The fall of the river is slight, and its banks at ordinary height of water are somewhat high. A canal, therefore, to irrigate the

most of the bottom lands would have to be taken out at considerable distance above the lands to be irrigated, and in most cases construction around these precipitous bluffs would be necessary, rendering the expense of construction and maintenance too onerous for the individual irrigator. One large project contemplates the reclamation of about 150,000 acres of land in the so-called Goshen Hole, which lies along the eastern border of the State, and surveys for this have already been made.

## LARAMIE RIVER.

The first gaging station established in Wyoming by the State irrigation department was at Woods Landing, on the Laramie River. This was in the winter of 1888–89, since which time records of discharge have been kept during the irrigation season for six of the eight succeeding years.

The selection of this stream, as the one to be first measured, was due to the complexity and importance of the problems growing out of the use of its waters. In the volume of its flow it is surpassed by a score of other streams in the State, but in the value of its water rights, the acreage of land irrigated, and the cost of its irrigation works, it easily takes first place. In addition, it is an interstate river, rising in Colorado and flowing into Wyoming, and a controversy has arisen over the relative rights of appropriators in the two States, which may give rise to prolonged and expensive litigation.

The Laramie River rises in the Medicine Bow range of mountains, about 25 miles south of the Wyoming boundary and near Chambers Lake, the source of Cache la Poudre River, one of the most important irrigation streams of Colorado. Nearly all the lofty mountains which drain into this river are in Colorado, so that practically the entire water supply for late irrigation comes from that State, the only important tributary in Wyoming, the Little Laramie, being fully appropriated and used by the irrigators along its banks.

For about 20 miles in Colorado the river valley varies from one-half mile to 2 miles in width, and is easily irrigated. After crossing into Wyoming there is a canyon about 8 miles long, below which are the Laramie plains, a plateau which the river enters at its southern and leaves at near its northern boundary, dividing it into two nearly equal parts. It is the largest body of land adapted to irrigation bordering any stream in the State, the irrigable area being from 3 to 20 miles wide, with a total length of about 75 miles. On leaving these plains the river turns to the east and cuts directly through the Laramie Range, formerly known as the Black Hills of Wyoming, in a narrow, precipitous canyon and with a total fall of 2,000 feet in 15 miles. Below this it flows through a narrow valley, nowhere over a mile wide, and bordered by rugged, broken hills which limit irrigation to the bottoms bordering the stream.

The irrigated lands along the stream are separated into three divisions: The valley lands in Colorado, a strip 20 miles long and from one-half to 2 miles in width, with an average elevation of about 8,000 feet, and production limited to native hay; the plateau lands of the Laramie plains, which are largely in excess of the stream's capacity to serve, with an average elevation slightly above 7,000 feet, and with production limited to hay and the hardier grains and vegetables; and the bottoms along the last 50 miles of the stream, with an average width of less than half a mile, an elevation varying between 4,600 and 4,800 feet, and capable of producing nearly all the fruits and vegetables grown in Colorado or Utah.

The ditches which make this stream notable are not those watering the land along its banks, but those which divert its water from the contiguous lands. Of these there are two, and aside from the complications in water rights which they create, they are both important and interesting works. The first of these is in Colorado, and its purpose is to turn the head waters of the Laramie into Cache la Poudre River, for the use of irrigators along that stream. The proximity of their sources makes this possible, but the rugged and precipitous nature of the country has made the work costly and difficult.[1] The head gate is over 9,000 feet above sea level, nearly up to timber line, and the entire five miles of ditch is cut along granite cliffs or through densely wooded stretches of timber. When full it will divert a little over one hundred second-feet, and as none of this returns as seepage for use below, its loss is a serious one to those having prior rights on the stream.

When measured in June last, the entire stream was being turned into this ditch, which was carrying about 70 second-feet. The discharge of the Laramie at Woods Landing the following day was 197 second-feet, so that the appropriators in Wyoming were losing at that date about one-fourth of their supply and about one-half their mean supply for the month of August.

As all the large appropriations in Wyoming are prior to this diversion in point of time, and as the flow of the stream was largely appropriated before any ditches were built in Colorado, the question as to whether prior rights can be enforced across State boundaries becomes a vital one to those on the lower portions of the stream. It takes on added importance in Wyoming because the water supply of the most important ditch project of the State depends on its settlement. This is the canal of the Wyoming Development Company, the second of the ditches which takes water away from the lands bordering the stream. By means of a tunnel 3,800 feet long about 700 second-feet can be turned from the Laramie into Blue Grass Creek, a small tributary of Sybille Creek, which in turn empties into the Laramie about 30 miles below where the water is turned out. South of the Sybille is a mag-

[1] For description see Irrigation near Greeley, Colorado, by David Boyd: Water-Supply and Irrigation Paper No. 9.

nificent plateau of which nearly 60,000 acres can be watered. As the soil is exceedingly fertile, and its elevation less than 5,000 feet, or nearly 1,500 feet below the mean of the southern half of the State, its reclamation is of more than local importance.

Any stream measurements on the Laramie intended to show its possibilities as a water supply for irrigation should include measurements at two points and show two things: The stream should be measured above all irrigation in Wyoming to determine the volume received from Colorado, which is practically equivalent to the volume received from the melting of winter snows. This will give an approximate measure of the area which can be reclaimed without resorting to storage; but in connection with these measurements there should be a second station, near the mouth of the stream and below the large diversion of the Wyoming Development Company above referred to, to show the water which runs to waste and to give an idea of how far the irrigated area can be extended by the use of storage. The stations maintained during the past two seasons were established with these ideas in view, the one at Woods Landing being above all Wyoming ditches and the one at Uva below those of any importance.

The records for 1896 can not be taken, however, as indicating the normal possibilities of this stream, because the season has been an unusual one, distinguished alike for the small snow fall of the preceding winter, the diminished volume due to this, and to the extent to which the summer supply was augmented by local rains. No season since irrigation began in Wyoming has witnessed as many cloud bursts or heavy rain storms during the latter part of the irrigation season as the one just closed. As many of these storms fell below the point where water can be stored, the season's record at Uva gives a largely exaggerated idea of the storage possibilities of this stream. Probably not one-half of the water which flowed past this gaging station after June 30 could have been utilized had all the storage basins along the stream been improved, because the storms occurred below where the water could have been diverted.

The rights to water from this stream have never been adjudicated, and the recorded claims give a greatly exaggerated idea of the actual extent of the irrigated territory. A summary of these claims is given below. By comparing the volume claimed with the volume available to supply these claims, it will be seen that later rights have little value.

In 1896 the mean discharge for June was 459 second-feet, while the claims to water under the Territorial laws, leaving out of account those filed under State laws, aggregate over 26,000 second-feet, or nearly six times the total supply. The total discharge from April 1 to October 1 was a little over 100,000 acre-feet, while water is claimed for 360,000 acres.

*Summary of claims to water filed in the State engineer's office, Cheyenne, Wyoming, up to October 31, 1896.*

LARAMIE RIVER.

| | |
|---|---|
| Number of claims | 58 |
| Number not giving capacity | 6 |
| Number not giving amount claimed | 20 |
| Number not giving acreage | 7 |
| Acreage said to be watered by 51 claims | 183,180 |
| Total capacity or volume claimed (second-feet) | 16,738 |

*Number of acres of land described in applications for permits to appropriate water.*

| | |
|---|---|
| Approved | 184,231 |
| Rejected | 720 |
| Canceled | 5,120 |
| Total | 190,074 |

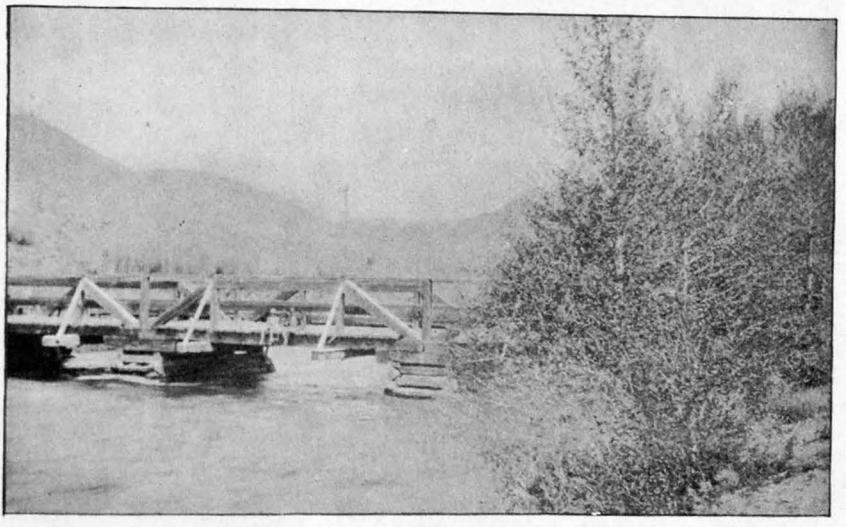


FIG. 19.—Bridge across Laramie at Woods, Wyoming.

## WOODS LANDING STATION ON LARAMIE RIVER.

This station has been described in Bulletin No. 131, page 28, and in Bulletin No. 140, page 95. It is on the Laramie atlas sheet. The measurements of discharge are made from a wagon bridge which spans the river at a point about 400 feet below the location of the gage rod, the width of the stream being about 90 feet. The bridge is a roughly constructed wooden one, resting upon two channel piers which are log cribs filled with loose rock, presenting a square end to the current. The current of the three openings under the bridge being much broken through eddies formed by the piers, it was found that a satisfactory gaging could not be made from the bridge itself. To overcome this difficulty timbers were spiked to the woodwork of the bridge projecting

upstream about 8 feet; on the extremities of these timbers a footboard is laid, and the current is thus measured before it is broken by the piers.

The bottom of the stream is composed of large granite bowlders. This character of bottom, while it renders the shape and slope of channel practically unchangeable, at the same time adds an element of uncertainty to the gaging results, especially at low-water stages. The rocks are of such uneven size that in taking the soundings the rod at one point may indicate a depth of six-tenths of a foot, while if moved a foot either way the depth might be a foot greater. This difficulty of obtaining a correct cross-section area at low water is also materially increased by the unevenness of the water surface, due to the rapid flow of the stream over the rough bottom.

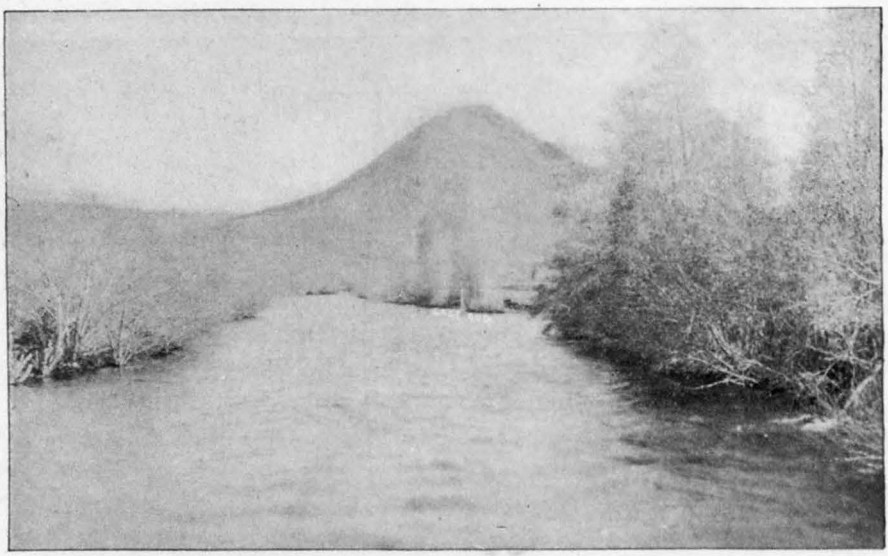


FIG. 20.—Looking up Laramie from bridge at Woods, Wyoming.

The permanent gage rod is fixed to a perpendicular post set firmly in the bed of the stream and braced at the top to adjacent trees. It stands about 4 feet from the river bank in a position which protects it from drift. The rod is connected with a permanent bench mark on a cottonwood tree near the margin of the river. Of the seven gagings made at this station, six of them were with the Price Acoustic meter No. 104, and the other with the Colorado meter; the velocities were taken at intervals of 5 and 10 feet, those at low water being at 5-foot sections, the others 10. The bench mark is a nail head in a notch on a cottonwood tree, 1 foot in diameter, 6 feet from the rod, and is level with the 7-foot mark on the rod. The observer is Mr. S. S. Woods. The record of daily gage heights for 1896, from April 12 to October 15, is given in Water-Supply and Irrigation Paper No. 11, page 50.

*List of discharge measurements made on Laramie River at Woods, Wyoming.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 24 | W. M. Gilcrest.... | 104 | 2.80 | 238 | 4.74 | 1,129 |
| 2 | Oct 23 | .....do ..... | ..... | 0.80 | 41 | 1.19 | 49 |
| | 1896. | | | | | | |
| 3 | Apr. 20 | W. M. Gilcrest.... | 104 | 0.85 | 37 | 1.94 | 75 |
| 4 | May 25 | .....do ..... | 74 | 2.40 | 230 | 3.36 | 797 |
| 5 | June 16 | .....do ..... | 104 | 1.75 | 145 | 2.65 | 350 |
| 6 | June 27 | Elwood Mead..... | 74 | 1.20 | 137 | 1.46 | 198 |
| 7 | Aug. 19 | W. M. Gilcrest.... | 104 | 0.85 | 43 | 1.79 | 81 |
| 8 | Aug. 30 | .....do ..... | 104 | 0.80 | 39 | 1.68 | 75 |
| 9 | Oct. 2 | C. T. Johnston.... | 104 | 1.00 | 142 | 1.16 | 121 |

*Rating table for Laramie River at Woods Landing, Wyoming, for 1896.*

| Gage height | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.10 | 4 | 1.00 | 120 | 1.90 | 565 | 2.80 | 1,699 |
| 0.20 | 11 | 1.10 | 140 | 2.00 | 691 | 2.90 | 1,825 |
| 0 30 | 19 | 1.20 | 165 | 2.10 | 817 | 3.00 | 1,951 |
| 0.40 | 29 | 1.30 | 190 | 2.20 | 943 | 3.10 | 2,077 |
| 0.50 | 38 | 1.40 | 220 | 2.30 | 1,069 | 3.20 | 2,103 |
| 0.60 | 49 | 1.50 | 255 | 2.40 | 1,195 | 3.30 | 2,229 |
| 0.70 | 62 | 1.60 | 295 | 2.50 | 1,321 | | |
| 0.80 | 76 | 1.70 | 350 | 2.60 | 1,447 | | |
| 0.90 | 91 | 1.80 | 435 | 2.70 | 1,573 | | |

*Estimated monthly discharge of Laramie River at Woods Landing, Wyoming.*

[Drainage area, 435 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 12 to 30..... | 754 | 69 | 222 | 8,360 | 0.36 | 0.51 |
| May ..... | 2,166 | 275 | 619 | 38,061 | 1.64 | 1.42 |
| June ..... | 1,195 | 165 | 465 | 27,669 | 1.19 | 1.07 |
| July ..... | 220 | 62 | 127 | 7,809 | 0.33 | 0.29 |
| August..... | 231 | 49 | 94 | 5,780 | 0.24 | 0.21 |
| September ..... | 190 | 62 | 116 | 6,902 | 0.29 | 0.26 |
| October 1 to 15 ..... | 130 | 120 | 122 | 3,630 | 0.15 | 0.28 |

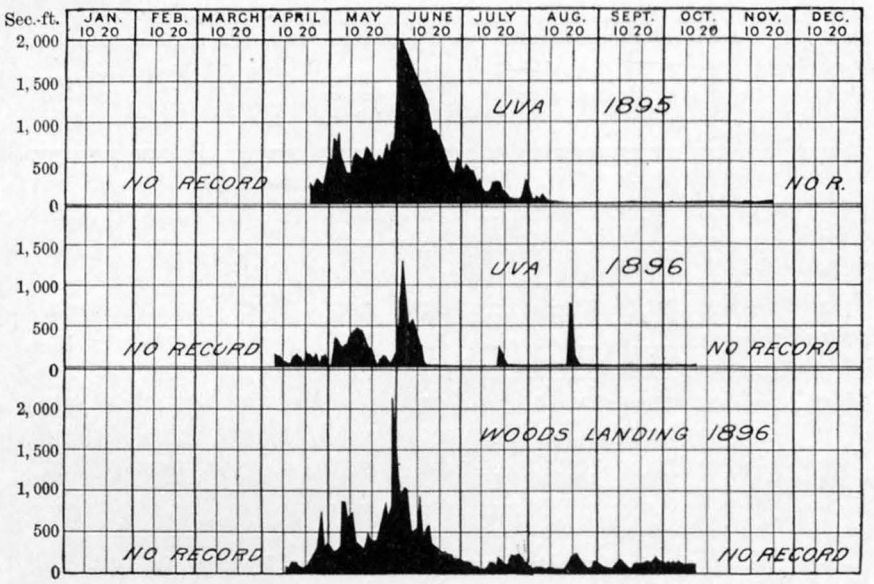



FIG. 21.—Discharge of Laramie River at Uva and Woods, Wyoming, 1896.

## UVA STATION ON LARAMIE RIVER.

This station was described in Bulletin No. 140, page 96. It is on the line of the Cheyenne Northern Railway, about 100 miles north of Cheyenne, in the Hartville quadrangle. The rod is fixed to the side of one of the cluster of piles which supports the railroad bridge in mid-channel.

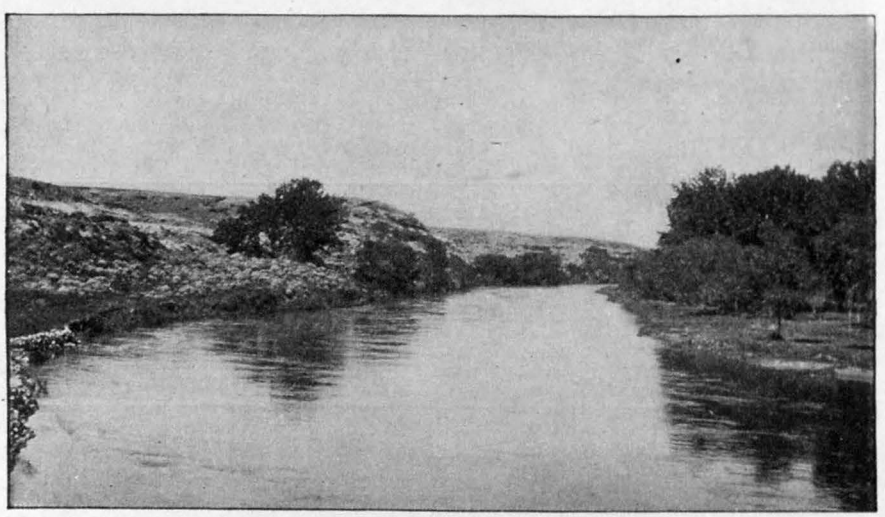


FIG. 22.—Laramie River at Uva, Wyoming, above railroad bridge.

The rod being about 1 mile from the town of Uva and the railway station, it was found most convenient to employ the railway section man, Mr. J. A. Carley, to take the daily readings. His duties call him to the

bridge but once a day, hence but one daily reading of the rod could be had. The point at which the railroad crosses the river being in a bend, it was not a proper place to make the gaging measurements. The nearest point, and the only available one at high stages of water for obtaining the velocities, is the wagon bridge, which crosses the stream with one clear span, about one-half mile below the railroad bridge. Here the river has a sufficient straight stretch above and below the bridge to insure a uniform current. The bench mark is a spike head on south side of pile at east end of bridge. It is 5.95 feet above 6-foot mark on rod. The record of daily gage heights for 1896, from April 6 to October 15, is given in Water-Supply and Irrigation Paper No. 11, page 51.

*List of discharge measurements made on Laramie River at Uva, Wyoming.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet.) | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 14 | W. M. Gilcrest.... | Floats. | 4.75 | 438 | 4.04 | 1,417 |
| 2 | July 15 | .....do ..... | ..... | 1.60 | 87 | 1.65 | 146 |
| 3 | Sept. 27 | .....do ..... | ..... | 0.75 | 4 | 1.51 | 6 |
| | 1896. | | | | | | |
| 4 | April 29 | W. M. Gilcrest.... | 104 | 1 90 | 125 | 1.58 | 217 |
| 5 | June 8 | .....do ..... | 104 | 2.70 | 200 | 2.54 | 549 |
| 6 | July 22 | .....do ..... | 104 | 1.40 | 12 | 1.15 | 16 |
| 7 | Sept. 5 | C. T. Johnston.... | 104 | 0.80 | 11 | 1.02 | 10 |

*Rating table for Laramie River at Uva, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* | *Feet.* | *Sec. Feet.* |
| 0.00 | 0 | 1.20 | 14 | 2.40 | 428 | 3.60 | 920 |
| 0.10 | 1 | 1.30 | 15 | 2.50 | 470 | 3.70 | 960 |
| 0.20 | 2 | 1.40 | 16 | 2.60 | 511 | 3.80 | 1,000 |
| 0.30 | 3 | 1.50 | 50 | 2.70 | 552 | 3.90 | 1,040 |
| 0.40 | 4 | 1.60 | 92 | 2.80 | 593 | 4.00 | 1,080 |
| 0.50 | 6 | 1.70 | 134 | 2.90 | 634 | 4.10 | 1,120 |
| 0.60 | 7 | 1.80 | 176 | 3.00 | 675 | 4.20 | 1,160 |
| 0.70 | 8 | 1.90 | 218 | 3.10 | 716 | 4 30 | 1,200 |
| 0.80 | 10 | 2.00 | 260 | 3.20 | 757 | 4.40 | 1,240 |
| 0.90 | 11 | 2.10 | 302 | 3.30 | 798 | 4.50 | 1,280 |
| 1.00 | 12 | 2.20 | 344 | 3 40 | 739 | 4.60 | 1,320 |
| 1.10 | 13 | 2.30 | 386 | 3.50 | 880 | | |

*Estimated monthly discharge of Laramie River at Uva, Wyoming.*

[Drainage area, 3,179 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second feet per square mile. |
| 1896. | | | | | | |
| April 6 to 30 | 260 | 15 | 127 | 6,300 | 0.03 | 0.04 |
| May | 470 | 16 | 240 | 14,758 | 0.09 | 0.08 |
| June | 1,320 | 11 | 260 | 15,471 | 0.09 | 0.08 |
| July | 260 | 8 | 28 | 1,722 | 0.01 | 0.01 |
| August | 757 | 7 | 60 | 3,689 | 0.02 | 0.02 |
| September | 10 | 8 | 9 | 536 | 0.00 | 0.00 |
| October 1 to 15 | 11 | 10 | 10 | 300 | 0.00 | 0.00 |

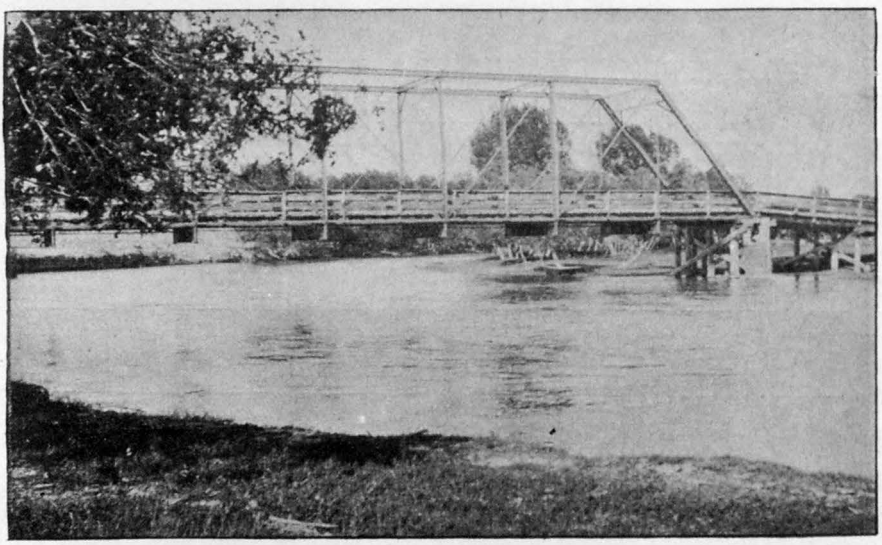


FIG. 23.—Laramie River wagon bridge at Uva, Wyoming.

## ORIN JUNCTION STATION ON NORTH PLATTE RIVER.

This station, described in Bulletin 140, page 98, is located at the bridge of the Cheyenne Northern Railway, near Orin Junction, Wyoming, at a point on the stream about 90 miles west from where it crosses the eastern boundary of the State. This point was selected, as it is easily reached from Cheyenne by means of the above railroad. It is below all of the principal tributaries of the stream, save the Laramie River, and upon this branch a separate station is located at Uva, which is about 18 miles above its confluence with the Platte. There being few

ditches and little use of the waters of the Platte below the gaging station it is an important one, as the results of the discharge obtained here will practically indicate the amount of waste or surplus water which leaves Wyoming.

The rod is fixed upon the midchannel pier of the railway bridge, and is connected with a permanent bench mark on shore. The bed of the stream is composed of heavy gravel and sand, the cross section being quite uniform. The channel is straight for some distance above and below the station; the fall is slight, and these conditions combine to insure as stable and uniform a cross section as can be expected in streams of this size. The section boss, Mr. P. J. Burns, was employed as observer, and as his duties require him to cross the bridge morning and evening it is possible to have two daily readings of the rod except on Sundays.

The stream at this station is divided into two permanent main channels by the bridge pier; at high water there is a third channel to the west of the second pier across which the bridge rests on piles, and at a certain stage of water a long cobble bar running down to the bridge divides this third channel into two, thus making at times four channels altogether. The current meter is always used for making measurements at this station, the method employed being to stretch from pier to pier a cord, having measured spaces marked off on it, to which a boat is made fast and slid from station to station. This method is perfectly satisfactory for the two main channels; but as there is no way of stretching the rope so that the boat can be used above the piles across the third channel it has to be dropped below, where, of course, the resulting measurement possesses an element of uncertainty by reason of the piles being so numerous as to interfere with the uniformity of the current. This difficulty can easily be avoided at a comparatively small cost by attaching projecting supports to the upper side of the piles, just above high water, upon which a footboard can be fastened and the current thus measured before being broken by these obstructions. The bench mark is a spike on top of cap on the set of piles nearest water at east end of bridge. It is 11.52 feet above datum. The records of daily gage heights from April 13 to October 15 and from December 2 to 18 are given in Water-Supply and Irrigation Paper No. 11, page 51.

*List of discharge measurements made on North Platte River, at Orin, Wyoming.*

| No. | Date. | Hydrographer. | Meter number | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 27 | W. M. Gilcrest.... | ..... | 3.89 | 959 | 4.29 | 4,110 |
| 2 | July 17 | .....do ..... | ..... | 2.90 | 769 | 3.80 | 2,475 |
| 3 | Sept. 26 | .....do ..... | ..... | 0.65 | 258 | 2.97 | 508 |
| | 1896. | | | | | | |
| 4 | May 27 | W. M. Gilcrest.... | 104 | 3.95 | 1,135 | 3.23 | 3,683 |
| 5 | June 10 | .....do ..... | 104 | 4.50 | 1,228 | 4.62 | 5,680 |
| 6 | July 20 | .....do ..... | 104 | 2.50 | 645 | 2.80 | 1,802 |
| 7 | Sept. 2 | .....do ..... | 104 | 1.20 | 434 | 2.27 | 985 |

*Rating table for North Platte River at Orin, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.0 | 400 | 1.6 | 1,230 | 3.2 | 2,500 | 4.8 | 7,000 |
| 0.1 | 440 | 1.7 | 1,300 | 3.3 | 2,600 | 4.9 | 7,450 |
| 0.2 | 500 | 1.8 | 1,360 | 3.4 | 2,720 | 5.0 | 7,850 |
| 0.3 | 540 | 1.9 | 1,430 | 3.5 | 2,860 | 5.1 | 8,300 |
| 0.4 | 600 | 2.0 | 1,500 | 3.6 | 3,000 | 5.2 | 8,700 |
| 0.5 | 650 | 2.1 | 1,560 | 3.7 | 3,160 | 5.3 | 9,150 |
| 0.6 | 700 | 2.2 | 1,620 | 3.8 | 3,320 | 5.4 | 9,600 |
| 0.7 | 750 | 2.3 | 1,690 | 3.9 | 3,520 | 5.5 | 10,000 |
| 0.8 | 800 | 2.4 | 1,760 | 4.0 | 3,740 | 5 6 | 10,400 |
| 0.9 | 850 | 2.5 | 1,840 | 4.1 | 4,000 | 5.7 | 10,800 |
| 1.0 | 900 | 2.6 | 1,920 | 4.2 | 4,360 | 5.8 | 11,200 |
| 1.1 | 950 | 2.7 | 2,000 | 4.3 | 4,740 | 5.9 | 11,600 |
| 1.2 | 1,000 | 2.8 | 2,095 | 4.4 | 5,240 | 6.0 | 12,000 |
| 1.3 | 1,050 | 2.9 | 2,195 | 4.5 | 5,650 | 6.1 | 12,450 |
| 1.4 | 1,100 | 3.0 | 2,295 | 4.6 | 6,150 | | |
| 1.5 | 1,160 | 3.1 | 2,395 | 4.7 | 6,600 | | |

*Estimated monthly discharge of North Platte River at Orin, Wyoming.*

[Drainage area, 14,828 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second feet per square mile. |
| April 13 to 30 | 6,150 | 1,936 | 3,113 | 111,150 | 0.14 | 0.21 |
| May | 8,075 | 2,684 | 5,070 | 311,742 | 0.39 | 0.34 |
| June | 12,315 | 1,634 | 5,261 | 313,051 | 0.39 | 0.35 |
| July | 1,840 | 950 | 1,339 | 82,332 | 0.10 | 0.09 |
| August | 1,465 | 775 | 1,008 | 61,980 | 0.08 | 0.07 |
| September | 1,085 | 825 | 974 | 57,957 | 0.08 | 0.07 |
| October 1 to 15 | 1,085 | 950 | 925 | 27,525 | 0.04 | 0.06 |

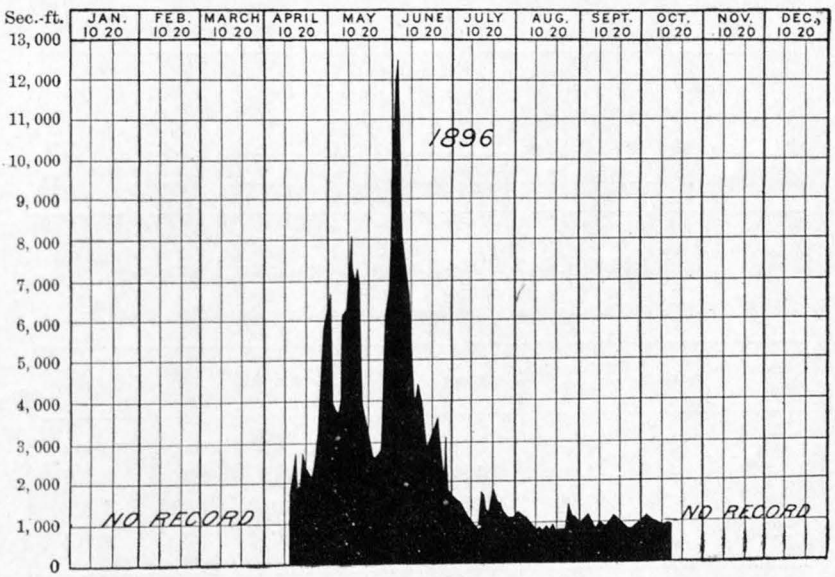



FIG. 24.—Discharge of North Platte River at Orin, Wyoming, 1896.

## CAMP CLARKE STATION ON NORTH PLATTE RIVER.

This station was established and observations commenced on June 27, 1896. It is located on the right bank of the river, about 40 feet above the Camp Clarke bridge, in the Camp Clarke quadrangle. The observer is Mr. Robert H. Willis, county surveyor of Cheyenne County, Nebraska, who lives about 1 mile from the gage. Observations are taken once daily. The gage consists of an oak piece, 2 by 4 inches, 10 feet long. It is fastened to cross-ties, which are bedded in the bank of the river. The face of the rod is inclined at an angle of 30 degrees to the horizontal, so that 2 feet along the rod are equal to 1 foot in the verti-

cal, and the rod is graduated accordingly. The channel at the station is fairly straight, above and below.

The bed, as elsewhere along this river, is of loose, coarse sand. Two bench marks were established. The first consists of a spike which is driven horizontally in the northeast side of the downstream pile of the bent at the north end of the first truss span on the south end of the bridge. This spike is 7.55 feet above the zero of the gage. The second bench mark is a point on the southeast corner of the window sill at the front of the store. This point is 9.74 feet above the zero of the gage. The rating table given below is based on the first two measurements of discharge, the third having been made after the presence of ice had altered the relation between gage heights and discharge.

*List of discharge measurements made on North Platte River, at Camp Clarke, Nebraska.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 27 | O. V. P. Stout | ..... | 3.18 | ..... | 2.55 | 3,600 |
| 2 | Aug. 10 | R. H. Willis | ..... | 2.41 | ..... | 1.63 | 812 |
| 3 | Nov. 21 | .....do | ..... | 2.70 | ..... | 1.36 | 931 |

*Rating table for North Platte River at Camp Clarke, Nebraska.*

[This table is applicable from June 27, 1896, to November 1, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.20 | 578 | 2.50 | 1,160 | 2.80 | 2,042 | 3.10 | 3,231 |
| 2.30 | 738 | 2.60 | 1,420 | 2.90 | 2,404 | 3.20 | 3,696 |
| 2.40 | 932 | 2.70 | 1,714 | 3.00 | 2,800 | 3.30 | 4,195 |

The following table gives the computed daily discharge during the period to which the rating table applies:

*Daily mean discharge (in cubic feet per second) of North Platte River at Camp Clarke for 1896.*

| Day. | June. | July. | August. | September. | October. | November. |
|---|---|---|---|---|---|---|
| 1 | ..... | 2,886 | 1,316 | 854 | 875 | 1,046 |
| 2 | ..... | 2,552 | 1,160 | 1,056 | 932 | 1,137 |
| 3 | ..... | 2,295 | 1,160 | 738 | 875 | 1,186 |
| 4 | ..... | 2,042 | 1,114 | 835 | 875 | 1,212 |
| 5 | ..... | 1,878 | 1,092 | 796 | 932 | 1,238 |
| 6 | ..... | 1,655 | 1,114 | 816 | 914 | 706 |
| 7 | ..... | 1,537 | 1,114 | 835 | 914 | 1,046 |
| 8 | ..... | 1,566 | 1,160 | 895 | 954 | 1,160 |
| 9 | ..... | 1,537 | 1,046 | 1,023 | 1,290 | ..... |
| 10 | ..... | 1,508 | 954 | 1,186 | 1,069 | ..... |
| 11 | ..... | 1,478 | 854 | 1,046 | 1,023 | ..... |
| 12 | ..... | 1,160 | 816 | 932 | 1,046 | ..... |
| 13 | ..... | 1,160 | 777 | 1,114 | 1,023 | ..... |
| 14 | ..... | 1,137 | 706 | 895 | 1,046 | ..... |
| 15 | ..... | 1,137 | 722 | 854 | 1,046 | ..... |
| 16 | ..... | 977 | 628 | 816 | 1,046 | ..... |
| 17 | ..... | 1,046 | 706 | 796 | 1,023 | ..... |
| 18 | ..... | 1,977 | 932 | 1,114 | 1,000 | ..... |
| 19 | ..... | 1,685 | 835 | 796 | 1,046 | ..... |
| 20 | ..... | 1,137 | 758 | 954 | 1,000 | ..... |
| 21 | ..... | 1,186 | 895 | 977 | 1,046 | ..... |
| 22 | ..... | 1,160 | 1,069 | 932 | 1,023 | ..... |
| 23 | ..... | 1,626 | ..... | 1,046 | 954 | ..... |
| 24 | ..... | 1,566 | ..... | 1,160 | 977 | ..... |
| 25 | ..... | 1,368 | 854 | 1,114 | 977 | ..... |
| 26 | ..... | 1,342 | 816 | 954 | 954 | ..... |
| 27 | ..... | 1,566 | 777 | 1,092 | 1,046 | ..... |
| 28 | 4,100 | 1,114 | 777 | 875 | 1,046 | ..... |
| 29 | 3,324 | 1,394 | 1,000 | 835 | 1,023 | ..... |
| 30 | 3,102 | ..... | 835 | 835 | 1,264 | ..... |
| 31 | ..... | 1,960 | 796 | ..... | 1,023 | ..... |
| Mean | ..... | 1,554 | 924 | 939 | 1,008 | ..... |

The following statement affords a comparison of the mean monthly discharge for the two seasons during which the record has been kept, and also of the computed discharge at Camp Clarke, 100 miles above North Platte:

*Mean monthly discharge in second-feet of the North Platte River at North Platte and at Camp Clarke, Nebraska.*

| Month. | North Platte. | | Camp Clarke, 1896. |
|---|---|---|---|
| | 1895. | 1896. | |
| March | 3,005 | ..... | ..... |
| April | 3,470 | *a* 2,490 | ..... |
| May | 7,033 | 4,557 | ..... |
| June | 10,991 | 6,340 | ..... |
| July | 3,137 | 1,135 | 1,554 |
| August | 492 | 915 | 924 |
| September | 241 | *b* 807 | 939 |
| October | 810 | ..... | ..... |
| November | 1,357 | ..... | ..... |
| December | 3,405 | ..... | ..... |

*a* 21 days in 1896. *b* 26 days in 1896.

Water is diverted for numerous canals at points between the two stations named above. Blue Creek and Birdwood Creek are the only considerable tributaries which enter the river between them. During the season of 1896 no measurements of the North Platte River were made by or reported to the Survey at points in Nebraska other than the gaging stations. Birdwood Creek is the only tributary which was measured. The gaging was made near the mouth of the creek and a short distance below the headgate of Bratts ditch. The discharge was found to be 133 second-feet. At the same time Bratts ditch was diverting 28.2 cubic feet per second, which, added to the measured discharge of the creek, would give a total discharge of 161.2 second-feet.

### NORTH PLATTE STATION ON NORTH PLATTE RIVER.

This station was established in 1894 and is under charge of Mr. Charles P. Ross. A description of the station, with a list of measurements made at the station and above on the same river, together with a rating table and a record of gage heights and daily discharge for 1895, were given on pages 99–102 of Bulletin No. 140. It is located in the North Platte quadrangle.

All of the discharge measurements have been made from the wagon bridge 1 mile north of the town of North Platte, this bridge being in sec. 28, T. 14 N., R. 30 W. It is a long, low, pile bridge, having 87 spans of approximately 20 feet each, crossing the main channel of the river.

North of this, at a distance of about 440 feet, is another bridge crossing a smaller branch or slough, and having 6 spans of about 20 feet each. The water, except in times of flood, does not pass under all of the spans of the long bridge, but usually the greater part flows under two or three of these, spreading out in shallow pools or streamlets under others, the greater number being over dry sand. The initial point for soundings is on the right bank, and consists of a mark on the railing on the upstream side of the bridge. The channel is nearly straight for about 500 feet, both above and below the station.

The rating table given below does not agree with that for 1895 as closely as one might reasonably expect in the case of a river of such a size and for two successive years. The points of greatest divergence, however, are those which are represented in the two years by actual gagings. The record of daily gage heights for 1896, from January 1 to February 29 and from April 10 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 52.

Measurements of discharge have been made as follows:

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Feb. 21 | C. P. Ross | 1 | 2.35 | 1,043 | 1.96 | 2,045 |
| 2 | June 13 | O. V. P. Stout | 78 | 3.35 | 2,736 | 3.20 | 9,000 |
| 3 | June 29 | do | 105 | 2.90 | 1,560 | 2.51 | 4,000 |
| 4 | July 25 | do | 105 | 2.05 | 600 | 1.90 | 1,260 |
| 5 | Sept. 8 | do | 105 | 1.50 | | | 547 |
| 6 | Oct. 1 | C. P. Ross | 1 | 1.90 | 722 | 1.74 | 1,258 |
| 7 | Nov. 9 | do | 1 | 1.85 | 526 | 2.01 | 1,056 |

Two rating tables have been prepared based upon the above measurements:

*Rating table for North Platte River at North Platte, Nebraska.*

[This table is applicable from April 1, 1896, to September 30, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 250 | 1.80 | 800 | 2.60 | 2,890 | 3.40 | 9,570 |
| 1.10 | 320 | 1.90 | 950 | 2.70 | 3,225 | 3.50 | 10,690 |
| 1.20 | 380 | 2.00 | 1,130 | 2.80 | 3,560 | 3.60 | 11,810 |
| 1.30 | 440 | 2.10 | 1,350 | 2.90 | 4,000 | 3.70 | 12,930 |
| 1.40 | 500 | 2.20 | 1,600 | 3.00 | 5,110 | 3.80 | 14,050 |
| 1.50 | 550 | 2.30 | 1,860 | 3.10 | 6,220 | 3.90 | 15,170 |
| 1.60 | 600 | 2.40 | 2,170 | 3.20 | 7,330 | 4.00 | 16,300 |
| 1.70 | 675 | 2.50 | 2,490 | 3.30 | 8,450 | | |

*Rating table for North Platte River at North Platte, Nebraska.*

[This table is applicable from October 1, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.50 | 384 | 1.90 | 1,236 | 2.30 | 2,731 | 2.70 | 4,882 |
| 1.55 | 455 | 1.95 | 1,387 | 2.35 | 2,963 | 2.75 | 5,198 |
| 1.60 | 537 | 2.00 | 1,551 | 2.40 | 3,205 | 2.80 | 5,524 |
| 1.65 | 628 | 2.05 | 1,722 | 2.45 | 3,458 | 2.85 | 5,860 |
| 1.70 | 730 | 2.10 | 1,903 | 2.50 | 3,721 | 2.90 | 6,206 |
| 1.75 | 841 | 2.15 | 2,095 | 2.55 | 3,995 | 2.95 | 6,562 |
| 1.80 | 963 | 2.20 | 2,297 | 2.60 | 4,280 | 3.00 | 6,928 |
| 1.85 | 1,094 | 2.25 | 2,509 | 2.65 | 4,576 | | |

*Estimated monthly discharge of North Platte River at North Platte, Nebraska.*

[Drainage area, 28,517 square miles.]

| Month. | Discharge in second-feet | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 10 to 30 | 3,560 | 1,860 | 2,823 | 117,579 | 0.078 | 0.099 |
| May | 7,888 | 2,680 | 4,558 | 280,262 | 0.180 | 0.160 |
| June | 16,300 | 2,680 | 6,334 | 376,898 | 0.240 | 0.222 |
| July | 2,680 | 250 | 1,134 | 69,727 | 0.046 | 0.040 |
| August | 1,860 | 460 | 919 | 56,507 | 0.037 | 0.032 |
| September | 1,240 | 550 | 857 | 50,995 | 0.033 | 0.030 |
| October | 2,509 | 730 | 1,150 | 70,711 | 0.046 | 0.040 |
| November | 3,721 | 730 | 2,166 | 128,886 | 0.083 | 0.075 |
| December | 5,860 | 2,731 | 4,348 | 267,350 | 0.175 | 0.152 |

## SOUTH PLATTE RIVER.

South Platte River rises in the south part in the main range of the Rocky Mountains and flows northeastward through a narrow canyon in the Front Range. It is described in Bulletin No. 140, page 102. A number of old measurements have been made on this river and its tributaries, notably on Bear Creek, which enters 6 miles above Denver, and on Bowlder, South Bowlder, St. Vrain, and Big Thompson creeks. Cache la Poudre River has been measured for a number of years by Prof. L. G. Carpenter at a point about 12 miles above Fort Collins. A complete record of these measurements may be found in Irrigation near Greeley, Colorado, by David Boyd: Water-Supply and Irrigation Paper No. 9.

### DEANSBURY STATION ON SOUTH PLATTE RIVER.

This station is described in Bulletin No. 140, page 103. It is located about 1,000 feet southwest of Deansbury, Colorado, a station on the Denver, Leadville and Gunnison Railroad, 27 miles from Denver, in the Platte Canyon quadrangle. It was established on November 15, 1895, by Mr. L. R. Hope. The discharge measurements are made from a footbridge crossing the stream. The gage rod is vertical, fastened to a 3 by 6 inch plank, and marked to 0.05 of a foot. An automatic register is also used. Both banks are high and not liable to overflow. The bed of the stream consists of gravel and small bowlders and is not liable to change. Measurements are made at this point during the winter months, since the channel being narrow and current swift, the river is less likely to freeze than at station No. 2.

Station No. 2 is located about 300 feet above station No. 1, and is used during the summer months, being a more desirable point for high-water measurements than station No. 1, owing to greater width of channel and lower velocity of the water. It was established on April 26, 1896. Measurements are made from a footbridge. The gage consists of a 2 by 4 inch timber, inclined, securely wired to rocks, and marked to vertical 0.10 of a foot, the space between the marks being 0.141 of a foot. The mean daily readings of the automatic register have been reported since June 1, 1896. The railroad embankment forms the right bank, while the left is low and subject to overflow at high water. The bed of the stream is rocky and not liable to change. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 52.

*List of discharge measurements made on South Platte River at Deansbury, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Nov. 30 | L. R. Hope | 21 | 4.00 | 49 | 4.03 | 197 |
| 2 | Dec. 1 | do | 21 | 3.20 | 37 | 2.78 | 102 |
| 3 | Dec. 7 | do | 21 | 3.60 | 44 | 3.59 | 160 |
| 4 | Dec. 8 | do | 21 | 3.65 | 45 | 3.71 | 166 |
| 5 | Dec. 14 | do | 21 | 3.80 | 47 | 3.88 | 183 |
| 6 | Dec. 20 | do | 21 | 3.35 | 38 | 3.51 | 135 |
| | 1896. | | | | | | |
| 7 | Jan. 12 | L. R. Hope | 20 | 3.05 | 34 | 2.77 | 94 |
| 8 | Jan. 18 | do | 20 | 3.05 | 33 | 2.86 | 94 |
| 9 | Jan. 27 | do | 20 | 2.90 | 31 | 2.86 | 90 |
| 10 | Feb. 4 | do | 20 | 3.18 | 35 | 3.29 | 116 |
| 11 | Feb. 11 | do | 20 | 3.10 | 33 | 3.02 | 101 |
| 12 | Feb. 19 | do | 20 | 2.97 | 32 | 2.84 | 91 |
| 13 | Feb. 23 | do | 20 | 3.42 | 40 | 3.58 | 144 |
| 14 | Mar. 18 | do | 20 | 3.07 | 32 | 3.01 | 97 |
| 15 | Mar. 20 | do | 20 | 3.75 | 47 | 3.89 | 184 |
| 16 | Mar. 30 | do | 20 | 5.15 | 68 | 5.51 | 372 |
| 17 | Apr. 2 | do | 20 | 4.30 | 57 | 4.52 | 259 |
| 18 | Apr. 13 | do | 20 | 4.85 | 64 | 5.15 | 329 |
| 19 | May 3 | do | 20 | 2.70 | 138 | 4.03 | 557 |
| 20 | May 26 | do | 20 | 2.55 | 128 | 3.80 | 485 |
| 21 | June 9 | do | 20 | 1.90 | 100 | 3.25 | 314 |
| 22 | June 14 | do | 20 | 1.44 | 83 | 2.82 | 235 |
| 23 | July 6 | do | 20 | 0.90 | 67 | 2.07 | 138 |
| 24 | July 24 | do | 20 | 1.66 | 98 | 2.95 | 289 |
| 25 | Aug. 14 | do | 20 | 0.73 | 60 | 2.11 | 125 |
| 26 | Aug. 25 | do | 20 | 1.30 | 82 | 2.52 | 205 |
| 27 | Sept. 28 | do | 20 | 1.50 | 91 | 2.63 | 239 |
| 28 | Oct. 10 | do | 20 | 1.42 | 92 | 2.55 | 233 |
| 29 | Oct. 20 | do | 20 | 1.23 | 85 | 2.29 | 193 |
| 30 | Oct. 31 | do | 20 | 1.33 | 88 | 2.41 | 212 |
| 31 | Nov. 10 | do | 20 | 1.27 | 87 | 2.31 | 201 |
| 32 | Dec. 5 | do | 20 | 3.25 | 43 | 2.78 | 120 |
| 33 | Dec. 9 | do | 20 | 3.14 | 44 | 2.54 | 112 |
| 34 | Dec. 16 | do | 20 | 3.07 | 41 | 2.85 | 116 |
| 35 | Dec. 27 | do | 20 | 2.79 | 36 | 2.36 | 90 |

Gagings Nos. 1 to 18, inclusive, and Nos. 32 to 35, inclusive, made at station No. 1. Gagings Nos. 19 to 31, inclusive, made at station No. 2.

*Rating table for station No. 1 on South Platte River at Deansbury, Colorado.*

[This table is applicable from November 15, 1895, to April 26, 1896, and from December 4, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.70 | 84 | 3.80 | 190 | 4.90 | 337 | 5.95 | 481 |
| 2.75 | 85 | 3.85 | 196 | 4.95 | 344 | 6.00 | 489 |
| 2.80 | 86 | 3.90 | 203 | 5.00 | 351 | 6.05 | 496 |
| 2.85 | 87 | 3.95 | 210 | 5.05 | 357 | 6.10 | 503 |
| 2.90 | 88 | 4.00 | 217 | 5.10 | 364 | 6.15 | 510 |
| 2.95 | 90 | 4.05 | 223 | 5.15 | 370 | 6.20 | 518 |
| 3.00 | 92 | 4.10 | 230 | 5.20 | 377 | 6.25 | 525 |
| 3.05 | 96 | 4.15 | 237 | 5.25 | 383 | 6.30 | 532 |
| 3.10 | 100 | 4.20 | 244 | 5.30 | 390 | 6.35 | 539 |
| 3.15 | 106 | 4.25 | 250 | 5.35 | 397 | 6.40 | 547 |
| 3.20 | 112 | 4.30 | 257 | 5.40 | 404 | 6.45 | 554 |
| 3.25 | 118 | 4.35 | 263 | 5.45 | 411 | 6.50 | 561 |
| 3.30 | 125 | 4.40 | 270 | 5.50 | 418 | 6.55 | 568 |
| 3.35 | 131 | 4.45 | 277 | 5.55 | 424 | 6.60 | 575 |
| 3.40 | 138 | 4.50 | 284 | 5.60 | 431 | 6.65 | 582 |
| 3.45 | 144 | 4.55 | 290 | 5.65 | 438 | 6.70 | 590 |
| 3.50 | 151 | 4.60 | 297 | 5.70 | 445 | 6.75 | 597 |
| 3.55 | 157 | 4.65 | 304 | 5.75 | 452 | 6.80 | 604 |
| 3.60 | 164 | 4.70 | 311 | 5.80 | 460 | 6.85 | 611 |
| 3.65 | 170 | 4.75 | 317 | 5.85 | 467 | 6.90 | 618 |
| 3.70 | 176 | 4.80 | 324 | 5.90 | 474 | 6.95 | 626 |
| 3.75 | 183 | 4.85 | 330 | | | | |

*Rating table for station No. 2, on South Platte River, at Deansbury, Colorado.*

[This table is applicable only from April 26, 1896, to December 3, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 118 | 1.20 | 190 | 1.70 | 272 | 2.20 | 371 |
| 0.75 | 125 | 1.25 | 197 | 1.75 | 281 | 2.25 | 384 |
| 0.80 | 132 | 1.30 | 205 | 1.80 | 291 | 2.30 | 398 |
| 0.85 | 139 | 1.35 | 213 | 1.85 | 300 | 2.35 | 414 |
| 0.90 | 146 | 1.40 | 221 | 1.90 | 310 | 2.40 | 430 |
| 0.95 | 153 | 1.45 | 229 | 1.95 | 320 | 2.45 | 447 |
| 1.00 | 161 | 1.50 | 238 | 2.00 | 330 | 2.50 | 465 |
| 1.05 | 168 | 1.55 | 246 | 2.05 | 340 | 2.55 | 486 |
| 1.10 | 175 | 1.60 | 254 | 2.10 | 350 | 2.60 | 508 |
| 1.15 | 182 | 1.65 | 263 | 2.15 | 360 | 2.65 | 531 |

*Rating table for station No. 2, on South Platte River, at Deansbury, Colorado*—Cont'd.

[This table is applicable only from April 26, 1896, to December 3, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.70 | 554 | 3.00 | 700 | 3.25 | 808 | 3.50 | 920 |
| 2.75 | 577 | 3.05 | 722 | 3.30 | 830 | 3.55 | 940 |
| 2.80 | 601 | 3.10 | 744 | 3.35 | 853 | 3.60 | 960 |
| 2.85 | 625 | 3.15 | 765 | 3.40 | 876 | 3.65 | 982 |
| 2.90 | 650 | 3.20 | 786 | 3.45 | 898 | 3.70 | 1,005 |
| 2.95 | 675 | | | | | | |

*Estimated monthly discharge of South Platte River at Deansbury, Colorado.*

[Drainage area, 2,600 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| November 15 to 30 | 311 | 190 | 241 | 7,648 | 0.05 | 0.09 |
| December | 224 | 92 | 145 | 8,915 | 0.07 | 0.06 |
| 1896. | | | | | | |
| January | 138 | 88 | 97 | 5,964 | 0.04 | 0.04 |
| February | 138 | 92 | 115 | 6,615 | 0.04 | 0.04 |
| March | 561 | 100 | 207 | 12,728 | 0.09 | 0.08 |
| April | 982 | 196 | 473 | 28,146 | 0.20 | 0.18 |
| May | 830 | 350 | 502 | 30,867 | 0.22 | 0.19 |
| June | 601 | 168 | 281 | 16,721 | 0.12 | 0.11 |
| July | 430 | 118 | 233 | 13,711 | 0.10 | 0.09 |
| August | 291 | 118 | 189 | 12,174 | 0.09 | 0.08 |
| September | 310 | 197 | 250 | 14,876 | 0.11 | 0.10 |
| October | 229 | 197 | 217 | 13,342 | 0.09 | 0.08 |
| November | 213 | 132 | 169 | 10,057 | 0.08 | 0.07 |
| December | 151 | 83 | 93 | 5,718 | 0.04 | 0.04 |
| Per annum | 982 | 83 | 235 | 170,919 | 1.22 | 0.09 |

## DENVER STATION ON SOUTH PLATTE RIVER.

This station is described in Bulletin No. 140, page 104. It is in the Denver quadrangle, and was established May 7, 1895, at the Twenty-third street viaduct, but was abandoned on June 18 of the same year, as the location was unfavorable and a sand bar had formed around the

gage rod. Only one discharge measurement was made at this station. The present station is at the Fifteenth street bridge, and was established July 15, 1895. The stream measurements are made from the lower side of the bridge, except at very low water. The gage consists of two 6 by 2 inch planks spiked together and fastened to posts driven into the river bank. It is inclined and graduated to vertical 0.10 of a foot, the space between marks being 0.156 of a foot. The bench mark is 107 feet southwesterly from the gage, and is a cross mark on top of the east abutment of the Fifteenth street bridge, on the north corner. It is marked B. M. and is 6.15 feet above the 9-foot mark of the gage rod.

The river is confined between slag embankments, and the bed is sandy and shifting. During the flood of August 22, 1896, in Cherry Creek, which enters immediately above the station, the channel near the slope rod filled in with sand, and all the water now flows down the left side of the river. On August 26, 1896, a short vertical rod, reading same as the slope rod, was spiked to a pile near left abutment of the bridge. Stream measurements made since this date are not applicable to gage heights previous to August 22. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 53.

*List of discharge measurements made on South Platte River at Denver, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 7 | P. J. Preston .... | 21 | ..... | 114 | 1.48 | 168 |
| 2 | July 23 | F. Cogswell ..... | 14 | 5.40 | 411 | 3.63 | 1,490 |
| 3 | Aug. 7 | P. J. Preston .... | 14 | 4.60 | 263 | 3.33 | 876 |
| 4 | Aug. 22 | .....do ..... | 14 | 3.90 | 162 | 2.75 | 447 |
| 5 | Nov. 9 | .....do ..... | 21 | 4.30 | 168 | 2.56 | 430 |
| 6 | Nov. 29 | .....do ..... | 14 | 3.90 | 128 | 2.37 | 303 |
| | 1896. | | | | | | |
| 7 | Jan. 6 | P. J. Preston .... | 14 | 3.60 | 85 | 2.15 | 183 |
| 8 | Apr. 8 | .....do ..... | 21 | 4.50 | 138 | 1.71 | 235 |
| 9 | May 29 | .....do ..... | 14 | 4.90 | 146 | 2.09 | 305 |
| 10 | July 1 | .....do ..... | 21 | 4.33 | 69 | 1.54 | 107 |
| 11 | July 25 | .....do ..... | Floats. | 6.10 | 348 | 3.78 | 1,316 |
| 12 | Aug. 5 | .....do ..... | 14 | 4.35 | 76 | 1.65 | 125 |
| 13 | Aug. 26 | R. S. Sumner .... | 21 | 4.80 | 57 | 1.46 | 83 |
| 14 | Sept. 11 | F. Cogswell ..... | 14 | 5.10 | 77 | 2.12 | 163 |
| 15 | Oct. 30 | P. J. Preston .... | 21 | 4.70 | 58 | 1.59 | 93 |
| 16 | Nov. 9 | .....do ..... | 21 | 4.75 | 57 | 1.76 | 100 |
| 17 | Dec. 9 | .....do ..... | 21 | 4.62 | 52 | 1.71 | 89 |

*Rating table for South Platte River at Denver, Colorado.*

[This table is applicable only from January 1, 1896, to June 15, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.40 | 131 | 3.35 | 165 | 4.30 | 224 | 5.25 | 355 |
| 2.45 | 132 | 3.40 | 168 | 4.35 | 229 | 5.30 | 364 |
| 2.50 | 134 | 3.45 | 170 | 4.40 | 234 | 5.35 | 372 |
| 2.55 | 136 | 3.50 | 172 | 4.45 | 239 | 5.40 | 381 |
| 2.60 | 138 | 3.55 | 174 | 4.50 | 244 | 5.45 | 390 |
| 2.65 | 140 | 3.60 | 177 | 4.55 | 250 | 5.50 | 399 |
| 2.70 | 142 | 3.65 | 180 | 4.60 | 256 | 5.55 | 408 |
| 2.75 | 143 | 3.70 | 183 | 4.65 | 262 | 5.60 | 417 |
| 2.80 | 145 | 3.75 | 186 | 4.70 | 268 | 5.65 | 426 |
| 2.85 | 146 | 3.80 | 189 | 4.75 | 275 | 5.70 | 435 |
| 2.90 | 148 | 3.85 | 192 | 4.80 | 282 | 5.75 | 444 |
| 2.95 | 150 | 3.90 | 195 | 4.85 | 289 | 5.80 | 453 |
| 3.00 | 152 | 3.95 | 198 | 4.90 | 297 | 5.85 | 462 |
| 3.05 | 153 | 4.00 | 202 | 4.95 | 305 | 5.90 | 471 |
| 3.10 | 155 | 4.05 | 205 | 5.00 | 313 | 5.95 | 480 |
| 3.15 | 157 | 4.10 | 209 | 5.05 | 321 | 6.00 | 489 |
| 3.20 | 159 | 4.15 | 212 | 5.10 | 330 | | |
| 3.25 | 161 | 4.20 | 216 | 5.15 | 338 | | |
| 3.30 | 163 | 4.25 | 220 | 5.20 | 347 | | |

*Rating table for South Platte River at Denver, Colorado.*

[This table is applicable only from June 16, 1896, to August 22, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.90 | 21 | 4.35 | 120 | 4.80 | 255 | 5.25 | 548 |
| 3.95 | 31 | 4.40 | 132 | 4.85 | 278 | 5.30 | 586 |
| 4.00 | 42 | 4.45 | 145 | 4.90 | 302 | 5.35 | 629 |
| 4.05 | 53 | 4.50 | 158 | 4.95 | 335 | 5.40 | 672 |
| 4.10 | 64 | 4.55 | 172 | 5.00 | 368 | 5.45 | 715 |
| 4.15 | 75 | 4.60 | 187 | 5.05 | 401 | 5.50 | 758 |
| 4.20 | 86 | 4.65 | 203 | 5.10 | 434 | | |
| 4.25 | 97 | 4.70 | 219 | 5.15 | 472 | | |
| 4.30 | 108 | 4.75 | 237 | 5.20 | 510 | | |

*Rating table for South Platte River at Denver, Colorado.*

[This table is applicable only from August 23, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.20 | 11 | 4.65 | 83 | 5.10 | 162 | 5.55 | 246 |
| 4.25 | 19 | 4.70 | 91 | 5.15 | 171 | 5.60 | 256 |
| 4.30 | 27 | 4.75 | 99 | 5.20 | 180 | 5.65 | 266 |
| 4.35 | 35 | 4.80 | 108 | 5.25 | 189 | 5.70 | 276 |
| 4.40 | 43 | 4.85 | 117 | 5.30 | 199 | 5.75 | 286 |
| 4.45 | 51 | 4.90 | 126 | 5.35 | 208 | 5.80 | 296 |
| 4.50 | 59 | 4.95 | 135 | 5.40 | 218 | | |
| 4.55 | 67 | 5.00 | 144 | 5.45 | 227 | | |
| 4.60 | 75 | 5.05 | 153 | 5.50 | 237 | | |

*Estimated monthly discharge of South Platte River at Denver, Colorado.*

[Drainage area, 3,840 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 202 | 163 | 182 | 11,190 | 0.06 | 0.05 |
| February | 229 | 172 | 198 | 11,159 | 0.05 | 0.05 |
| March | 289 | 198 | 225 | 13,834 | 0.07 | 0.06 |
| April | 444 | 239 | 301 | 17,911 | 0.09 | 0.08 |
| May | 408 | 229 | 291 | 17,892 | 0.09 | 0.08 |
| June | 364 | 53 | 200 | 11,900 | 0.06 | 0.05 |
| July | 758 | 42 | 164 | 10,084 | 0.04 | 0.04 |
| August | 187 | 42 | 115 | 7,071 | 0.03 | 0.03 |
| September | 180 | 108 | 145 | 8,628 | 0.04 | 0.04 |
| October | 180 | 27 | 111 | 6,825 | 0.03 | 0.03 |
| November | 126 | 83 | 101 | 6,010 | 0.03 | 0.03 |
| December | 126 | 75 | 103 | 6,333 | 0.03 | 0.03 |
| Per annum | 444 | 42 | 178 | 128,837 | 0.62 | 0.05 |

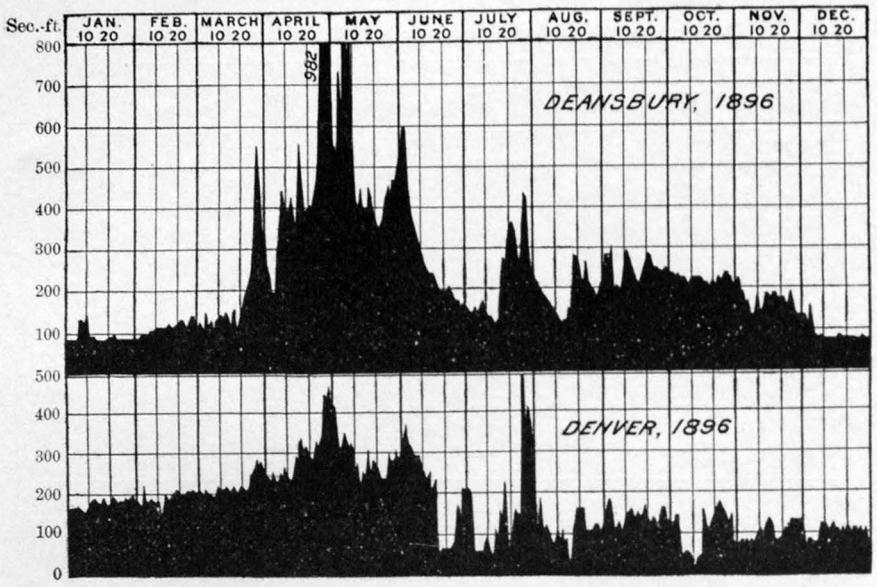



FIG. 25.—Discharge of South Platte River at Deansbury and Denver, Colorado, 1896.

## ORCHARD STATION ON SOUTH PLATTE RIVER.

This station is described in Bulletin No. 140, page 112. It is located one-fourth mile southwest of Orchard, Colorado, and was established November 20, 1895. The gage is inclined, consisting of two 2 by 4 inch planks, spiked together and fastened to posts driven into the river bank. It is marked to vertical 0.10 of a foot, the space between the marks being 0.127 of a foot. The bench mark consists of a 2 by 4 inch stick driven almost to the surface of the ground 8 feet back from the rod. The top of this is 0.30 foot above the 8-foot mark on the rod. The initial point for soundings is on the right shore. The left bank is high and the right low and liable to overflow, the bed of the stream being sandy and shifting. Measurements are made by wading, but a sufficient number have not been obtained for the estimation of the daily discharge. The primary object of this station is to obtain the winter flow of the Platte at this point. The station was reopened December 1, 1896. The observer is Mr. W. N. Bachelder.

On November 21, 1895, a station was established at Green City bridge, about 6 miles west of Orchard. The river at that point discharges through two channels, and as for other reasons the location is not a desirable one, the station was abandoned March 18, 1896. The record of daily gage heights for 1895, from November 22 to December 31, and 1896, from January 1 to April 4 and from December 1 to 31, is given in Water-Supply and Irrigation Paper No. 11, page 53.

*List of discharge measurements made on South Platte River at Orchard, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Nov. 20 | P. J. Preston ..... | 21 | 4.00 | 327 | 2.53 | 829 |
| 2 | Dec. 27 | .....do ..... | 21 | 3.83 | 285 | 2.34 | 667 |
| | 1896. | | | | | | |
| 3 | Feb. 19 | H. A. Sumner..... | 21 | 3.90 | 287 | 2.33 | 669 |
| 4 | Oct. 22 | P. J. Preston ..... | 21 | 3.20 | 121 | 1.99 | 240 |
| 5 | Dec. 12 | .....do ..... | 21 | 4.55 | 294 | 1.87 | 550 |

## MORRISON STATION ON BEAR CREEK.

This station is described in Bulletin No. 140, page 106. It is in the Golden quadrangle, and was established May 19, 1895, in the upper part of Morrison, Colorado. During the flood of July 24, 1896, the gage rod was washed out, and a new rod was placed in the stream on August 4, 1896, about 150 feet above the railroad depot. This rod consists of two inclined planks, 2 by 4 inches by 8 feet long, spiked together, and fastened to posts driven into the ground. It is divided into vertical tenths of a foot, the space between the marks being 0.127 of a foot. Three nails in a tree in right bank 190.5 feet below gage rod are 10.14 feet above zero of gage. Both banks are low and liable to overflow at high water. Measurements are made by wading, but the bridge above the gage can be used at high water.

From level notes taken August 4, 1896, the following approximate estimate is made of the discharge of Bear Creek at this point during the flood of Friday, July 24, 1896: Depth in main channel, 5.40 feet; velocity of main channel, 19.80 feet per second; total area of cross section, 465 square feet; total discharge, 8,600 second-feet; high-water mark of the flood referred to the present gage at the 10.90-foot mark. The cross section was taken some 200 feet above the present gage. The observer is Mr. Frank Ewers. The record of daily gage heights for 1896, from April 6 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 54.

*List of discharge measurements made on Bear Creek at Morrison, Colorado.*

| No. | Date | Hydrographer. | Meter number. | Gage height (feet) | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 18 | P. J. Preston..... | 21 | 0.90 | 22 | 2.17 | 47 |
| 2 | June 12 | .....do ..... | 21 | 2.05 | 69 | 4.77 | 331 |
| 3 | July 24 | .....do ..... | 21 | 1.65 | 58 | 2.96 | 171 |
| 4 | Oct. 9 | .....do ..... | 21 | 1.05 | 30 | 2.15 | 64 |
| | 1896. | | | | | | |
| 5 | June 17 | P. J. Preston..... | 21 | 0.75 | 23 | 1.41 | 32 |
| 6 | Aug. 4 | .....do ..... | 21 | 2.90 | 18 | 3.00 | 55 |
| 7 | Sept. 19 | R. S. Sumner..... | 21 | 3.05 | 21 | 3.80 | 80 |
| 8 | Oct. 30 | P. J. Preston ..... | 21 | 2.55 | 11 | 1.44 | 16 |

*Rating table for Bear Creek at Morrison, Colorado.*

[This table is applicable from January 1, 1896, to August 4, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.60 | 11 | 1.10 | 71 | 1.50 | 137 | 1.90 | 249 |
| 0.70 | 23 | 1.20 | 86 | 1.60 | 159 | 2.00 | 299 |
| 0.80 | 34 | 1.30 | 101 | 1.70 | 184 | 2.10 | 370 |
| 0.90 | 46 | 1.40 | 118 | 1.80 | 213 | 2.15 | 417 |
| 1.00 | 58 | | | | | | |

*Rating table for Bear Creek at Morrison, Colorado.*

[This table is applicable from August 5, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.50 | 9 | 2.90 | 57 | 3.20 | 101 | 3.50 | 154 |
| 2.60 | 20 | 3.00 | 71 | 3.30 | 117 | 3.60 | 173 |
| 2.70 | 32 | 3.10 | 86 | 3.40 | 135 | 3.70 | 193 |
| 2.80 | 44 | | | | | | |

*Estimated monthly discharge of Bear Creek at Morrison, Colorado.*

[Drainage area, 170 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 6 to 30 | 86 | 23 | 49 | 2,425 | 0.28 | 0.29 |
| May | 71 | 34 | 51 | 3,136 | 0.35 | 0.30 |
| June | 58 | 23 | 32 | 1,904 | 0.21 | 0.19 |
| July 1 to 24 | 58 | 9 | 33 | 1,560 | 0.17 | 0.19 |
| August 5 to 31 | 71 | 38 | 53 | 2,835 | 0.30 | 0.31 |
| September | 71 | 38 | 50 | 2,975 | 0.32 | 0.29 |
| October | 44 | 26 | 35 | 2,152 | 0.22 | 0.20 |

## MARSHALL STATION ON SOUTH BOULDER CREEK.

This station is described in Bulletin No. 140, page 107. It is located about 3 miles west of Marshall and was established on May 14, 1895. The gage consists of an inclined 2 by 6 inch timber, with a 1 by 6 inch scale nailed to it, and is fastened to a tree and to stakes driven into the ground. It is marked to vertical 0.10 of a foot, the distance between the marks being 0.22 of a foot. The bench mark is a stone, 15 feet northwest of the gage, marked with black paint. Its elevation is 6.99 feet above zero of rod. Measurements are usually made by wading near the gage, but a footbridge 20 feet above can be used in high water. The "Community ditch" and the "South Boulder and Coal Creek ditch" both take out water above the gage, and this amount must be added to the discharge at the station to obtain total run-off of the drainage basin of the creek. The observer is Mr. C. E. Barber. The record of daily gage heights for 1896 from April 1 to October 31 is given in Water-Supply and Irrigation Paper No. 11, page 54.

*List of discharge measurements made on South Boulder Creek, near Marshall, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 14 | P. J. Preston | 21 | 2.00 | 53 | 3.09 | 164 |
| 2 | July 18 | do | 21 | 2.00 | 61 | 3.19 | 195 |
| 3 | Oct. 10 | do | 21 | 1.05 | 25 | 1.68 | 42 |
| | 1896. | | | | | | |
| 4 | July 3 | P. J. Preston | 21 | 1.50 | 38 | 2.34 | 88 |
| 5 | Aug. 8 | do | 21 | 0.96 | 19 | 1.45 | 27 |
| 6 | Sept. 24 | R. S. Sumner | 21 | 1.00 | 22 | 1.43 | a31 |
| 7 | Oct. 17 | P. J. Preston | 21 | 0.90 | 18 | 1.36 | 24 |

a Gaging made 3 miles above Marshall, Colorado.

*Rating table for South Boulder Creek at Marshall, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 15 | 1.20 | 52 | 1.70 | 122 | 2.20 | 288 |
| 0.75 | 16 | 1.25 | 57 | 1.75 | 132 | 2.25 | 323 |
| 0.80 | 18 | 1.30 | 63 | 1.80 | 143 | 2.30 | 358 |
| 0.85 | 21 | 1.35 | 69 | 1.85 | 155 | 2.35 | 401 |
| 0.90 | 24 | 1.40 | 75 | 1.90 | 167 | 2.40 | 443 |
| 0.95 | 27 | 1.45 | 82 | 1.95 | 181 | 2.45 | 493 |
| 1.00 | 31 | 1.50 | 89 | 2.00 | 196 | 2.50 | 543 |
| 1.05 | 36 | 1.55 | 97 | 2.05 | 214 | 2.55 | 603 |
| 1.10 | 41 | 1.60 | 105 | 2.10 | 233 | 2.60 | 663 |
| 1.15 | 46 | 1.65 | 113 | 2.15 | 260 | | |

*Estimated monthly discharge of South Boulder Creek near Marshall, Colorado.*

[Drainage area, 125 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| May 15 to 31 | 445 | 148 | 238 | 8,024 | 1.19 | 1.90 |
| June | 1,090 | 261 | 531 | 31,597 | 4.74 | 4.25 |
| July | 314 | 130 | 205 | 12,605 | 1.89 | 1.64 |
| August | 166 | 62 | 99 | 6,087 | 0.91 | 0.79 |
| September | 77 | 20 | 37 | 2,202 | 0.32 | 0.29 |
| October | 84 | 14 | 36 | 2,214 | 0.32 | 0.28 |

*Estimated monthly discharge of South Boulder Creek at Marshall, Colorado.*

[Drainage area, 125 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April | 167 | 18 | 72 | 4,284 | 0.64 | 0.58 |
| May | 603 | 97 | 219 | 13,465 | 2.02 | 1.75 |
| June | 358 | 105 | 204 | 12,138 | 1.82 | 1.63 |
| July | 105 | 52 | 75 | 4,612 | 0.69 | 0.60 |
| August | 167 | 27 | 42 | 2,582 | 0.39 | 0.34 |
| September | 46 | 31 | 37 | 2,202 | 0.33 | 0.30 |
| October | 31 | 18 | 23 | 1,414 | 0.21 | 0.18 |

## BOULDER STATION ON BOULDER CREEK.

This station is described in Bulletin No. 140, page 108. It is located about 1½ miles above the town of Boulder and was established on May 13, 1895. The gage rod consists of an inclined 2 by 6 inch timber, with a 1 by 6 inch scale fastened to it and spiked to stakes driven into the ground. It is marked to a vertical 0.10 foot, the space between the marks being 0.207 foot. The bench mark is a large stone, 20 feet north of the gage. Its elevation is 9.95 feet above the zero of the rod. The observer is Mrs. Carrie Osgood. Both banks are high and rocky and not liable to overflow. The bed of the creek is quite rocky. Measurements are usually made by wading, but during high water can be made from a bridge 40 feet above the gage. The record of daily gage heights for 1896, from April 1 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 55.

*List of discharge measurements made on Boulder Creek at Boulder, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square (feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 17 | P. J. Preston..... | 21 | 1.90 | 83 | 3.80 | 317 |
| 2 | Oct. 3 | .....do ..... | 21 | 0.50 | 32 | 1.04 | 36 |
| | 1896. | | | | | | |
| 3 | July 2 | P. J. Preston..... | 21 | 1.30 | 51 | 2.71 | 139 |
| 4 | July 30 | .....do ..... | 21 | 1.10 | 46 | 2.40 | 110 |
| 5 | Sept. 23 | R. S. Sumner..... | 21 | 0.80 | 31 | 2.22 | 69 |
| 6 | Oct. 16 | P. J. Preston..... | 21 | 0.50 | 21 | 1.71 | 35 |

*Rating table for Boulder Creek at Boulder, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.20 | 7 | 0.75 | 63 | 1.30 | 141 | 1.85 | 292 |
| 0.25 | 11 | 0.80 | 69 | 1.35 | 150 | 1.90 | 317 |
| 0.30 | 15 | 0.85 | 75 | 1.40 | 159 | 1.95 | 363 |
| 0.35 | 20 | 0.90 | 81 | 1.45 | 169 | 2.00 | 410 |
| 0.40 | 25 | 0.95 | 87 | 1.50 | 180 | 2.05 | 467 |
| 0.45 | 30 | 1.00 | 94 | 1.55 | 192 | 2.10 | 523 |
| 0.50 | 35 | 1.05 | 101 | 1.60 | 204 | 2.15 | 590 |
| 0.55 | 40 | 1.10 | 108 | 1.65 | 218 | 2.20 | 656 |
| 0.60 | 46 | 1.15 | 116 | 1.70 | 232 | 2.25 | 733 |
| 0.65 | 51 | 1.20 | 124 | 1.75 | 250 | 2.30 | 809 |
| 0.70 | 57 | 1.25 | 132 | 1.80 | 268 | | |

*Estimated monthly discharge of Boulder Creek at Boulder, Colorado.*

[Drainage area, 179 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| May 14 to 31 | 421 | 229 | 316 | 11,286 | 1.19 | 1.77 |
| June | 750 | 382 | 502 | 29,871 | 3.12 | 2.80 |
| July | 550 | 261 | 355 | 21,827 | 2.28 | 1.98 |
| August | 345 | 132 | 205 | 12,605 | 1.33 | 1.15 |
| September | 145 | 58 | 86 | 5,117 | 0.54 | 0.48 |
| October | 114 | 5 | 44 | 2,705 | 0.29 | 0.25 |
| 1896. | | | | | | |
| April | 292 | 7 | 80 | 4,760 | 0.50 | 0.45 |
| May | 809 | 87 | 240 | 14,757 | 1.54 | 1.34 |
| June | 466 | 141 | 264 | 15,709 | 1.65 | 1.48 |
| July | 250 | 101 | 150 | 9,223 | 0 97 | 0.84 |
| August | 218 | 46 | 88 | 6,210 | 0.64 | 0.56 |
| September | 108 | 46 | 73 | 4,344 | 0.46 | 0.41 |
| October | 51 | 20 | 33 | 2,029 | 0.21 | 0.18 |

## LYONS STATION ON ST. VRAIN CREEK.

This station is described in Bulletin No. 140, page 109. It is located one-half mile southeast of Lyons, below the intersection of the north and south forks of the St. Vrain, and was established May 11, 1895. The supply ditch takes water out on the left side of the stream above the gage. To obtain the total run-off of the drainage basin of the creek at this station the amount of water in the ditch will have to be added to the discharge of the creek. The gage is an inclined 2 by 4 inch timber marked to vertical 0.10 of a foot, the space between the marks being 0.134 of a foot, and is fastened to posts driven into the ground. Both banks are low and liable to overflow, and the bed of the stream is composed of gravel. Measurements are usually made by wading, but at high water can be made from a wagon bridge 400 feet below the gage. The observer is Miss Bessie Sites. The record of daily gage heights for 1896, from April 1 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 55.

*List of discharge measurements made on St. Vrain Creek at Lyons, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 11 | P. J. Preston..... | 21 | 1.65 | 78 | 3.33 | 260 |
| 2 | July 20 | .....do ..... | 21 | 3.40 | 103 | 3.27 | 336 |
| 3 | Oct. 2 | .....do ..... | 21 | 2.10 | 24 | 2.78 | 65 |
| | 1896. | | | | | | |
| 4 | June 6 | P. J. Preston..... | 21 | 3.57 | 119 | 3.27 | 389 |
| 5 | July 29 | .....do ..... | 21 | 2.70 | 43 | 4.41 | 189 |
| 6 | Sept. 22 | R. S. Sumner..... | 21 | 2.50 | 56 | 1.98 | 110 |
| 7 | Oct. 14 | P. J. Preston..... | 21 | 2.22 | 36 | 1.49 | 53 |

*Rating table for St. Vrain Creek at Lyons, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.60 | 5 | 2.45 | 103 | 3.10 | 283 | 3.75 | 428 |
| 1.70 | 6 | 2.50 | 116 | 3.15 | 295 | 3.80 | 439 |
| 1.80 | 7 | 2.55 | 131 | 3.20 | 306 | 3.85 | 450 |
| 1.90 | 9 | 2.60 | 146 | 3.25 | 318 | 3.90 | 462 |
| 2.00 | 12 | 2.65 | 163 | 3.30 | 329 | 3.95 | 473 |
| 2.05 | 18 | 2.70 | 180 | 3.35 | 340 | 4.00 | 484 |
| 2.10 | 27 | 2.75 | 195 | 3.40 | 351 | 4.05 | 495 |
| 2.15 | 37 | 2.80 | 209 | 3.45 | 362 | 4.10 | 506 |
| 2.20 | 47 | 2.85 | 222 | 3.50 | 373 | 4.15 | 517 |
| 2.25 | 57 | 2.90 | 235 | 3.55 | 384 | 4.20 | 529 |
| 2.30 | 67 | 2.95 | 247 | 3.60 | 395 | 4.25 | 540 |
| 2.35 | 78 | 3.00 | 259 | 3.65 | 406 | 4.30 | 551 |
| 2.40 | 90 | 3.05 | 271 | 3.70 | 417 | | |

*Estimated monthly discharge of St. Vrain Creek at Lyons, Colorado.*

[Drainage area, 209 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| June 13 to 30 | 1,040 | 430 | 711 | 25,380 | 2.34 | 3.40 |
| July | 680 | 259 | 410 | 25,210 | 2.26 | 1.96 |
| August | 488 | 134 | 229 | 14,080 | 1.27 | 1.10 |
| September | 125 | 72 | 93 | 5,534 | 0.49 | 0.44 |
| October | 230 | 80 | 189 | 11,621 | 1.04 | 0.90 |
| 1896. | | | | | | |
| April | 247 | 5 | 74 | 4,403 | 0.39 | 0.35 |
| May | 573 | 103 | 229 | 14,080 | 1.27 | 1.10 |
| June | 417 | 195 | 320 | 19,041 | 1.71 | 1.53 |
| July | 417 | 116 | 211 | 12,974 | 1.16 | 1.01 |
| August | 529 | 47 | 154 | 9,776 | 0.87 | 0.76 |
| September | 373 | 67 | 129 | 7,676 | 0.68 | 0.61 |
| October | 90 | 5 | 55 | 3,382 | 0.30 | 0.26 |

## ARKINS STATION ON BIG THOMPSON CREEK.

This station is described in Bulletin No. 140, page 110. It is located about 9 miles west of Loveland and about 600 feet below the "Home Supply Dam," and was established May 9, 1895. The gage is vertical, unpainted, but notched for each foot and 0.10 of a foot, and is fastened to the timbers of a bridge. The bench mark is a notch in a tree about 50 feet below the gage, on the left-hand side of the stream. Its elevation is 4.92 feet above the zero of the rod. The right bank is high, but the left is low and liable to overflow at high water. The bed of the stream is of gravel with some bowlders. Measurements are usually made from the upper side of the wagon bridge. The head-gates of the Home Supply Ditch and Handy Ditch are located above the dam. The observer is Mr. E. Chasteen. The record of daily gage heights for 1896, from April 28 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 56.

*List of discharge measurements made on Big Thompson Creek near Arkins, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height. (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 9 | P. J. Preston..... | 21 | 1.25 | 120 | 2.17 | 260 |
| 2 | July 19 | .....do ..... | 21 | 1.90 | 139 | 3.59 | 499 |
| 3 | Oct. 1 | .....do ..... | 21 | 0.45 | 56 | 0.75 | 42 |
| | 1896. | | | | | | |
| 4 | June 1 | P. J. Preston..... | 21 | 1.70 | 128 | 3.14 | 403 |
| 5 | July 28 | .....do ..... | 21 | 1.50 | 112 | 2.56 | 286 |
| 6 | Oct. 15 | .....do ..... | 21 | 0.80 | 74 | 1.01 | 74 |

*Rating table for Big Thompson Creek near Arkins, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.10 | 6 | 0.65 | 40 | 1.20 | 180 | 1.75 | 443 |
| 0.15 | 8 | 0.70 | 50 | 1.25 | 195 | 1.80 | 483 |
| 0.20 | 10 | 0.75 | 62 | 1.30 | 211 | 1.85 | 524 |
| 0.25 | 12 | 0.80 | 74 | 1.35 | 228 | 1.90 | 566 |
| 0.30 | 15 | 0.85 | 86 | 1.40 | 246 | 2.00 | 649 |
| 0.35 | 18 | 0.90 | 99 | 1.45 | 266 | 2.05 | 692 |
| 0.40 | 21 | 0.95 | 112 | 1.50 | 286 | 2.10 | 735 |
| 0.45 | 24 | 1.00 | 125 | 1.55 | 311 | 2.15 | 778 |
| 0.50 | 27 | 1.05 | 138 | 1.60 | 337 | 2.20 | 821 |
| 0.55 | 30 | 1.10 | 152 | 1.65 | 370 | 2.25 | 866 |
| 0.60 | 34 | 1.15 | 166 | 1.70 | 403 | 2.30 | 911 |

*Estimated monthly discharge of Big Thompson Creek near Arkins, Colorado.*

[Drainage area, 305 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896 | | | | | | |
| May | 911 | 5 | 218 | 13,404 | 0.83 | 0.72 |
| June | 483 | 180 | 285 | 16,959 | 1.03 | 0.93 |
| July | 403 | 152 | 225 | 13,834 | 0.85 | 0.74 |
| August | 443 | 38 | 144 | 8,854 | 0.54 | 0.47 |
| September | 195 | 74 | 119 | 7,081 | 0.44 | 0.39 |
| October | 138 | 20 | 66 | 4,058 | 0.25 | 0.22 |

## LOUP RIVER.

### ST. PAUL STATION ON NORTH LOUP RIVER.

[Drainage area, 4,024 square miles.]

This station is on the left bank, at the lower side of the wagon bridge, 4 miles north of St. Paul, Nebraska, in the St. Paul quadrangle. The gage consists of a piece of oak 2 by 3 inches, 16 feet long, with the face inclined 30 degrees to the horizontal. This rests upon cross-ties well bedded and covered, the bottom of the rod being thrust into the bed of the river. The zero of this rod is 15.01 feet below the top of the lower horizontal projecting part of the footplate at the north end of the west truss of the north span of the bridge. The observer is James Stout, jr. A description of this station, together with the results obtained in 1895, is given on pages 114 and 115 of Bulletin No. 140. The gage and the observer are the same as for 1895. A daily record of gage heights has been obtained for the period from March 29 to November 1. Soundings made by the observer at intervals during the season have proved to be of little value in making up the record of discharge. The record of the year's soundings and discharge measurements is presented in the following table:

*List of measurements made on North Loup River at St. Paul, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| May 9 | E. N. Corbin | 78 | 3.40 | 455 | 2.50 | 1,138 |
| May 24 | Jas. Stout, jr | ..... | 3.33 | 456 | ..... | ..... |
| June 1 | .....do | ..... | 3.48 | 495 | ..... | ..... |
| June 11 | O. V. P. Stout | 78 | 2.30 | ..... | ..... | 1,337 |
| July 7 | James Stout, jr | ..... | 2.30 | 578 | ..... | ..... |
| July 9 | E. T. Youngfelt | (*a*) | 2.10 | 420 | 2.67 | 1,120 |
| July 15 | Jas Stout, jr | ..... | 2.10 | 623 | ..... | ..... |
| Aug. 2 | .....do | ..... | 2.10 | 584 | ..... | ..... |
| Aug. 15 | .....do | ..... | 2.07 | 517 | ..... | ..... |
| Aug. 21 | E. T. Youngfelt | (*a*) | 2.05 | 433 | 2.03 | 880 |
| Sept. 1 | Jas. Stout, jr | ..... | 2.04 | 530 | ..... | ..... |
| Sept. 15 | .....do | ..... | 2.22 | 546 | ..... | ..... |
| Sept. 23 | E. T. Youngfelt | (*a*) | 2.15 | 454 | 2.06 | 935 |
| Oct. 2 | Jas. Stout, jr | ..... | 2.20 | 489 | ..... | ..... |
| Oct. 17 | .....do | ..... | 2.15 | 697 | ..... | ..... |
| Nov. 2 | .....do | ..... | 2.20 | 730 | ..... | ..... |
| Nov. 14 | .....do | ..... | 2.20 | 588 | ..... | ..... |

*a* Price acoustic.

Up to the time of the flood on June 5 and 6 the general appearance of the river at the gaging station was as in 1895. The discharge on May 9, 1896, with a gage height of 3.40, was found to be 1,138 second-feet. This discharge corresponds in the rating table for 1895 to a height of 3.15 feet on the gage. The discharge from April 1 to June 5, 1896, has been estimated by adding 3.40 minus 3.15, equal 0.25 feet to the observed gage height, and taking from the rating table for 1895 the discharge corresponding to the resulting gage height. A rating table has been prepared which applies either directly or indirectly to the various subperiods from June 7 to November 1, 1896.

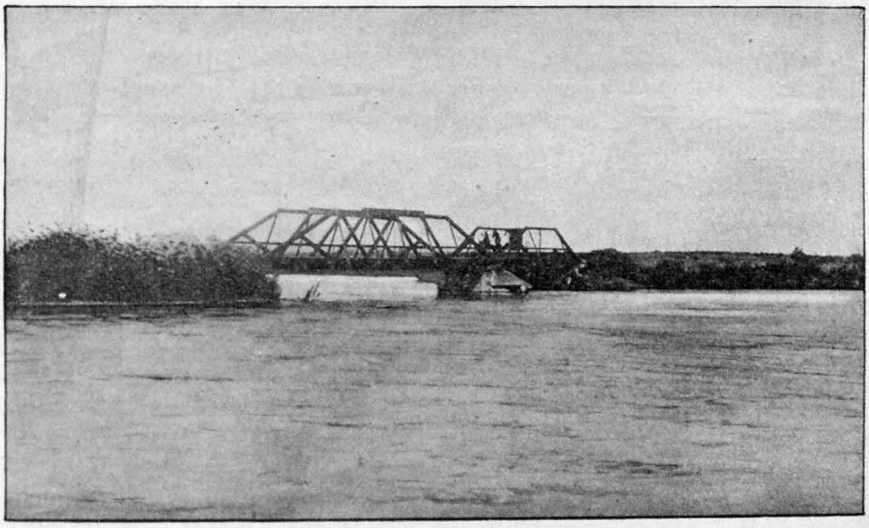


FIG. 26.—North Loup River near Burwell, Nebraska.

*Rating table for North Loup River at St. Paul, Nebraska.*

[Applying in general indirectly to the period succeeding the flood of June, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.50 | 465 | 2.20 | 1,000 | 2.90 | 1,660 | 3.50 | 2,290 |
| 1.60 | 530 | 2.30 | 1,080 | 3.00 | 1,760 | 3.60 | 2,400 |
| 1.70 | 600 | 2.40 | 1,175 | 3.10 | 1,860 | 3.70 | 2,525 |
| 1.80 | 680 | 2.50 | 1,260 | 3.20 | 1,960 | 3.80 | 2,625 |
| 1.90 | 750 | 2.60 | 1,360 | 3.30 | 2,060 | 3.90 | 2,750 |
| 2.00 | 835 | 2.70 | 1,460 | 3.40 | 2,175 | 3.95 | 2,825 |
| 2.10 | 915 | 2.80 | 1,560 | | | | |

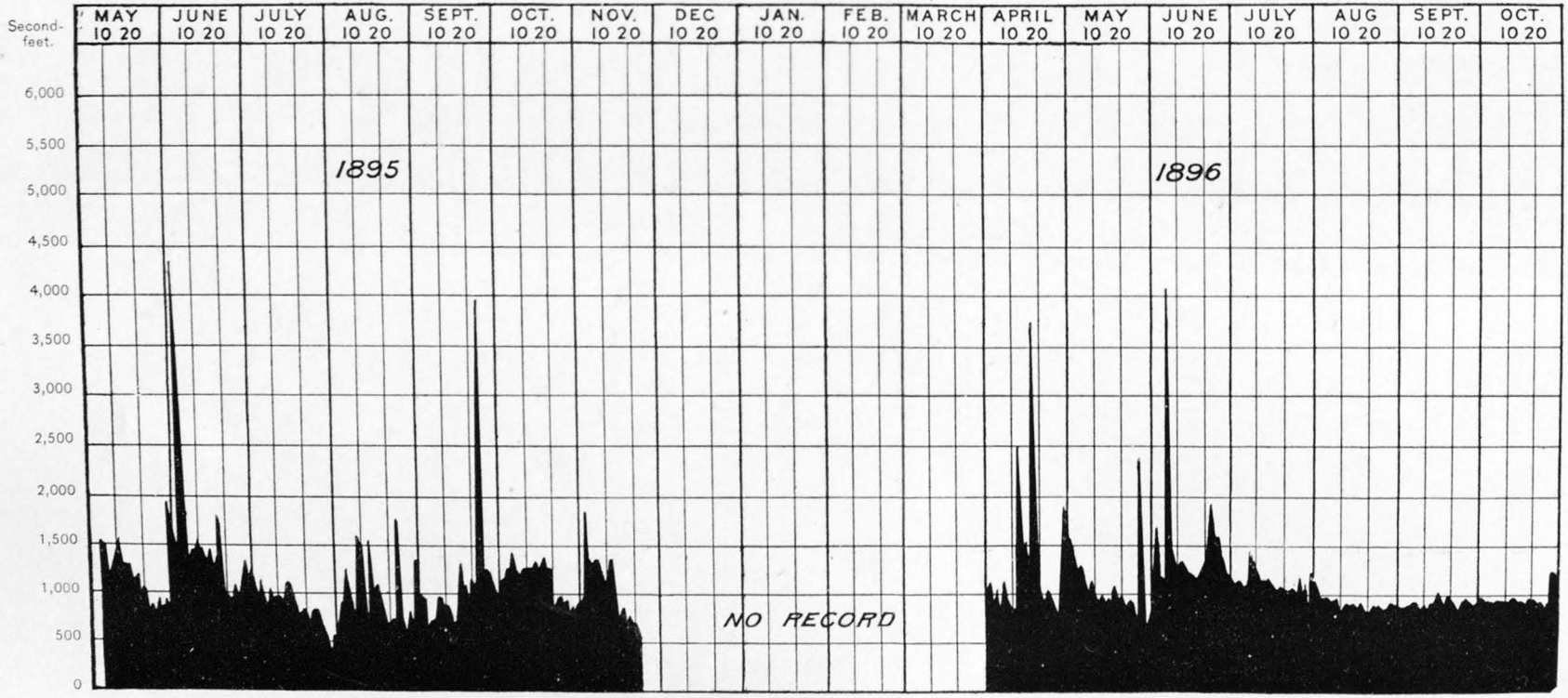
The indirect method of applying a rating table to the deduction of discharge from observed gage heights is explained in the following

pages in connection with the discussion of the period following the June flood in the Loup River at Columbus. The discharge estimated in this manner is recorded in the following table:

*Daily mean discharge in cubic feet per second of North Loup River at St. Paul, Nebraska.*

| Day. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|---|
| 1 | 1,078 | 1,521 | 1,698 | 1,138 | 1,072 | 860 | 949 |
| 2 | 1,139 | 1,455 | 1,455 | 1,110 | 992 | 843 | 965 |
| 3 | 930 | 1,233 | 1,139 | 1,120 | 957 | 835 | 915 |
| 4 | 1,078 | 1,263 | 1,139 | 1,080 | 992 | 883 | 932 |
| 5 | 844 | 1,263 | 1,170 | 1,080 | 974 | 890 | 932 |
| 6 | 987 | 1,139 | 4,100 | 1,072 | 949 | 908 | 923 |
| 7 | 1,139 | 1,078 | 2,825 | 1,100 | 915 | 932 | 923 |
| 8 | 987 | 987 | 1,540 | 1,128 | 932 | 883 | 940 |
| 9 | 901 | 1,139 | 1,340 | 1,460 | 957 | 851 | 940 |
| 10 | 844 | 987 | 1,260 | 1,350 | 860 | 883 | 940 |
| 11 | 844 | 901 | 1,337 | 1,200 | 850 | 860 | 940 |
| 12 | 2,519 | 958 | 1,290 | 1,128 | 890 | 908 | 965 |
| 13 | 1,962 | 901 | 1,270 | 1,120 | 900 | 932 | 983 |
| 14 | 1,455 | 930 | 1,230 | 1,128 | 883 | 1,016 | 949 |
| 15 | 1,553 | 901 | 1,200 | 1,090 | 900 | 1,000 | 949 |
| 16 | 1,263 | 1,078 | 1,165 | 1,048 | 867 | 883 | 949 |
| 17 | 1,455 | 1,203 | 1,155 | 1,032 | 875 | 908 | 923 |
| 18 | 3,767 | 987 | 1,147 | 1,056 | 900 | 957 | 915 |
| 19 | 1,962 | 873 | 1,257 | 1,072 | 843 | 1,016 | 965 |
| 20 | 1,293 | 987 | 1,330 | 1,064 | 835 | 983 | 965 |
| 21 | 958 | 844 | 1,540 | 1,032 | 867 | 940 | 949 |
| 22 | 958 | 901 | 1,930 | 1,008 | 899 | 890 | 923 |
| 23 | 1,048 | 958 | 1,590 | 1,016 | 875 | 867 | 940 |
| 24 | 958 | 930 | 1,530 | 1,056 | 890 | 932 | 923 |
| 25 | 901 | 901 | 1,560 | 991 | 867 | 923 | 888 |
| 26 | 844 | 702 | 1,370 | 1,184 | 867 | 949 | 837 |
| 27 | 779 | 2,327 | 1,370 | 983 | 867 | 923 | 880 |
| 28 | 1,139 | 759 | 1,300 | 1,056 | 890 | 923 | 940 |
| 29 | 1,962 | 570 | 1,212 | 923 | 900 | 890 | 1,220 |
| 30 | 1,618 | 702 | 1,184 | 1,184 | 883 | 923 | 1,220 |
| 31 | ..... | 873 | ..... | 1,155 | 890 | ..... | 1,120 |
| Mean .. | 1,305 | 1,040 | 1,494 | 1,102 | 904 | 913 | 958 |

On the night of June 5 rains of unprecedented volume and intensity fell upon the watershed of this stream, so that on the morning of June 6 the river was discharging a volume of water greater than had ever been known before. At the gaging station it was 3,000 feet wide, and




DISCHARGE OF NORTH LOUP RIVER AT ST. PAUL, NEBRASKA, 1895-96.

the surface of the water rose to a height of 14.9 feet[1] above zero of the gage. The average depth of the water for the entire width was about 6 feet. It is estimated that the maximum rate of discharge was 90,000 cubic feet per second. The two 100-foot truss spans at the south end of the bridge at the gaging station were carried away, and the current cut the channel far into the south bank above the site of the bridge.

The gage was not disturbed, as it was protected from the current by the north pier of the bridge. A large quantity of sand from the bed of the river was scoured out and deposited on the adjoining fields. Just before the flood the ordinary gage heights ranged from 3.20 feet to 3.40 feet above zero of the gage. After the flood subsided the range was from 2.10 to 2.55 feet, thus indicating that the surface of the water at ordinary stages had been lowered to the extent of about 1 foot.

### ST. PAUL STATION ON MIDDLE LOUP RIVER.

This station is located on the right bank of the stream at the lower side of the wagon and railroad bridge, 1 mile south of St. Paul, Nebraska, in the St. Paul quadrangle. The drainage area is 6,849 square miles. The gage consists of an oak stick, 2 by 3 inches, 16 feet long, inclined 30 degrees to the horizon. This is securely fastened to cross-ties bedded in the soil. The zero of the rod is 9.62 feet below the bottom of the downstream end of the cap of the first river bent at the south end of the bridge. This station was established and observations were commenced on May 5, 1895. A description of the station and a record of the results obtained in 1895 are to be found on pages 115–118 of Bulletin No. 140. The observer is A. C. Snyder, a farmer, who lives one-third of a mile distant.

A daily record of gage heights has been obtained for the period from March 29 to December 1, 1896. Soundings were made by the observer at frequent intervals throughout the season. It was hoped that these soundings would supplement the measurements of discharge in such a way as to make possible a more satisfactory rating of the station than that which is based on discharge measurements alone. In this instance the soundings were of some value for the purpose intended. In the following table are recorded the results of the soundings and the discharge measurements made in 1896:

[1] According to high-water mark and levels run by Mr. Robert Harvey, civil engineer of St. Paul.

*List of discharge measurements made on Middle Loup River, at St. Paul, Nebraska.*

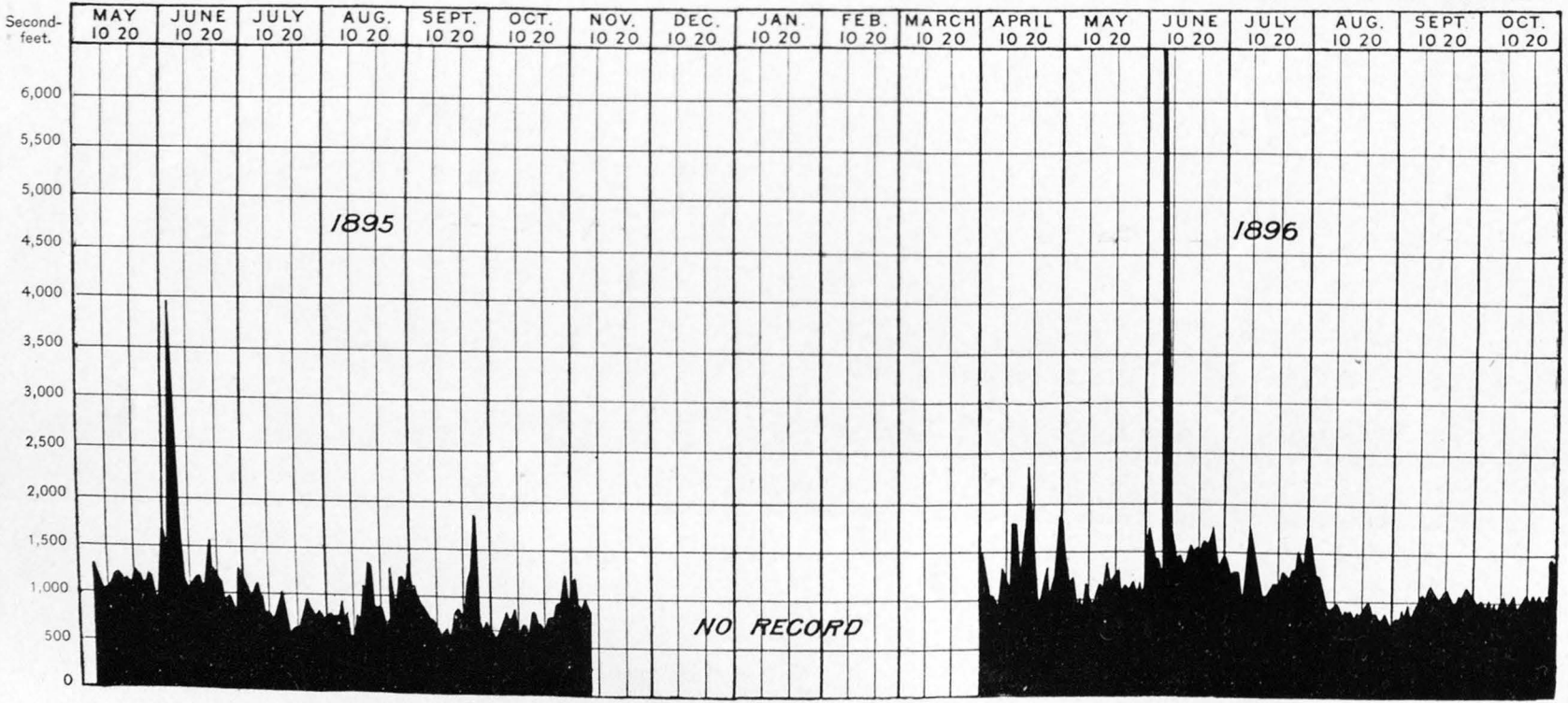
| Date. | Hydrographer. | Meter number. | Gage height (feet) | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). | Mean depth in feet. |
|---|---|---|---|---|---|---|---|
| 1896. | | | | | | | |
| May 8 | E. N. Corbin.... | 78 | 1.36 | 466 | 2.02 | 940 | 0.78 |
| May 21 | A. C. Snyder.... | ..... | 1.55 | 596 | ..... | ..... | 0.87 |
| June 1 | .....do ..... | ..... | 1.80 | 973 | ..... | ..... | 1.36 |
| June 11 | O. V. P. Stout... | 78 | 1 24 | 475 | 2.95 | 1,400 | 1.25 |
| July 1 | A. C. Snyder.... | ..... | 1.35 | 653 | ..... | ..... | 1.39 |
| July 9 | E. T. Youngfelt. | (*a*) | 1.42 | 608 | 2.19 | 1,332 | 1.13 |
| July 15 | A. C. Snyder.... | ..... | 1.26 | 483 | ..... | ..... | 1.17 |
| Aug. 1 | .....do ..... | ..... | 1.62 | 688 | ..... | ..... | 1.25 |
| Aug. 15 | .....do ..... | ..... | 1.34 | 452 | ..... | ..... | 0.92 |
| Aug. 21 | E. T. Youngfelt. | (*a*) | 1.42 | 511 | 1.92 | 984 | 0.91 |
| Sept. 1 | A. C. Snyder.... | ..... | 1.30 | 440 | ..... | ..... | 0.96 |
| Sept. 15 | .....do ..... | ..... | 1.61 | 627 | ..... | ..... | 1.09 |
| Sept. 23 | E. T. Youngfelt. | (*a*) | 1.53 | 560 | 1.81 | 1,015 | 0.93 |
| Oct. 1 | A. C. Snyder.... | ..... | 1.50 | 533 | ..... | ..... | 0.98 |
| Oct. 15 | .....do ..... | ..... | 1.55 | 606 | ..... | ..... | 1.02 |

*a* Price acoustic.

It is evident that very little relation is discoverable between gage heights and discharge, hence no rating table is offered. In making up the record of daily discharge for the following table a method was used which is quite tedious in detail. It was based upon the principle credited to Prof. A. M. Ryon on page 87 of Bulletin No. 140.

*Daily mean discharge, in cubic feet per second, of Middle Loup River at St. Paul, Nebraska, for 1896.*

| Day. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|---|
| 1..... | 1,490 | 1,440 | 1,720 | 1,315 | 1,685 | 806 | 970 |
| 2..... | 1,360 | 1,300 | 1,550 | 1,240 | 1,550 | 806 | 1,022 |
| 3..... | 1,060 | 1,150 | 1,430 | 1,270 | 1,450 | 854 | 914 |
| 4..... | 1,020 | 1,230 | 1,460 | 1,270 | 1,200 | 914 | 880 |
| 5..... | 1,030 | 1,050 | 1,290 | 1,270 | 1,210 | 818 | 985 |
| 6..... | 900 | 900 | ..... | 1,195 | 1,125 | 962 | 1,010 |
| 7..... | 1,020 | 1,015 | ..... | 1,080 | 955 | 782 | 938 |
| 8..... | 1,170 | 870 | 2,250 | 960 | 942 | 794 | 1,000 |
| 9..... | 1,310 | 1,360 | 1,774 | 1,332 | 900 | 806 | 914 |
| 10..... | 1,200 | 1,015 | 1,515 | 1,770 | 955 | 974 | 1,046 |
| 11..... | 1,050 | 890 | 1,400 | 1,420 | 980 | 1,058 | 1,082 |
| 12..... | 1,800 | 1,030 | 1,465 | 1,270 | 942 | 1,010 | 1,010 |
| 13..... | 1,800 | 1,060 | 1,300 | 1,200 | 840 | 1,034 | 974 |
| 14..... | 1,730 | 1,150 | 1,300 | 1,100 | 885 | 1,190 | 1,034 |




DISCHARGE OF MIDDLE LOUP RIVER AT ST. PAUL, NEBRASKA, 1895–96.

*Daily mean discharge, in cubic feet per second, of Middle Loup River at St. Paul, Nebraska, for 1896*—Continued.

| Day. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|---|
| 15 | 1,210 | 1,080 | 1,560 | 1,040 | 870 | 1,142 | 1,110 |
| 16 | 1,330 | 1,440 | 1,590 | 1,050 | 890 | 1,070 | 962 |
| 17 | 1,360 | 1,300 | 1,540 | 1,110 | 810 | 1,058 | 974 |
| 18 | 2,000 | 1,260 | 1,485 | 1,170 | 890 | 1,000 | 1,000 |
| 19 | 2,430 | 1,165 | 1,560 | 1,160 | 870 | 1,058 | 1,070 |
| 20 | 1,730 | 1,210 | 1,470 | 1,170 | 955 | 1,118 | 1,106 |
| 21 | 1,070 | 1,310 | 1,660 | 1,260 | 984 | 1,130 | 1,010 |
| 22 | 910 | 1,080 | 1,650 | 1,220 | 1,000 | 1,046 | 1,082 |
| 23 | 1,170 | 1,170 | 1,580 | 1,210 | 880 | 1,015 | 1,000 |
| 24 | 1,210 | 1,080 | 1,795 | 1,300 | 840 | 926 | 1,070 |
| 25 | 1,340 | 1,170 | 1,820 | 1,300 | 880 | 985 | 985 |
| 26 | 1,000 | 1,210 | 1,645 | 1,440 | 820 | 1,034 | 1,094 |
| 27 | 1,190 | 1,200 | 1,505 | 1,540 | 760 | 1,036 | 1,070 |
| 28 | 1,300 | 1,000 | 1,417 | 1,480 | 820 | 1,106 | 1,010 |
| 29 | 1,860 | 1,215 | 1,315 | 1,320 | 855 | 1,154 | 1,370 |
| 30 | 1,860 | 1,070 | 1,455 | 1,280 | 746 | 1,094 | 1,478 |
| 31 | ..... | 1,345 | ..... | 1,670 | 722 | ..... | 1,106 |
| Mean .. | 1,364 | 1,154 | 1,542 | 1,271 | 975 | 993 | 1,041 |

Heavy rains which fell in the valleys of small tributaries of this stream caused a considerable freshet on June 6. The gage heights on that day, as noted by Observer Snyder, are as follows: 1.54 at 6 a. m.; 4.52 at 8 a. m.; 4.55 at 8.30 a. m.; 4.60 at 8.45 a. m.; 4.70 at 9 a. m.; 4.75 at 9.15 a. m.; 4.82 at 9.35 a. m.; 4.85 at 10.25 a. m.; 3.50 at 6 p. m., and 3.95 at 10 p. m. At 6 a. m. on June 7 the gage read 3.35. The observer notes that the freshet was caused by a cloudburst on Oak and Turkey creeks. It is estimated that the maximum rate of discharge was 16,000 cubic feet per second. The damage caused by the freshet was confined to the valleys of the small streams.

## MISCELLANEOUS DISCHARGE MEASUREMENTS.

The following measurements at points other than regular stations were made by Prof. O. V. P. Stout in 1896:

| Date. | Name of stream. | Where measured. | Meter number. | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Aug. 29 | South Loup..... | Ravenna ... | 105 | 98 | 1.45 | 142 |
| Aug. 30 | Middle Loup.... | Seneca ..... | 105 | 94 | 2.26 | 212 |
| Do.... | .....do ..... | Dunning ... | 105 | 218 | 1.48 | 323 |

## COLUMBUS STATION ON LOUP RIVER.

This station was described on page 32 of Bulletin No. 131, and the results obtained up to the end of 1895 were published on pages 118–120 of Bulletin No. 140. Gage heights have been observed twice daily in 1896 until December 1. The station is located just above the iron bridge of the Union Pacific Railway, just west of Columbus, Nebraska, in the David City quadrangle. The drainage area is 13,542 square miles, and is partly mapped on the David City, Stromsburg, St. Paul, Grand Island, Wood River, Loup, Hazard, Kearney, and Brady Island atlas sheets. The observer is M. Savage, bridge watchman. The distance of the observer's house from the gaging station is about a half mile; from the bridge, 50 yards. The gage is of oak, 3 inches by 6 inches, 12 feet long, fastened by lag screws to a pile, which forms part of the training works above the bridge. The rod is vertical. The 12-foot mark on the rod is 7 feet below a point 2 feet east of the third panel-point of the north truss of the east span, counting the end of the span as the first panel-point. All levels are taken from the top of the bottom chord. This is not a good location, but after considerable search it seemed to be the best available. Observations were begun October 13, 1894. Soundings and discharge measurements were made in 1896, as noted in the following table:

*List of discharge measurements made on Loup River at Columbus, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Mar. 15 | O. V. P. Stout | Floats. | 3.88 | 475 | 3.27 | 1,550 |
| May 3 | Wm. Grant | 78 | 5.12 | 1,194 | 3.56 | 4,256 |
| June 4 | O. V. P. Stout | 78 | 4.76 | 957 | 3.37 | 3,222 |
| June 24 | do | 78 | 4.10 | 1,057 | 3.04 | 3,206 |
| June 30 | M. Savage | | 3.90 | 921 | | |
| July 14 | do | | 4.08 | 814 | | |
| July 22 | E. T. Youngfelt | 78 | 3.91 | 835 | 2.90 | 2,420 |
| July 31 | M. Savage | | 4.14 | 846 | | |
| Aug. 10 | do | | 3.96 | 887 | | |
| Aug. 28 | E. T. Youngfelt | 78 | 3.75 | 726 | 3.08 | 2,234 |
| Sept. 8 | M. Savage | | 3.78 | 931 | | |
| Sept. 25 | E. T. Youngfelt | 78 | 4.09 | 797 | 2.97 | 2,370 |
| Sept. 30 | M. Savage | | 4.05 | 778 | | |

GAGING STATION ON MIDDLE LOUP RIVER AT ST. PAUL, NEBRASKA.

*Rating table for Loup River at Columbus, Nebraska.*

[This table is applicable only from April 1, 1896, to June 5, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.50 | 640 | 4.20 | 1,888 | 4.90 | 3,613 | 5.60 | 5,797 |
| 3.60 | 788 | 4.30 | 2,106 | 5.00 | 3,897 | 5.70 | 6,146 |
| 3.70 | 947 | 4.40 | 2,334 | 5.10 | 4,190 | 5.80 | 6,504 |
| 3.80 | 1,116 | 4.50 | 2,572 | 5.20 | 4,494 | 5.90 | 6,871 |
| 3.90 | 1,296 | 4.60 | 2,817 | 5.30 | 4,807 | 6.00 | 7,248 |
| 4.00 | 1,483 | 4.70 | 3,073 | 5.40 | 5,128 | | |
| 4.10 | 1,680 | 4.80 | 3,338 | 5.50 | 5,458 | | |

Inasmuch as no permanent relation between gage height and discharge could be found for the period from June 8 to November 1, the above table was applied in an indirect manner to deduce discharges from gage heights for that period. Thus, on June 24, when the gage height was 4.10, the discharge was found to be 3,206 second-feet. This discharge corresponds in the rating table to a gage height of 4.75. Then it is assumed that if $4.75 - 4.10 = 0.65$ be added to the gage height for any day about that time, the discharge given in the table for the resulting gage height will be the discharge for that day. In the same manner it was found that 0.52 must be added to the actual gage height to obtain the gage height corresponding to the measured discharge on July 22. The decrease in this additive correction was assumed to take place at a uniform rate during the period between the two gagings. In this way the record of daily discharge to November 1, 1896, was made up. A record of daily discharge from April 1 to November 1, 1896, is presented in the following table:

*Daily mean discharge (in cubic feet per second) of Loup River at Columbus, Nebraska, for 1896.*

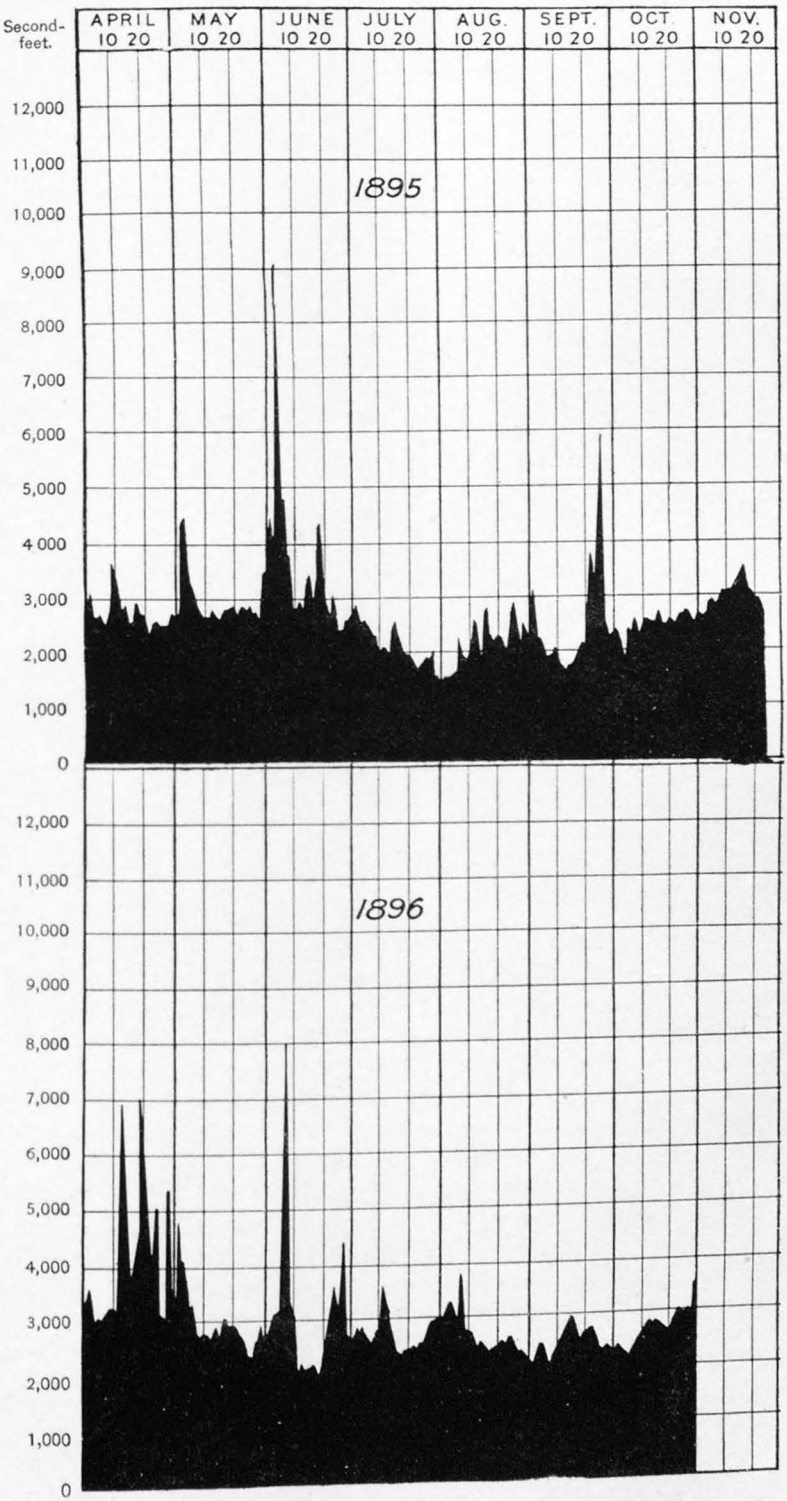
| Day. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|---|
| 1..... | 3,205 | 4,807 | 2,694 | 2,817 | 3,100 | 2,063 | 2,402 |
| 2..... | 3,558 | 4,220 | 3,126 | 2,694 | 3,203 | 2,150 | 2,380 |
| 3..... | 3,205 | 4,220 | 3,153 | 2,832 | 3,258 | 2,264 | 2,287 |
| 4..... | 2,945 | 3,897 | 3,205 | 2,792 | 3,258 | 2,455 | 2,287 |
| 5..... | 3,126 | 3,312 | 3,613 | 2,670 | 3,021 | 2,430 | 2,240 |
| 6..... | 3,048 | 3,390 | ..... | 2,597 | 2,868 | 2,287 | 2,287 |
| 7..... | 3,126 | 3,048 | ..... | 2,500 | 3,811 | 2,170 | 2,358 |
| 8..... | 3,205 | 2,768 | 8,000 | 2,572 | 3,338 | 2,063 | 2,477 |
| 9..... | 3,338 | 2,694 | 3,421 | 2,768 | 2,668 | 2,063 | 2,548 |
| 10..... | 3,393 | 2,743 | 3,073 | 2,621 | 2,620 | 2,170 | 2,548 |

*Daily mean discharge (in cubic feet per second) of Loup River at Columbus, Nebraska, for 1896*—Continued.

| Day. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|---|
| 11 | 3,365 | 2,867 | 1,991 | 3,670 | 2,620 | 2,287 | 2,694 |
| 12 | 4,434 | 2,621 | 2,203 | 3,258 | 2,384 | 2,572 | 2,817 |
| 13 | 6,950 | 2,728 | 2,063 | 3,048 | 2,429 | 2,694 | 2,817 |
| 14 | 5,797 | 2,892 | 2,086 | 2,892 | 2,482 | 2,867 | 2,768 |
| 15 | 4,650 | 2,645 | 2,106 | 2,525 | 2,429 | 2,968 | 2,832 |
| 16 | 3,725 | 3,022 | 2,180 | 2,334 | 2,382 | 2,968 | 2,743 |
| 17 | 4,160 | 3,022 | 2,106 | 2,334 | 2,288 | 2,832 | 2,645 |
| 18 | 4,650 | 2,945 | 1,991 | 2,310 | 2,382 | 2,694 | 2,645 |
| 19 | 7,018 | 2,892 | 1,928 | 2,406 | 2,406 | 2,548 | 2,621 |
| 20 | 5,937 | 2,892 | 2,406 | 2,406 | 2,454 | 2,597 | 2,597 |
| 21 | 5,157 | 2,832 | 2,867 | 2,455 | 2,502 | 2,645 | 2,817 |
| 22 | 4,017 | 2,670 | 3,338 | 2,420 | 2,454 | 2,670 | 2,918 |
| 23 | 5,032 | 2,621 | 3,725 | 2,482 | 2,596 | 2,728 | 2,945 |
| 24 | 5,060 | 2,455 | 3,258 | 2,482 | 2,596 | 2,524 | 3,022 |
| 25 | 3,205 | 2,358 | 4,160 | 2,596 | 2,502 | 2,370 | 2,945 |
| 26 | 3,126 | 2,310 | 4,494 | 2,727 | 2,358 | 2,334 | 2,968 |
| 27 | 3,100 | 2,621 | 3,021 | 2,945 | 2,288 | 2,370 | 3,022 |
| 28 | 5,326 | 2,645 | 2,743 | 2,970 | 2,264 | 2,406 | 2,832 |
| 29 | 3,613 | 2,867 | 2,670 | 2,970 | 2,264 | 2,310 | 3,022 |
| 30 | 1,970 | 2,917 | 2,621 | 2,970 | 2,180 | 2,287 | 3,585 |
| 31 | ..... | 2,621 | ..... | 3,021 | 2,106 | ..... | 3,613 |

On June 6 a great flood occurred. Mr. Savage, the observer at Columbus, states that the water began to rise rapidly at about 2 p. m. His 5 p. m. observation shows a gage height of 9.75. The 7 p. m. observation, which was the highest noted, was 12.55. He states that the water near his house, which is about one-third of a mile from the bridge and river, and on the downstream side of the railroad track, continued to rise slowly until about 2 a. m. on Sunday, June 7. It is believed, however, that the height at the gage attained a maximum little, if any, in excess of 12.55, as noted at 7 p. m. on June 6.

Professor Stout visited the station on June 10; found no definite high-water mark at the bridge, but a step in the upstream wing of the left abutment, which shows no signs of having been swept by the flood, is at an elevation of about 13 feet above zero of the gage, as indicated by sight with a hand level.




DISCHARGE OF LOUP RIVER AT COLUMBUS, NEBRASKA, 1895–96.

The bridge consists of spans as follows, the lengths being those given by Mr. Savage and checked roughly in a few instances by Professor Stout:

| | Feet. |
|---|---|
| One Pegram truss | 200 |
| One Pegram truss | 150 |
| Eight through trusses, at 150 feet | 1,200 |
| Total | 1,550 |

A few rough measurements form the basis for an estimate that the area of cross section through which the maximum flood passed is about 11,500 square feet. The velocity, even at the west end of the bridge, was sufficient to lay, but not to break, well-grown willow saplings 10 feet high and $1\frac{1}{2}$ inches or more in diameter. At the east end of the

FIG. 27.—Gaging station on Loup River at Columbus, Nebraska, showing location of gage rod.

bridge stones averaging the size of a man's head and larger were torn out of the riprap. Owing to the fact that the ordinary channel is here restricted by the bridge, that the bed is also strewn with débris from former bridges and floods, and that a vigorous growth of brush and willows occupies a width of about 1,000 feet of the flood channel, an estimate of discharge, based upon the data at hand, is not at all reliable.

Chailly's formula,[1] $v=5.67\sqrt{a\ g}$, indicates that the velocity of current against the east bank was about 7.5 feet per second. The maximum velocity was probably not much in excess of this. Assuming 7.5 feet per second as the mean for 500 feet from the east bank, we obtain an estimated discharge of 33,000 second-feet for that portion. The

[1] Irrigation Canals and Other Irrigation Works, P. J. Flynn, p. 51.

discharge through the remaining 7,000 square feet of obstructed section can only be guessed. It runs probably in the neighborhood of 37,000 second-feet. Hence the total estimated maximum discharge took place at the rate of about 70,000 second-feet and lasted from 7 p. m. on June 6 to 2 a. m. on June 7. The maximum rate of discharge in the North Loup at St. Paul is believed to have exceeded this (estimated at 90,000 second-feet), but the maximum flood height was not so well sustained.

A table is given on page 120 of Bulletin No. 140 to show the ratio in 1895 between the combined discharge of the Middle and North Loups at St. Paul and the discharge of the Loup at Columbus. The ratio is expressed in percentages, and the figures for 1895 and 1896 are both given in the following table:

*Percentage of the discharge of the Loup River at Columbus, Nebraska, contributed by the Middle and North Loup rivers at St. Paul, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 83.1 | 81.5 | 81.3 | 85.5 | 81.2 | 81.1 |
| 1896 | 73.4 | (*a*) | 87.5 | 69.4 | 77.5 | 73.2 |

*a* Omitted on account of great freshet.

It has been noted that the ratio in 1895 was nearly constant, closely approximating the ratio of the corresponding drainage areas, and that the combined discharge of the two rivers at St. Paul, together with the estimated discharge of the tributaries which enter the Loup River below St. Paul, are about equal to the discharge at Columbus. These facts seemed to indicate that the part of the Loup River between St. Paul and Columbus was below the region of considerable contributions from springs.

It will be noted that the ratio in 1896 was not nearly so constant as in 1895. In attempting to discover the wide variation from the conditions which the record of 1895 had led us to expect, the following tabular comparisons have been made. The figures in the last line of this and the next four succeeding tables express the ratio, in percentages, which the 1896 discharge bears to that of 1895:

*Mean monthly discharge (second-feet) of the Middle Loup River at St. Paul, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 1,173 | 1,396 | 861 | 973 | 877 | 840 |
| 1896 | 1,154 | 1,542 | 1,271 | 975 | 993 | 1,041 |
| | 98.3 | 110.5 | 147.7 | 100.0 | 113.3 | 123.9 |

*Mean monthly discharge (second-feet) of the North Loup River at St. Paul, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 1,189 | 1,531 | 864 | 984 | 1,094 | 1,146 |
| 1896 | 1,040 | 1,494 | 1,102 | 904 | 913 | 958 |
| | 87.5 | 97.6 | 127.6 | 91.9 | 83.5 | 83.6 |

*Mean monthly discharge (second-feet) of the Middle and North Loup rivers (combined) at St. Paul, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 2,362 | 2,927 | 1,725 | 1,957 | 1,871 | 1,986 |
| 1896 | 2,194 | 3,036 | 2,373 | 1,879 | 1,906 | 1,999 |
| | 92.9 | 103.7 | 137.5 | 96.0 | 101.8 | 100.6 |

*Mean monthly discharge (second-feet) of the Loup River at Columbus, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 2,966 | 3,591 | 2,122 | 2,289 | 2,427 | 2,450 |
| 1896 | 2,985 | ..... | 2,712 | 2,623 | 2,460 | 2,732 |
| | 100.6 | ..... | 127.7 | 114.5 | 101.3 | 111.5 |

*Mean monthly net discharge (second-feet) contributed to the Loup River between St. Paul and Columbus, Nebraska.*

| Year. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1895 | 604 | 664 | 397 | 332 | 556 | 464 |
| 1896 | 791 | ..... | 339 | 744 | 554 | 733 |
| | 130.9 | ..... | 85.4 | 224.2 | 100.0 | 158.0 |

The figures for the last table above are obtained by subtracting the combined discharge of the two rivers at St. Paul, for any month, from the discharge of the Loup River at Columbus for the same month. It is possible that the variations in the ratios of the several discharges may be found to correspond in some way to variations in the distribution of the rainfall over the drainage area of the streams. A cursory examination of rainfall records, however, fails to reveal any such relation.

## PLATTE RIVER.

### COLUMBUS STATION ON PLATTE RIVER.

This station was originally established on the south side of the river, near the bridge which crosses the channel on the sixth principal meridian. As thus located it was described on page 121 of Bulletin No. 140. On June 4, 1896, the gage was moved to the north side of the river, it having become apparent that the main current of the river was close to this bank. As at present located the gage is on the left bank of the main channel of the river, about 75 feet above the meridian bridge. The observer is George E. Barnum, a farmer, whose

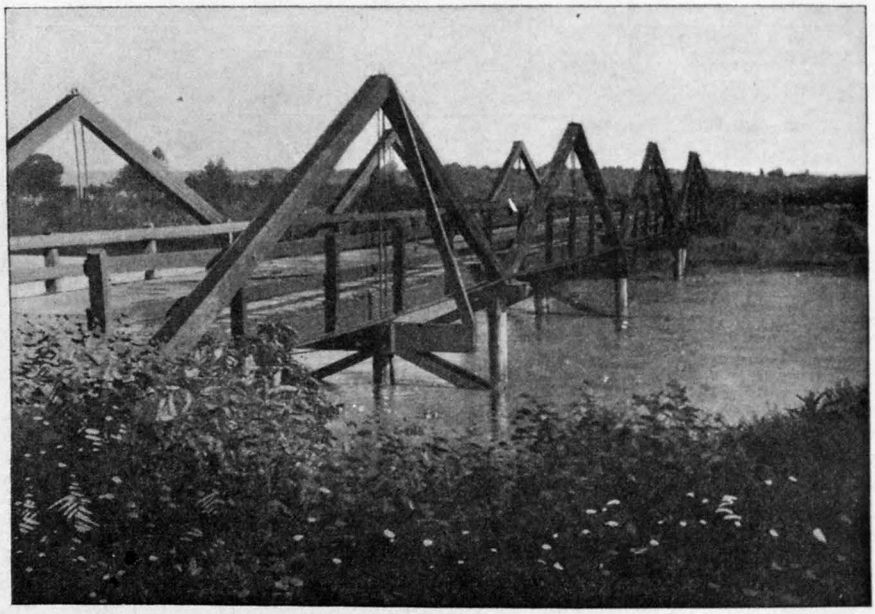


FIG. 28.—Looking north across south channel of Platte River, near Columbus, Nebraska.

house is about one-half mile from the gage. Observations have been taken twice daily. The gage consists of a portion of the oak piece which served as a gage on the opposite side of the river in 1895. It is 3 by 4 inches in section and is 12 feet long. Its face is inclined to the horizontal at an angle of 30°, so that 2 feet along the gage corresponds to 1 foot in the vertical, and it is graduated accordingly. It is fastened to cross-ties which are bedded and to stakes which are driven in the bank of the river. The channel is straight both above and below the gage.

A round stump on the west side of the road and 80 feet north of the north end of the north truss of the bridge and a square stump directly opposite on the east side of the road were selected as bench marks. The top of the first is 7.38 feet above the zero of the gage, and the top

of the second is 7.66 feet above the zero of the gage. Measurements of discharge have been made in 1896 as follows:

*List of discharge measurements made on Platte River at Columbus, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). *a* | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| May 2 | Wm. Grant..... | 78 | ..... | 1,890 | 2.26 | 4,550 |
| June 5 | O. V. P. Stout..... | (*b*) | 3.19 | 1,680 | 2.44 | 4,320 |
| June 14 | .....do ..... | 78 | 4.11 | 3,282 | 2.88 | 10,307 |
| June 30 | .....do ..... | 78 | 3.35 | 1,806 | 2.30 | 4,450 |
| July 22 | E. T. Youngfelt.... | (*b*) | ..... | 10 | 1.40 | 14 |
| Aug. 26 | O. V. P. Stout..... | (*c*) | 1.06 | ..... | ..... | 1 |
| Aug. 28 | E. T. Youngfelt.... | ..... | ..... | ..... | ..... | *d* 0 |
| Sept. 6 | O. V. P. Stout..... | ..... | *e* 0.60 | ..... | ..... | *d* 0 |
| Sept. 25 | E. T. Youngfelt.... | ..... | 1.70 | 136 | 1.39 | 188 |

*a* Areas and mean velocities are for main channel.
*b* Price acoustic.
*c* Estimate.
*d* Dry.
*e* Sand.

A rating table based on these measurements has been prepared and is presented herewith:

*Rating table for Platte River at Columbus, Nebraska, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.70 | 188 | 2.50 | 1,975 | 3.20 | 4,040 | 3.90 | 8,250 |
| 1.80 | 425 | 2.60 | 2,250 | 3.30 | 4,400 | 4.00 | 9,300 |
| 1.90 | 620 | 2.70 | 2,500 | 3.40 | 4,850 | 4.10 | 10,400 |
| 2.00 | 825 | 2.80 | 2,780 | 3.50 | 5,280 | 4.20 | 11,630 |
| 2.10 | 1,030 | 2.90 | 3,060 | 3.60 | 5,750 | 4.30 | 12,960 |
| 2.20 | 1,250 | 3.00 | 3,360 | 3.70 | 6,450 | 4.40 | 14,390 |
| 2.30 | 1,475 | 3.10 | 3,700 | 3.80 | 7,300 | 4.50 | 15,920 |
| 2.40 | 1,775 | | | | | | |

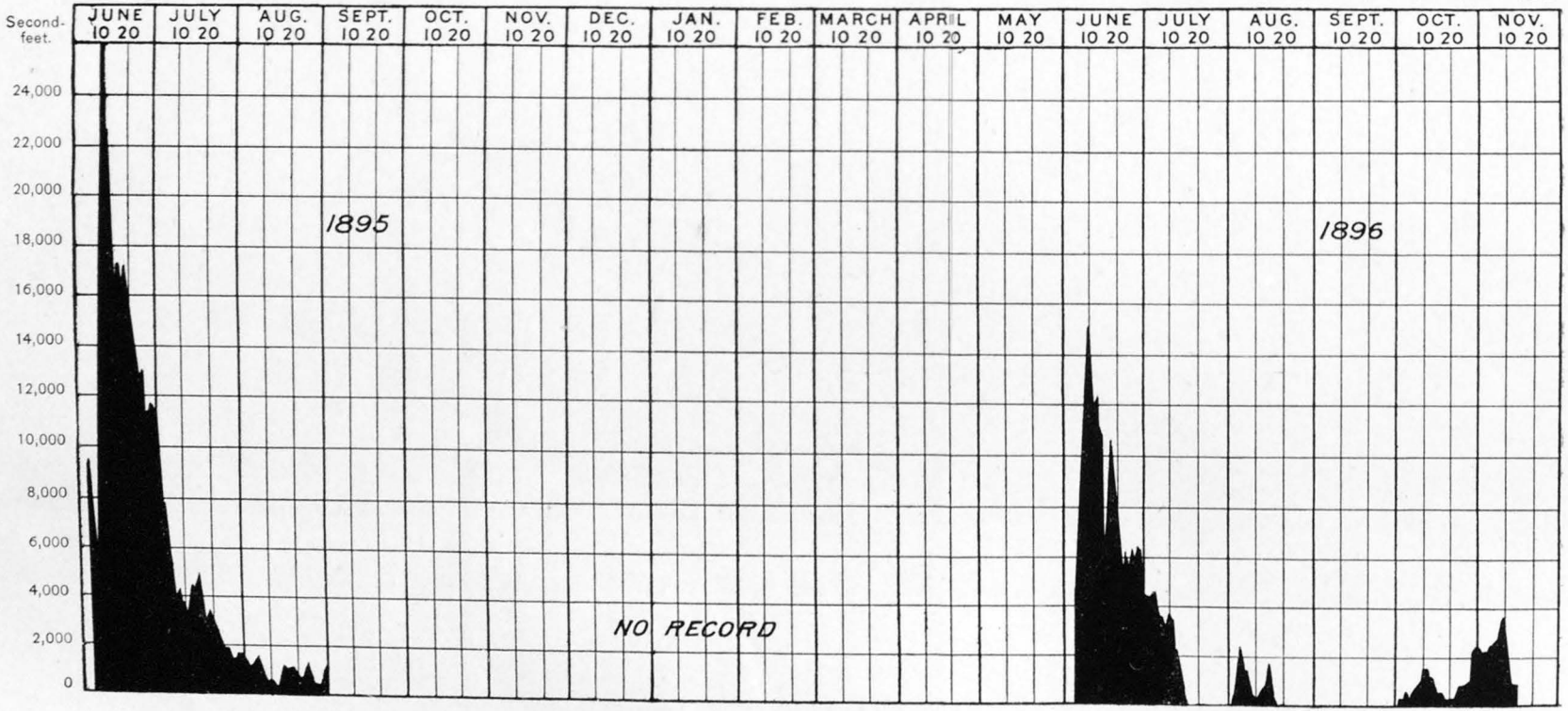
The zero of the gage in 1896 is 2.88 feet lower than zero of the gage in 1895. Comparing the above rating table with that for 1895 it is seen that the two ratings are widely discrepant for the smaller discharges, but agree quite closely for the larger discharges. The record of daily discharge appears in the following table.

*Daily mean discharge (in cubic feet per second) of Platte River at Columbus, Nebraska, above mouth of Loup River, for 1895–96.*

| Day. | 1895. | | | 1896. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | June. | July. | Aug. | June. | July. | Aug. | Sept. | Oct. | Nov. |
| 1 | ..... | 9,315 | 1,250 | ..... | 4,400 | Dry. | Dry. | 188 | 2,250 |
| 2 | ..... | 7,900 | 975 | ..... | 4,400 | 620 | Dry. | 188 | 2,250 |
| 3 | ..... | 6,600 | 590 | ..... | 4,490 | 2,375 | Dry. | 305 | 2,250 |
| 4 | 9,420 | 6,210 | 698 | 4,850 | 4,490 | 1,850 | Dry. | 188 | 2,425 |
| 5 | 8,600 | 5,170 | 782 | 4,320 | 4,280 | 1,250 | Dry. | 305 | 2,500 |
| 6 | 7,100 | 4,165 | 846 | 5,260 | 3,700 | 1,140 | Dry. | 425 | 2,500 |
| 7 | 5,170 | 3,895 | 564 | 5,750 | 3,700 | 725 | Dry. | 525 | 2,640 |
| 8 | 7,500 | 4,345 | 444 | 7,050 | 3,505 | 425 | Dry. | 620 | 2,780 |
| 9 | 11,250 | 3,720 | 312 | 9,715 | 3,190 | 350 | Dry. | 725 | 3,535 |
| 10 | 12,580 | 3,720 | 472 | 14,900 | 3,880 | 188 | Dry. | 1,250 | 2,780 |
| 11 | 27,200 | 3,205 | 336 | 11,975 | 3,570 | 305 | Dry. | 1,250 | 1,600 |
| 12 | 22,400 | 4,435 | 264 | 12,185 | 2,475 | 425 | Dry. | 1,030 | 620 |
| 13 | 22,420 | 4,345 | 96 | 10,925 | 1,975 | 620 | Dry. | 1,030 | 620 |
| 14 | 19,280 | 4,615 | 1,105 | 10,400 | 1,530 | 1,725 | Dry. | 620 | 620 |
| 15 | 17,460 | 4,985 | 910 | 6,100 | 725 | 930 | Dry. | 425 | ..... |
| 16 | 16,150 | 4,165 | 910 | 8,250 | 188 | 188 | Dry. | 425 | ..... |
| 17 | 17,130 | 3,375 | 845 | 10,400 | Dry. | Dry. | Dry. | 425 | ..... |
| 18 | 16,150 | 2,950 | 845 | 8,250 | Dry. | Dry. | Dry. | 188 | ..... |
| 19 | 16,970 | 3,545 | 910 | 7,950 | Dry. | Dry. | Dry. | 188 | ..... |
| 20 | 16,150 | 3,205 | 672 | 6,100 | Dry. | Dry. | Dry. | 188 | ..... |
| 21 | 14,960 | 2,700 | 536 | 5,750 | Dry. | Dry. | Dry. | 188 | ..... |
| 22 | 14,400 | 2,530 | 878 | 5,510 | Dry. | Dry. | Dry. | 188 | ..... |
| 23 | 13,470 | 2,135 | 1,250 | 6,380 | Dry. | Dry. | Dry. | 350 | ..... |
| 24 | 12,580 | 1,980 | 1,340 | 5,750 | Dry. | Dry. | Dry. | 565 | ..... |
| 25 | 12,800 | 1,980 | 1,070 | 6,380 | Dry. | Dry. | Dry. | 620 | ..... |
| 26 | 12,250 | 1,745 | 725 | 6,100 | Dry. | Dry. | Dry. | 620 | ..... |
| 27 | 10,590 | 1,380 | 508 | 6,450 | Dry. | Dry. | Dry. | 725 | ..... |
| 28 | 11,550 | 1,380 | 416 | 6,380 | Dry. | Dry. | Dry. | 785 | ..... |
| 29 | 11,750 | 1,525 | 360 | 5,145 | Dry. | Dry. | Dry. | 845 | ..... |
| 30 | 11,450 | 1,525 | 336 | 4,535 | Dry. | Dry. | Dry. | 2,250 | ..... |
| 31 | ..... | 1,470 | 1,140 | ..... | Dry. | Dry. | Dry. | 2,500 | ..... |
| Mean | 14,027 | 3,685 | 722 | 7,510 | 1,629 | 423 | 000 | 649 | ..... |

NORFOLK STATION ON SOUTH FORK OF ELKHORN RIVER.

This station was established on July 16, 1896. It is about 2 miles south of Norfolk, near the line of Thirteenth street extended. The gage is on the left bank of the river. It consists of an oak piece, 2 by 4 inches, 12 feet long. The face is inclined 30° to the horizon, and the foot marks are 2 feet apart on the rod. The rod rests on beveled




DISCHARGE OF PLATTE RIVER AT COLUMBUS, NEBRASKA, 1895-96.

blocks which rest in turn on horizontally bedded cross-ties. All are firmly fastened together by lag screws, and the earth of the bank is well tamped around and over the ties.

The stream furnishes power for gristmills above the station, and the effect of their ponding water over night and releasing it in the morning has been observed at the gage. The observer is Mr. Burr Taft, a farmer, whose home is about 300 yards from the gage. Observations have been made once daily, usually in the early evening, at which time it is believed that the gage height is about equal to that corresponding to the normal or average rate of discharge for the twenty-four hours.

The river bed at the station is composed of sand and mud. There is a curve in the channel about 400 feet above the station and an island just below. At the time of low water the point of the island divides the gaging section into two parts. Thus far, the hydrographer has waded the stream when gaging, but flood gagings must be made from the Thirteenth street bridge. The zero of the gage is 8.21 feet below a small spike driven horizontally into a tree near the root, about 20 feet back and downstream from the gage. Also, the zero of the gage is 3.96 feet below the head of a lag screw which is placed vertically in the horizontal trunk of a large living willow tree which overhangs the stream about 15 feet below the gage. Measurements of discharge have been made as follows:

*List of discharge measurements made on South Fork of Elkhorn River at Norfolk, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| July 16 | O. V. P. Stout..... | 105 | 0.98 | 119 | 1.60 | 191 |
| Aug. 27 | .....do ..... | 105 | 0.89 | 115 | 1.52 | 175 |
| Sept. 12 | .....do ..... | 105 | 0.86 | 117 | 1.50 | 176 |

The following rating table has been prepared to conform to the gagings and to the facts that the range of variation in gage height and discharge during the season of record was not wide, and that the width of the stream at the station is nearly constant for a considerable height after the point of the island is once covered:

*Rating table for South Fork of Elkhorn River at Norfolk, Nebraska, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 153 | 1.00 | 197 | 1.30 | 298 | 1.60 | 445 |
| 0.80 | 165 | 1.10 | 230 | 1.40 | 336 | 1.70 | 512 |
| 0.90 | 179 | 1.20 | 263 | 1.50 | 378 | 1.80 | 570 |

The record of daily discharge, as deduced from the above rating table and from the observed gage heights, is given in the following table:

*Daily mean discharge (in cubic feet per second) of Elkhorn River at Norfolk, Nebraska, for 1896.*

| Day. | July. | Aug. | Sept. | Oct. | Nov. |
|---|---|---|---|---|---|
| 1 | ..... | 570 | 158 | 182 | 313 |
| 2 | ..... | 409 | 163 | 182 | 313 |
| 3 | ..... | 294 | 161 | 185 | 298 |
| 4 | ..... | 253 | 163 | 186 | 298 |
| 5 | ..... | 233 | 158 | 188 | ..... |
| 6 | ..... | 213 | 158 | 186 | ..... |
| 7 | ..... | 206 | 157 | 185 | ..... |
| 8 | ..... | 203 | 155 | 213 | ..... |
| 9 | ..... | 197 | 158 | 213 | ..... |
| 10 | ..... | 191 | 170 | 213 | ..... |
| 11 | ..... | 191 | 172 | 213 | ..... |
| 12 | ..... | 179 | 167 | 216 | ..... |
| 13 | ..... | 180 | 170 | 226 | ..... |
| 14 | ..... | 177 | 179 | 216 | ..... |
| 15 | ..... | 183 | 176 | 213 | ..... |
| 16 | 191 | 176 | 174 | 213 | ..... |
| 17 | 186 | 183 | 179 | 210 | ..... |
| 18 | 184 | 188 | 182 | 213 | ..... |
| 19 | 185 | 186 | 183 | 220 | ..... |
| 20 | 178 | 185 | 185 | 213 | ..... |
| 21 | 174 | 193 | 185 | 213 | ..... |
| 22 | 172 | 186 | 186 | 210 | ..... |
| 23 | 216 | 186 | 182 | 210 | ..... |
| 24 | 213 | 179 | 179 | 213 | ..... |
| 25 | 206 | 176 | 178 | 210 | ..... |
| 26 | 226 | 170 | 182 | 203 | ..... |
| 27 | 226 | 167 | 180 | 223 | ..... |
| 28 | 213 | 165 | 186 | 203 | ..... |
| 29 | 194 | 163 | 186 | 213 | ..... |
| 30 | 206 | 165 | 182 | 243 | ..... |
| 31 | 321 | 162 | ..... | 298 | ..... |
| Mean | 206 | 210 | 173 | 210 | ..... |

## MISCELLANEOUS MEASUREMENTS.

| Date. | By whom. | Name of stream. | Where measured. | Discharge (cubic feet per second). | Mean velocity (feet per second). |
|---|---|---|---|---|---|
| 1896. | | | | | |
| June 29 | O. V. P. Stout | South Platte River. | North Platte | 0.0 | |
| | | Platte River | Kearney | | |
| July 9 | do | North Loup River | Burwell | a 625.0 | 2.87 |
| July 10 | do | Calamus River | do | 368.0 | 2.94 |
| Aug. 30 | do | Middle Loup River. | Seneca | 212.0 | 2.45 |
| Aug. 30 | do | do | Dunning | 323.0 | 1.48 |
| July 16 | do | North Fork Elkhorn River. | Norfolk | 70.0 | 1.39 |
| Oct. 2 | Adna Dobson | Elkhorn River | Atkinson | 11.15 | |
| July 23 | O. V. P. Stout | do | Waterloo | 4.95 | 1.64 |
| July 17 | do | Union Creek | Madison | 38.3 | 1.42 |
| June 23 | E. T. Youngfelt | Niobrara River | Marsland, Dawes County. | 4.0 | |
| Oct. 4 | Adna Dobson | do | Valentine | 71.2 | |
| Oct. 4 | do | Minichaduza Creek. | Fort Niobrara | 45.2 | |
| Oct. 3 | do | Pine River | Long Pine | 47.1 | |
| June 24 | E. T. Youngfelt | White River | Sec. 23, T. 31 N., R. 53 W. | 23.3 | |
| June 24 | do | do | Crawford | 30.7 | |
| June 25 | do | do | Whitney | 27.2 | |
| June 24 | do | Soldier Creek | Fort Robinson | 3.23 | |
| June 24 | do | Fort Robinson Ditch | do | 0.79 | |
| June 24 | do | White Clay Creek | N. line sec. 2, T. 31, R. 52 W. | 4.0 | |
| June 24 | do | Squaw Creek | N. line sec. 1, T. 31, R. 52 W. | 0.66 | |
| June 25 | do | West Ash Creek | N. line sec. 25, T. 32, R. 51 W. | 1.73 | |
| June 25 | do | East Ash Creek | ⅛ mile above mouth. | 1.09 | |
| June 25 | do | Little Cottonwood Creek. | In sec. 7, T. 32 N., R. 51 W. | 0.1 | |
| June 25 | do | Big Cottonwood Creek. | 6 miles west of Whitney. | 0.2 | |
| June 25 | do | Indian Creek | Near mouth | 0.06 | |
| Aug. 28 | O. V. P. Stout | South Loup River | Callaway | 48.0 | 1.15 |
| Aug. 29 | do | do | Ravenna | 142.0 | 1.45 |
| July 11 | do | Loup River | Fullerton | 2,900.0 | (b) |
| July 11 | do | Cedar River | do | 238.0 | c 2.24 |
| July 21 | do | do | Cedar Rapids | 212.0 | 1.79 |
| July 14 | do | Beaver Creek | Genoa | 110.0 | 1.71 |
| Aug. 14 | W. J. McEathron | do | do | 111.2 | |
| July 21 | O. V. P. Stout | do | Albion | 47.4 | 1.13 |
| July 23 | do | Shell Creek | Platte Center | 15.3 | 0.94 |
| July 24 | do | do | Schuyler | 26.3 | 1.20 |
| July — | W. J. McEathron | Looking Glass Creek | Near mouth | 15.0 | |
| June 28 | O. V. P. Stout | Pumpkinseed Creek | Carey's Ranch | 22.2 | 2.11 |

a River about 3 inches higher than on the following morning. Said to be about 4 inches above normal. Rise due to rain on night of July 8.

b Rough gaging.

c Marks of flood of June 5–6, 1896, are approximately 7 feet above stage of water at time of gaging.

## KANSAS BASIN.

The drainage basin of the Kansas River lies between that of the Platte and Arkansas, being entirely within the region of the Great Plains and principally within the arid or semiarid area. It has no mountain tributaries, but depends entirely for its water supply upon the water which, falling within or near the basin, percolates slowly to the drainage channels. The catchment area extends from eastern Colorado to the Missouri River, a distance from east to west of 485 miles. Its extreme width is about 200 miles and its drainage area 61,400 square miles. The Kansas River and its tributaries are described at length in Volume XVII, Tenth Census, pages 56 to 77. A description of the topography of this basin is also given in Bulletin 140, page 123.

### REPUBLICAN RIVER.

This stream unites with the Smoky Hill near Junction City to form the Kansas River proper. The area drained is 25,837 square miles, and the minimum flow, as observed at Junction City, is about 200 second-feet. It is described more at length in Bulletin 140, page 125. Two stations have been maintained on the Republican proper, and several on tributaries.

### HAIGLER STATION ON NORTH FORK REPUBLICAN RIVER.

On June 17, 1896, arrangements were made with Mr. James A. Porter, of Haigler, Nebraska, to make frequent gagings of the North Fork of the Republican River at that place. No gage rod was placed in the river, as it was very shallow, flowed over a sandy bed, and was said to be subject to sudden floods of greater or less volume, which might be expected to change the relation between gage height and discharge at frequent intervals throughout the season. While in one instance at least, that on July 16, his result is variant from that obtained by a better-equipped hydrographer, his list of gagings represents very fairly the record of the discharge of the stream for the season up to the middle of September.

In the following table of discharge measurements, those by Mr. Porter were made either with floats or with a small paddle wheel which he has rated after attaching a registering device, and which may be expected to measure surface velocities with a fair degree of accuracy when no wind is blowing. The other discharge measurements were made with a Price acoustic meter, the property of the Nebraska State Irrigation Department.

On August 25, when the stream at Haigler was discharging at the rate of 10 second-feet, at a point 2 miles west of Ives it was carrying only 5 second-feet, and was dry at Benkelman. Between Haigler and Ives no water is diverted, and the only tributary is Buffalo Creek, which is a very steady spring-fed little stream carrying uniformly about

8 second-feet at a point 7 miles north of Haigler. Rock Creek enters the Republican at Ives with 12 second-feet, and the Dundy County and neighboring ditches head about 7 miles west of Benkelman. A ditch of which Messrs. Morse and Callahan, of Benkelman, are the principal owners heads near Ives, on the south side of the river.

*List of discharge measurements made at Haigler, Nebraska, in 1896.*

| Date. | Hydrographer. | Name of stream. | Discharge in second-feet. |
|---|---|---|---|
| 1896. | | | |
| June 17 | O. V. P. Stout | Republican River | *a* 8.24 |
| June 17 | do | Arickaree Creek | 15.12 |
| June 17 | do | Republican River | *b* 23.92 |
| June 17 | do | Porters Ditch | *c* 8.98 |
| June 23 | James A. Porter | Republican River | 256.0 |
| June 24 | do | do | 200.0 |
| June 25 | do | do | 84.0 |
| June 29 | do | do | 275.0 |
| July 3 | do | do | 68.0 |
| July 6 | do | do | 43.0 |
| July 8 | do | do | 45.0 |
| July 9 | do | do | 85.0 |
| July 13 | do | do | 36.0 |
| July 16 | do | do | 30.0 |
| July 16 | E. T. Youngfelt | do | *d* 6.17 |
| July 16 | do | Arickaree Creek | *d* 3.63 |
| July 22 | James A. Porter | Republican River | 20.0 |
| July 25 | do | do | 30.0 |
| July 27 | do | do | 50.0 |
| July 28 | do | do | 5.0 |
| Aug. 3 | do | do | Dry. |
| Aug. 16 | do | do | *e* 10.0 |
| Aug. 18 | do | do | *e* 12.0 |
| Aug. 25 | do | do | 15.0 |
| Aug. 25 | E. T. Youngfelt | do | *b* 10.04 |
| Aug. 28 | James A. Porter | do | 20.0 |
| Sept. 1 | do | do | 190.0 |
| Sept. 6 | do | do | 15.0 |
| Sept. 15 | do | do | 20.0 |
| Sept. 18 | E. T. Youngfelt | do | *b* 24.5 |

*a* Above mouth of Arickaree.

*b* Below mouth of Arickaree.

*c* The water of Porters Ditch is diverted from the Republican and wastes into the Arickaree. On June 17 the ditch was gaged only a short distance above where it wastes into the Arickaree.

*d* The sum of these two gagings by Mr. Youngfelt = +9.8 second-feet, as against 30 second-feet obtained by Mr. Porter in early morning of same day.

*e* Rain.

WAUNETA STATION ON FRENCHMAN RIVER.

This station was established in 1895 for the purpose of supplementing and perhaps ultimately replacing the station at Palisade, on the same stream. It was thought that the more permanent bed, the less distance between banks, and the higher banks at Wauneta offered advantages for accurate gaging and stability of relation between gage height and discharge which could not be obtained at Palisade. For the smaller or ordinary rates of discharge, at least, this has not proved to be the case. No relation between gage height and discharge has been observable which will hold throughout more than a very short period of time. That this is true will appear upon an examination of the following table:

*List of discharge measurements made on Frenchman River at Wauneta, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Discharge (second-feet). |
|---|---|---|---|---|
| 1896. | | | | |
| May 15 | C. E. Crownover | 105 | 2.20 | 84.9 |
| June 18 | O. V. P. Stout | (a) | 1.84 | 47.7 |
| July 14 | E. T. Youngfelt | (a) | 2.15 | 91.3 |
| Aug. 12 | O. V. P. Stout | 105 | 1.90 | 46.2 |
| Sept. 16 | E. T. Youngfelt | (a) | 2.07 | 84.7 |
| Oct. 17 | C. E. Crownover | 105 | 2.00 | 62.5 |

a Price acoustic.

The station is described on page 131 of Bulletin No. 140. On August 12, 1896, the zero of the gage was lowered one foot. A part of the published description should, therefore, be amended to read as follows: "One of the bench marks is the stone door step of a concrete house which stands below the gage on the right bank, the elevation of this being 20.99 feet above the zero of the gage. A second bench mark is the top of a stake at the northwest corner of the lot in which this house stands, this point being 20.33 feet above the zero of the gage." Mr. W. W. Fisher has continued as observer during the season of 1896. The only record of daily discharge which can be offered is that which appears in the following table.

*Daily mean discharge (in cubic feet per second) of Frenchman River at Wauneta, Nebraska, for 1896.*

| Date. | Aug. | Sept. | Date. | Aug. | Sept. | Date. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|
| 1 | ..... | 86.4 | 12 | ..... | 68.5 | 22 | 88.5 | 70.7 |
| 2 | ..... | 86.4 | 13 | ..... | 70.7 | 23 | 86.5 | 70.7 |
| 3 | ..... | 84.1 | 14 | ..... | 70.7 | 24 | 86.4 | 70.7 |
| 4 | ..... | 84.1 | 15 | ..... | 73.0 | 25 | 88.5 | 70.7 |
| 5 | ..... | 84.1 | 16 | 68.5 | 73.0 | 26 | 88.5 | 73.0 |
| 6 | ..... | 86.4 | 17 | 68.5 | 73.0 | 27 | 86.4 | ..... |
| 7 | ..... | 86.4 | 18 | 88.5 | 70.7 | 28 | 86.4 | ..... |
| 8 | ..... | 84.1 | 19 | 73.0 | 73.0 | 29 | 84.1 | ..... |
| 9 | ..... | 86.4 | 20 | 68.5 | 73.0 | 30 | 88.5 | ..... |
| 10 | ..... | 88.5 | 21 | 88.5 | 70.7 | 31 | 88.5 | ..... |
| 11 | ..... | 88.5 | | | | | | |

PALISADE STATION ON FRENCHMAN RIVER.

This station was established and observations were commenced on October 14, 1894. The gage is immediately above the bridge of the Burlington and Missouri River Railroad, about three-fourths of a mile westerly from the railroad station at Palisade, Nebraska. The observations were taken until recently by Mr. J. M. Reed, a farmer living at a distance of about 75 yards from the gage. On October 1, 1896, he was succeeded by Mr. A. J. Koontz, who moved into the house which had been occupied by the former observer. The gage is an oak stick, 2 by 4 inches, and about 14 feet long. It is fastened to ties which are bedded in the right bank of the river, and the face was set at an angle of 30° to the horizon. The foot marks are 2 feet apart along the rod. The bench mark is the top of the screw thread on the bottom of the east side of the north pile of the second bent from Palisade. This point is 7.89 feet above the zero of the gage as originally set. On June 18, 1896, it was found that the 7, 5, 4, 3, and 2 foot marks on the gage were respectively 0.87, 2.87, 3.83, 4.76, and 5.65 feet below the bench mark.

The bed of the stream at this point is of loose, shifting sand, and changes considerably from time to time. Both banks are relatively low and liable to overflow at times of high water. Rating tables were prepared in 1895, each table applying to only a portion of the season and each being based on somewhat insufficient data. During the season of 1896 considerable pains were taken to obtain enough data upon which to base an accurate estimate of the daily discharge of the stream. Arrangements were made with the observer to make frequent soundings at the gaging section. Two supplementary gages were also put in—one above and one below the main gage. The south or upstream

gage is about 325 feet above the main gage. It consists of an iron pipe driven into the sandy bed of the river beside the right bank. The top of the pipe is 2.24 feet above the original zero of the main gage. Observations of river height are made by measuring up or down, as the case may be, from the top of the pipe to the surface of the water.

The north or downstream gage is about 300 feet below the main gage. It is of the same kind as the south gage, is on the right bank of the river, and observations are made in the same manner as in the case of the south gage. The top of the pipe is 1.46 feet above the original zero of the main gage. A tabular statement of the river heights on the main and supplementary gages is presented in Water-Supply and Irrigation Paper No. 11, page 56.

*List of discharge measurements made on Frenchman River at Palisade, Nebraska.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| May 15 | C. E. Crownover..... | 105 | 1.55 | 56.1 | 1.84 | 103.1 |
| June 18 | O. V. P. Stout..... | (*a*) | 1.35 | 32.4 | 1.56 | 50.5 |
| July 15 | E. T. Youngfelt..... | (*a*) | 1.46 | 53.8 | 1.72 | 92.7 |
| Aug. 13 | O. V. P. Stout..... | 105 | 1.36 | 46.3 | 1.39 | 64.1 |
| Sept. 16 | E. T. Youngfelt..... | (*a*) | 1.51 | 53.9 | 1.57 | 84.8 |
| Oct. 17 | C. E. Crownover..... | 105 | 1.50 | 53.7 | 1.54 | 82.5 |

*a* Price acoustic.

It has been found impracticable, even with the aid of the soundings and the readings on the supplementary gages, to prepare a thoroughly satisfactory rating table. The following, however, will apply directly to the period from August 13 to October 29, 1896, inclusive, and has been applied indirectly in the manner described in connection with the Loup River at Columbus to the period from May 1 to August 13, 1896:

*Rating table for Frenchman River at Palisade, Nebraska.*

[To be applied directly to period from August 13 to October 29, and indirectly to the period from May 1 to August 13, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.30 | 56.0 | 1.60 | 97.3 | 1.80 | 171 |
| 1.40 | 69.7 | 1.70 | 130.0 | 1.90 | 215 |
| 1.50 | 83.6 | | | | |

The following table of daily mean discharge has been deduced from this rating table and the observed gage heights:

*Daily mean discharge (in cubic feet per second) of Frenchman River at Palisade, Nebraska, for 1896.*

| Date. | May. | June. | July. | Aug. | Sept. | Oct. |
|---|---|---|---|---|---|---|
| 1 | 200.0 | 92.0 | 110.2 | 79 5 | 81.0 | 81.0 |
| 2 | 140.0 | 89.2 | 110.2 | 76.6 | 78.0 | 83.6 |
| 3 | 140.0 | 89.2 | 109.8 | 75.3 | 78.0 | 86.5 |
| 4 | 130.0 | 89.2 | 112.3 | 75.3 | 83.6 | 89.2 |
| 5 | 140.0 | 86.5 | 109.8 | 74.0 | 86 6 | 89.2 |
| 6 | 123.5 | 85.0 | 107.0 | 72.6 | 81.0 | 87.8 |
| 7 | 120.5 | 82.3 | 103.0 | 74.0 | 83.6 | 83.6 |
| 8 | 116.6 | 79.5 | 92.0 | 71.2 | 76.6 | 81.0 |
| 9 | 116.6 | 79.5 | 85.0 | 71.2 | 76.6 | 81.0 |
| 10 | 116.6 | 78.0 | 83.6 | 69.7 | 81.0 | 76.6 |
| 11 | 118.0 | 76.6 | 83.6 | 66.8 | 81.0 | 76.6 |
| 12 | 108.5 | 74.0 | 85.0 | 64.1 | 76.6 | 81.0 |
| 13 | 104.3 | 74.0 | 87.8 | 64.1 | 83.6 | 81.0 |
| 14 | 104.3 | 69.7 | 90.6 | 62.8 | 83.6 | 76.6 |
| 15 | 103.0 | 65.5 | 92.7 | 64.1 | 83.6 | 81.0 |
| 16 | 116.5 | 61.4 | 145.0 | 64.1 | 81.0 | 83.6 |
| 17 | 112.3 | 60.0 | 93.4 | 83.6 | 83.6 | 83.6 |
| 18 | 113.6 | 50.5 | 90.6 | 81.0 | 83.6 | 83.6 |
| 19 | 110.0 | 51.3 | 89.2 | 78.0 | 81.0 | 87.8 |
| 20 | 107.0 | 53.0 | 89.2 | 81.0 | 81.0 | 86.5 |
| 21 | 100.2 | 71.2 | 86.5 | 85.0 | 81.0 | 86.5 |
| 22 | 103.0 | 66.8 | 85.0 | 92.0 | 83.6 | 83.6 |
| 23 | 105.7 | 116.5 | 86.5 | 83.6 | 81.0 | 83.6 |
| 24 | 104.3 | 93.4 | 86.5 | 81.0 | 83.6 | 83.6 |
| 25 | 100.2 | 101.5 | 86.5 | 83.6 | 83.6 | 81.0 |
| 26 | 100 2 | 103.0 | 87.8 | 83.6 | 89.2 | 81.0 |
| 27 | 98.8 | 93.4 | 87.8 | 81.0 | 83.6 | 76.6 |
| 28 | 98.7 | 87.8 | 86.5 | 76.6 | 83.6 | 76.6 |
| 29 | 97.2 | 89.2 | 85.0 | 72.6 | 83.6 | 81.0 |
| 30 | 92.0 | 800.0 | 82.3 | 81.0 | 81.0 | ..... |
| 31 | 105.7 | ..... | 79.5 | 76.6 | ..... | ..... |
| Mean | 114.4 | 103.6 | 93.9 | 75.7 | 81.6 | 82.5 |

SUPERIOR STATION ON REPUBLICAN RIVER.

This station was established on June 20, 1896, about 1 mile westerly from Superior, in the Superior quadrangle, in latitude 40° 2′, and longitude 98° 05′. The drainage area is 22,347 square miles, and is partly mapped on the Superior, Red Cloud, Holdredge, Beaver, Gothenburg, Lexington, Norton, Phillipsburg, Smith Center, and Mankato atlas

sheets. It is on the left bank of the river, about 25 feet above the iron highway bridge. A dam and the head of a mill race are only a short distance below the bridge.

The observer, E. E. Cady, lives in Superior. The gage consists of an oak piece 2 by 4 inches, 10 feet long. The face is inclined 30° to the horizontal, and the foot marks are placed 2 feet apart to correspond to this inclination. The rod is fastened to cross-ties which are bedded in the bank of the river. This location is on the outside of an easy bend in the river. The bed of the river is of mud and sand. The top of

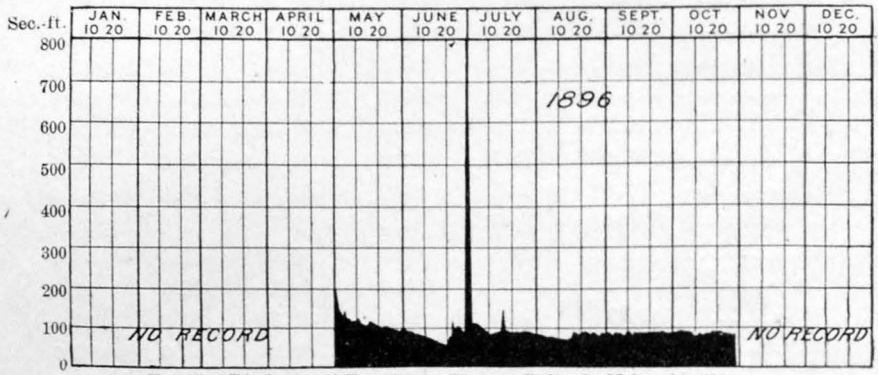



FIG. 29.—Discharge of Frenchman River at Palisade, Nebraska, 1896.

the rim of the upstream cylinder of the north pier is 15.42 feet above zero of the gage. A record of daily gage observations of river height was kept from June 20 to December 1, 1896. Soundings and measurements of discharge have been made as shown in the following table:

*List of soundings and discharge measurements made on Republican River at Superior, Nebraska.*

| Date. | Hydrographer or observer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| June 20 | O. V. P. Stout | (a) | 0.92 | 445 | 1.57 | 700 |
| June 30 | E. E. Cady | ..... | 0.82 | 442 | ..... | ..... |
| July 11 | .....do | ..... | 1 38 | 724 | ..... | ..... |
| July 17 | E. T. Youngfelt | (a) | 0.78 | 447 | 1.31 | 585 |
| July 30 | E. E. Cady | ..... | 0.63 | 454 | ..... | ..... |
| Aug. 8 | .....do | ..... | 0.93 | 580 | ..... | ..... |
| Aug. 21 | .....do | ..... | 0.79 | 484 | ..... | ..... |
| Aug. 24 | E. T. Youngfelt | (a) | 0.89 | 489 | 1.40 | 684 |
| Sept. 1 | E. E. Cady | ..... | 0.44 | 403 | ..... | ..... |
| Sept. 11 | .....do | ..... | 0.50 | 405 | ..... | ..... |
| Sept. 21 | E. T. Youngfelt | (a) | 0.42 | 358 | 0.64 | 227.5 |
| Oct. 25 | R. A. Trail | 105 | 0.45 | 296 | 0.24 | 72 |
| Dec. 23 | E. T. Youngfelt | (b) | 0.73 | ..... | ..... | 515 |

a Price acoustic.

b Weir and Price acoustic.

On December 23, 1896, a survey of the gaging station was made by Mr. E. T. Youngfelt, assistant State engineer of Nebraska. Following are some of the important facts which were obtained: The crest of the dam is 215 feet long. For 200 feet of this length the crest is nearly level and is at a mean elevation of 0.02 foot below the zero of the gage. For a length of 15 feet the crest is 0.8 foot higher than the portion which has just been described. The head of the mill race is about 200 feet above the dam. The discharge of the mill race was measured, and the mean head of water on a length of 200 feet of the crest of the dam was noted as 0.75 foot. The discharge of the mill race was found to be 85 second-feet, and that passing over the crest of the dam, as computed from the measured head and length of crest, is 430 second-feet, giving a total of 515 second-feet, as noted in the foregoing table.

The flow in the mill race is regulated at the mill. When the gates at the mill are shut, there is no current in the mill race, and the entire discharge of the river passes over the dam except at the time of highest floods. The miller informed Mr. Youngfelt that water was used by the mill at a nearly constant rate. If this be true, a rating table can be constructed which will give the discharge over the dam for the different gage heights and the observer can be instructed to note whether the mill race is discharging or stagnant at the time that he reads the gage. If it is discharging, 85 second-feet should be added to the amount given by the rating table.

*Rating table for Republican River at Superior, Nebraska, for 1896.* [a]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.10 | 22 | 1.00 | 728 | 1.90 | 2,096 | 2.80 | 3,975 |
| 0.20 | 59 | 1.10 | 856 | 2.00 | 2,284 | 2.90 | 4,213 |
| 0.30 | 106 | 1.20 | 982 | 2.10 | 2,476 | 3.00 | 4,454 |
| 0.40 | 169 | 1.30 | 1,122 | 2.20 | 2,673 | 3.10 | 4,703 |
| 0.50 | 240 | 1.40 | 1,268 | 2.30 | 2,876 | 3.20 | 4,952 |
| 0.60 | 321 | 1.50 | 1,409 | 2.40 | 3,085 | 3.30 | 5,211 |
| 0.70 | 408 | 1.60 | 1,582 | 2.50 | 3,299 | 3.40 | 5,470 |
| 0.80 | 505 | 1.70 | 1,748 | 2.60 | 3,519 | 3.50 | 5,735 |
| 0.90 | 610 | 1.80 | 1,926 | 2.70 | 3,746 | | |

[a] The rating table gives the amount which passes over the dam for the different gage heights. If the mill race is discharging at the time the gage height is observed, 85 second-feet must be added to the quantity given by the rating table in order to obtain the total discharge of the river.

The following table of the daily mean discharge for the period following June 20, 1896, has been constructed by adding in each case 85 second feet to the quantity in the rating table which corresponds to the observed gage height. It is almost certain that this correction should not have been made for some days, and therefore the monthly

means as obtained from the table of discharge will slightly exceed the true value:

*Daily mean discharge (in second-feet) of the Republican River at Superior, Nebraska, in 1896.*

| Date. | June. | July. | Aug. | Sept. | Oct. | Nov. |
|---|---|---|---|---|---|---|
| 1 | ..... | 685 | 928 | 282 | 223 | 333 |
| 2 | ..... | 4,300 | 903 | 261 | 204 | 282 |
| 3 | ..... | 4,850 | 864 | 311 | 223 | 373 |
| 4 | ..... | ..... | 467 | 268 | 229 | 342 |
| 5 | ..... | 3,025 | 467 | 216 | 241 | 325 |
| 6 | ..... | 2,147 | 467 | 210 | 229 | 342 |
| 7 | ..... | 1,750 | 1,279 | 204 | 210 | 333 |
| 8 | ..... | 1,940 | 730 | 197 | 191 | 415 |
| 9 | ..... | 1,904 | 1,816 | 204 | 204 | 406 |
| 10 | ..... | 1,528 | 467 | 268 | 191 | 441 |
| 11 | ..... | 1,325 | 415 | 325 | 223 | 398 |
| 12 | ..... | 1,165 | 341 | 304 | 191 | 432 |
| 13 | ..... | 911 | 304 | 289 | 204 | 441 |
| 14 | ..... | 813 | 268 | 423 | 191 | 476 |
| 15 | ..... | 720 | 261 | 289 | 191 | 442 |
| 16 | ..... | 652 | 228 | 289 | 204 | 532 |
| 17 | ..... | 551 | 1,395 | 275 | 204 | 512 |
| 18 | ..... | 570 | 1,466 | 406 | 197 | 476 |
| 19 | ..... | 552 | 1,042 | 296 | 191 | 390 |
| 20 | 720 | 532 | 611 | 303 | 204 | 325 |
| 21 | 600 | 580 | 580 | 268 | 223 | 357 |
| 22 | 513 | 450 | 790 | 296 | 268 | 382 |
| 23 | 551 | 484 | 695 | 311 | 229 | 415 |
| 24 | 441 | 450 | 632 | 282 | 217 | 365 |
| 25 | 450 | 441 | 611 | 223 | 229 | 941 |
| 26 | 1,052 | 423 | 522 | ..... | 217 | 1,137 |
| 27 | 642 | 382 | 467 | 268 | 229 | 450 |
| 28 | 673 | 374 | 432 | 254 | 223 | 459 |
| 29 | 642 | 398 | 365 | 289 | 415 | ..... |
| 30 | 610 | 432 | 333 | 282 | 382 | 493 |
| 31 | ..... | 1,004 | 296 | ..... | 365 | ..... |

Mr. Youngfelt also set an iron pipe, 3 inches in diameter and 4 feet long, for a bench mark. The cap of the pipe is marked "U. S. Geological Survey B.M." This bench mark is 83 feet north of the upstream cylinder of the north pier of the bridge, and is 10 feet west of the line of the upstream truss of the bridge. It is 1 foot inside a wire fence. The top of the pipe is 4 inches above the ground. The elevation of the top of the pipe is 4.88 feet above the zero of the gage.

## JUNCTION CITY STATION ON REPUBLICAN RIVER.

This station was established April 26, 1895, by Mr. Arthur P. Davis. It is located at the wagon bridge at the north end of Washington street, Junction City, Kansas, and is near the junction of this river with the Smoky Hill, forming the Kansas River. The measurements give the total run off of the Republican River. The observer is Mr. John Davis, who lives about 200 yards from the station. The gage consists of two oak timbers, 4 inches by 4 inches, one nearly vertical, the other much inclined; the latter is bolted to a post driven into the bed of the river and bolted to a cottonwood tree, and the vertical portion is spiked to the same tree. The scale is painted on pine boards nailed to these oak timbers. The inclined scale is marked in tenths of a foot from 1 to 10 feet, and the vertical portion from 10 to 27 feet. The bench mark consists of a 60-penny nail driven into the base of the abutment at an elevation of 10.67 feet on the scale. A second bench mark is the top of the stone in the base of the bridge abutment 18 feet south of the gage; its elevation is 14.51 feet. A subsidiary gage has been placed 507 feet upstream. It consists of a vertical oak stick, with a painted scale nailed to it, and referred to the same datum as the lower gage. The difference in reading, therefore, gives the slope of the river for this distance. The initial point for soundings is on the right bank at the end of the bridge. The channel is straight above the station for about 100 feet, then curving to the northwest. Below it is straight for several hundred feet. The right bank is high and not likely to overflow. The left bank is low and may be overflowed in high water. The bed of the stream is sandy, and especially so from the center to the left bank, and is constantly changing. All measurements are taken from the bridge.

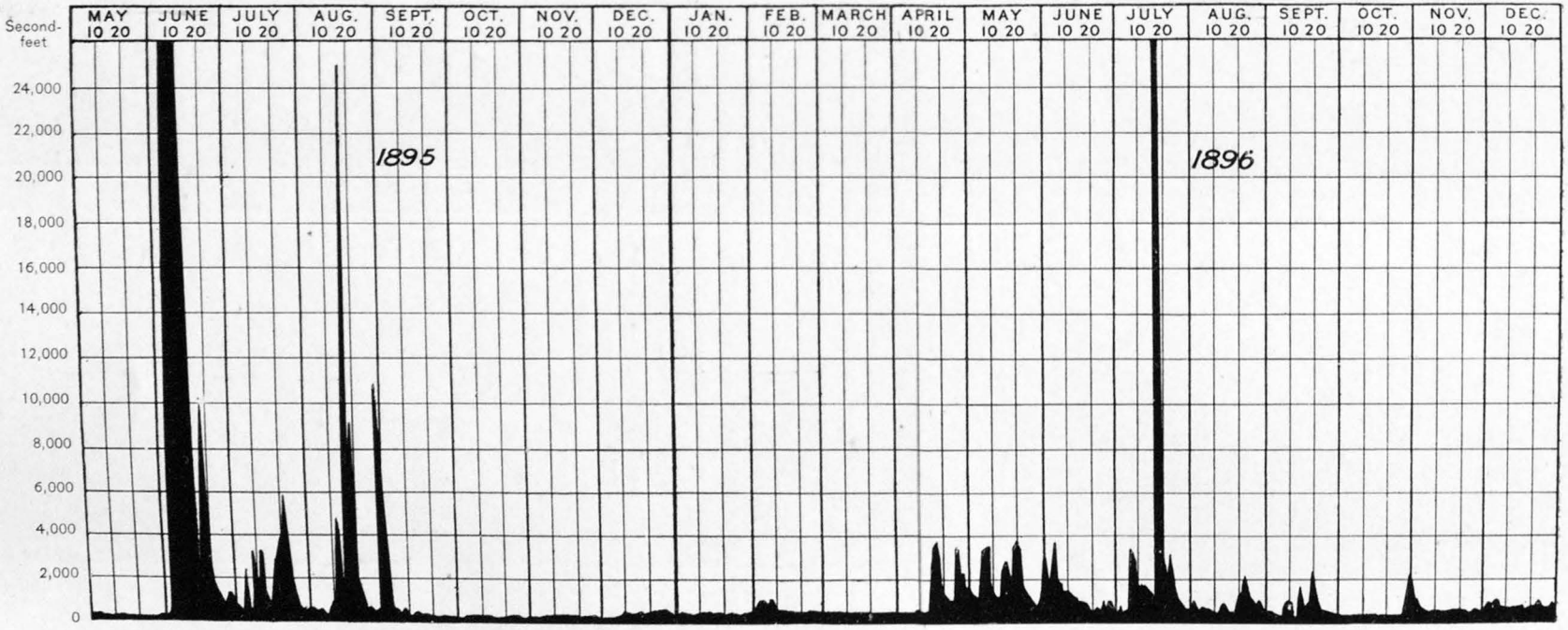
This station is in the Junction City quadrangle, in latitude 39° 3′ and longitude 96° 50′. The drainage area is 25,837 square miles, and is partly mapped on the Clay Center, Washington, Concordia, Mankato, Smith Center, Red Cloud, Holdredge, Arapahoe, and Norton sheets. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 57.

*List of discharge measurements made on Republican River at Junction City, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 27 | A. P. Davis..... | 28 | 3.00 | 144 | 1.52 | 219 |
| 2 | Aug. 20 | W. G. Russell ..... | 28 | 4.75 | 701 | 2.72 | 1,911 |
| 3 | Oct. 11 | .....do ..... | 61 | 2.57 | 144 | 1.95 | 281 |
| 4 | Nov. 11 | .....do ..... | 28 | 2.60 | 147 | 1.95 | 286 |
| 5 | Dec. 13 | .....do ..... | 28 | 2.95 | 187 | 2.02 | 378 |
| 6 | Dec. 27 | .....do ..... | 28 | 3.18 | 187 | 2.38 | 445 |
| | 1896. | | | | | | |
| 7 | Jan. 15 | W. G. Russell ..... | *a* 28 | 3.50 | 263 | 1.91 | 504 |
| 8 | Jan. 27 | .....do ..... | 28 | 3.12 | 235 | 1.74 | 410 |
| 9 | Feb. 10 | .....do ..... | 28 | 3.70 | 321 | 2.32 | 745 |
| 10 | Apr. 16 | .....do ..... | 28 | 6.50 | 1,000 | 3.62 | 3,621 |
| 11 | May 14 | .....do ..... | 28 | 5.75 | 953 | 3.29 | 3,135 |
| 12 | June 16 | .....do ..... | 28 | 3.90 | 599 | 1.86 | 1,116 |
| 13 | June 27 | .....do ..... | 28 | 4.30 | 518 | 2.87 | 1,488 |
| 14 | July 11 | .....do ..... | 28 | 4.20 | 440 | 2.61 | 1,150 |
| 15 | Aug. 12 | .....do ..... | 28 | 3.55 | 389 | 2.22 | 866 |
| 16 | Aug. 28 | .....do ..... | *b* 55 | 4.00 | 428 | 2.63 | 1,126 |
| 17 | Sept. 19 | .....do ..... | 55 | 4.90 | 515 | 3.31 | 1,705 |
| 18 | Sept. 30 | .... do ..... | 55 | 2.80 | 147 | 2.64 | 388 |
| 19 | Oct. 20 | .....do ..... | 55 | 2.75 | 186 | 1.91 | 355 |
| 20 | Oct. 28 | .....do ..... | 55 | 2.80 | 219 | 1.58 | 347 |
| 21 | Nov. 17 | .....do ..... | 55 | 3.30 | 268 | 2.22 | 594 |
| 22 | Dec. 10 | .....do ..... | 55 | 3.50 | 310 | 1.78 | 551 |

*a* Haskell meter.

*b* Price large meter.




DISCHARGE OF REPUBLICAN RIVER AT JUNCTION CITY, KANSAS, 1895–96.

*Rating table for Republican River at Junction City, Kansas.*

[This table is applicable only from January 1, 1896, to July 1, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.80 | 380 | 3.90 | 916 | 5.00 | 1,830 | 6.10 | 3,390 |
| 2.90 | 388 | 4.00 | 1,026 | 5.10 | 1,960 | 6.20 | 3,450 |
| 3.00 | 396 | 4.10 | 1,117 | 5.20 | 2,105 | 6.30 | 3,510 |
| 3.10 | 410 | 4.20 | 1,150 | 5.30 | 2,260 | 6.40 | 3,570 |
| 3.20 | 440 | 4.30 | 1,217 | 5.40 | 2,425 | 6.50 | 3,621 |
| 3.30 | 467 | 4.40 | 1,287 | 5.50 | 2,605 | 6.60 | 3,680 |
| 3.40 | 495 | 4.50 | 1,362 | 5.60 | 2,810 | 6.70 | 3,740 |
| 3.50 | 554 | 4.60 | 1,440 | 5.70 | 3,025 | 6.80 | 3,800 |
| 3.60 | 612 | 4.70 | 1,523 | 5.80 | 3,140 | 6.90 | 3,860 |
| 3.70 | 715 | 4.80 | 1,610 | 5.90 | 3,250 | 7.00 | 3,920 |
| 3.80 | 825 | 4.90 | 1,705 | 6.00 | 3,335 | 7.10 | 3,980 |

*Estimated monthly discharge of Republican River at Junction City, Kansas.*

[Drainage area, 25,837 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| July | 6,000 | 439 | 1,800 | 110,678 | 0.09 | 0.08 |
| August | *a*25,000 | 265 | 3,192 | 196,269 | 0.16 | 0.14 |
| September | 4,170 | 219 | 542 | 32,251 | 0.026 | 0.023 |
| October | 326 | 220 | 249 | 15,310 | 0.012 | 0.011 |
| November | 355 | 230 | 282 | 16,779 | 0.013 | 0.012 |
| December | 575 | 230 | 392 | 24,103 | 0.019 | 0.017 |
| 1896. | | | | | | |
| January | 556 | 392 | 448 | 27,547 | 0.020 | 0.017 |
| February | 1,131 | 504 | 756 | 43,486 | 0.031 | 0.029 |
| March | 504 | 504 | 504 | 30,990 | 0.022 | 0.019 |
| April | 3,770 | 485 | 1,414 | 84,139 | 0.061 | 0.055 |
| May | 3,920 | 785 | 2,124 | 130,601 | 0.095 | 0.082 |
| June | 3,980 | 494 | 1,370 | 81,520 | 0.059 | 0.053 |
| July | *a*37,500 | 594 | 3,678 | 226,153 | 0.162 | 0.139 |
| August | 2,340 | 459 | 893 | 54,909 | 0.039 | 0.034 |
| September | 2,425 | 326 | 667 | 39,690 | 0.028 | 0.024 |
| October | 2,180 | 356 | 475 | 29,207 | 0.021 | 0.018 |
| November | 1,480 | 459 | 655 | 38,976 | 0.027 | 0.023 |
| December | 1,121 | 594 | 810 | 49,805 | 0.036 | 0.031 |
| Per annum | *a*37,500 | 326 | 1,150 | 837,023 | 0.601 | 0.044 |

*a* Estimated.

## MEASUREMENTS AT POINTS OTHER THAN GAGING STATIONS.

| Date. | By whom. | Name of stream. | Where measured. | Discharge (cubic feet per second). | Mean velocity (feet per second). |
|---|---|---|---|---|---|
| 1896. | | | | | |
| June 17 | O. V. P. Stout | Arickaree River | Haigler | 6.14 | |
| July 16 | E. T. Youngfelt | do | do | 3.63 | |
| June 17 | do | Buffalo Creek | Near Moores Ranch | 7.90 | |
| Aug. 25 | do | Republican River | 2 miles west of Ives. | 5.00 | |
| June 16 | O. V. P. Stout | Rock Creek | At B. and M. Ry. crossing. | 12.16 | |
| Aug. 25 | E. T. Youngfelt | do | do | 12.20 | |
| June 16 | do | Horse Creek | do | 0.22 | |
| June 16 | O. V. P. Stout | Republican River | 7 miles west of Benkelman. | 87.52 | |
| June 16 | do | Dundy County irrigation ditch. | At head gate | 6.19 | |
| June 16 | do | Neighbor ditch | do | 1.12 | |
| June 16 | do | Republican River | Benkelman | 29.30 | |
| Aug. 25 | E. T. Youngfelt | do | do | 0.00 | |
| June 16 | do | South Fork Republican. | do | 3.25 | |
| June 16 | do | do | 3,000 feet west of above. | 1.39 | |
| June 19 | O. V. P. Stout | Republican River | Culbertson | *a* 6.48 | |
| May 16 | C. E. Crownover | do | do | *a* 78.36 | |
| June 19 | O. V. P. Stout | Stinking Water | Palisade | *b* 12.24 | |
| Sept. 17 | E. T. Youngfelt | do | do | *c* 20.00 | |
| June 19 | O. V. P. Stout | Frenchman River | Sec. 33, T. 4, R. 32 | 26.30 | |
| June 19 | E. T. Youngfelt | do | Culbertson | 13.40 | |
| June 19 | O. V. P. Stout | Culbertson Canal | At head gate | *d* 60.80 | |
| May 17 | C. E. Crownover | Republican River | Oxford | 254.50 | |
| June 20 | O. V. P. Stout | do | do | 109.40 | |
| June 28 | do | Pumpkinseed Creek | Careys Ranch | *e* 22.20 | 2.11 |
| Sept. 9 | do | Birdwood Creek | Sutherland | 133.00 | 2.05 |
| Sept. 9 | do | Bratts ditch | do | 28.20 | |

*a* Above mouth of Frenchman.
*b* Above mill at Palisade.
*c* Below mill at Palisade.
*d* Total discharge of Frenchman River was about 1.25 second-feet more than this.
*e* Gaged below Bratts ditch, which at the time was carrying 28.2 second feet.

The measurements of the Republican River (North Fork) which were made in the vicinity of Benkelman on June 16, 1896, are related to each other as follows: The gaging near Benkelman was made at about noon; the other gagings west of there were made in the afternoon, when the discharge had been considerably increased by rains which had fallen farther up the river. The Neighbor ditch and the Dundy County ditch divert their water from the river just below the gaging section, 7 miles west of Benkelman.

On the morning of June 19 the discharge of the Culbertson Canal was measured at the head gate near Palisade. It was diverting the

entire discharge of the Frenchman River, except about 1¼ second-feet. The amount entering the canal was found to be 60.8 second-feet. At about noon the river was gaged in sec. 33, T. 4 N., R. 32 W., of the sixth principal meridian, where it was found that the discharge was 26.3 second-feet. This amount is made up of the 1¼ second-feet which passed the head gate of the Culbertson Canal, the discharge of Stinking Water Creek, which enters the Frenchman a short distance below the head gate, and seepage. A measurement of the Stinking Water on that day showed it to be discharging at the rate of 12.24 second-feet, but as a mill pond is situated on the stream between its mouth and the gaging section, it may be that the true discharge into the Frenchman is not indicated by the measurement which was made. It is believed, however, that the difference on that day was slight. At Culbertson the discharge of the Frenchman into the Republican River was found to be 13.4 second-feet. Two canals between Culbertson and the place of measurement in section 33 were diverting 2.28 and 15.92 second-feet, respectively. Stinking Water Creek is the only tributary received by the Frenchman between Palisade and Culbertson which needs to be considered in this connection.

## SMOKY HILL RIVER.

Smoky Hill River rises in eastern Colorado, and drains an area of 20,428 square miles. It has two considerable tributaries, the Saline and the Solomon, draining, respectively, 3,611 and 6,882 square miles. Measurements have been continued on all three of these streams.

### BELOIT STATION ON SOLOMON RIVER.

This station was established April 22, 1895, by Mr. Arthur P. Davis, at the wagon bridge on the south edge of the town of Beloit, Kansas. The present observer is Mr. W. F. Jordon, who was appointed June 22, 1896, the former observer having moved away. The present gage is a spruce board, 12 feet long, graduated in feet and tenths, spiked to the upstream edge of the bridge floor, above the deepest water. It is read by lowering a heavy sash weight by a small brass chain with a small ring therein, whose lower edge, when the weight touches the water, gives the same reading as the water surface gave on the old gage. The bridge pier is graduated from 6 feet up to the bridge floor. It was impossible to fasten a gage in the river as there is solid rock at 18 inches beneath the bed. The bench mark consists of a tenpenny nail driven into the base of a cottonwood tree, 35 feet northwest of the pier upon which the marks are made. Its elevation is 13.70 feet. Measurements are made from the bridge, the initial point being at the south edge of the stone abutment on the left bank of the stream.

There has been more or less dredging of the bed of this stream here during the year, especially during October and November, and the bed seems to have bowlders, too; hence the same gage heights do not give

same depths. The mill just above the gage uses several water wheels, and at times runs but one, then more than one, giving varying amounts of flow, and it is impossible to get very accurate results. The stream is straight for about 200 feet above and for a much longer distance below.

This station is in the Beloit quadrangle in latitude 39° 27′, longitude 98° 7′. Its drainage area is partly mapped on the Beloit, Mankato, Smith Center, Phillipsburg, and Norton sheets. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 57.

*List of discharge measurements made on Solomon River at Beloit, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 20 | A. P. Davis | 28 | 2.90 | ..... | 1.60 | 148 |
| 2 | Aug. 19 | W. G. Russell | 28 | 3.27 | 119 | 1.64 | 195 |
| 3 | Oct. 31 | .....do | 3 | 2.10 | 25 | 0.33 | 8 |
| 4 | Nov. 1 | .....do | 3 | 2.93 | 63 | 1.24 | 78 |
| 5 | Dec. 13 | .....do | 28 | 2.85 | 91 | 1.19 | 109 |
| 6 | Dec. 27 | .....do | 28 | 2.80 | 98 | 1.07 | 105 |
| | 1896. | | | | | | |
| 7 | Jan. 14 | W. G. Russell | *a* 28 | 1.90 | ..... | ..... | *b* 5 |
| 8 | Jan. 14 | .....do | 28 | 2.75 | 104 | 1.01 | 115 |
| 9 | Jan. 31 | .....do | 28 | 2.65 | 102 | 1.22 | 125 |
| 10 | Feb. 12 | .....do | 28 | 2.75 | 109 | 1.13 | 123 |
| 11 | Apr. 17 | .....do | 28 | 4.58 | 325 | 2.26 | 734 |
| 12 | May 14 | .....do | 28 | 4.35 | 302 | 2.12 | 638 |
| 13 | June 5 | .....do | 28 | *c* 4.80 | 388 | 1.95 | 756 |
| 14 | June 27 | .....do | 28 | 4.05 | 251 | 0.83 | 209 |
| 15 | July 9 | .....do | 28 | 4.25 | 300 | 1.18 | 353 |
| 16 | Aug. 12 | .....do | 28 | 4.20 | 281 | 0.93 | 261 |
| 17 | Aug. 28 | .....do | *d* 55 | 4.15 | 277 | 0.79 | 220 |
| 18 | Sept. 19 | .....do | 55 | 3.90 | 194 | 0.69 | 135 |
| 19 | Sept. 30 | .....do | 55 | 3.40 | 168 | 0.53 | 88 |
| 20 | Oct. 20 | .....do | 55 | 3.10 | 143 | 0.61 | 87 |
| 21 | Oct. 28 | .....do | 55 | 3.00 | 138 | 0.61 | 84 |
| 22 | Nov. 17 | .....do | 55 | 3.00 | 181 | 0.53 | 96 |
| 23 | Dec. 11 | .....do | 55 | 3.10 | 169 | 0.55 | 94 |

*a* Haskell meter. *b* Estimated; no current. *c* New gage. *d* Price large meter.

*Rating table for Solomon River at Beloit, Kansas.*

[This table is applicable only from January 1, 1896, to June 20, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.00 | 15 | 3.60 | 390 | 5.00 | 842 | 7.60 | 4,860 |
| 2.10 | 25 | 3.70 | 425 | 5.20 | 938 | 7.80 | 5,630 |
| 2.20 | 38 | 3.80 | 460 | 5.40 | 1,046 | 8.00 | 5,930 |
| 2.30 | 51 | 3.90 | 490 | 5.60 | 1,167 | 8.20 | 6,250 |
| 2.40 | 65 | 4.00 | 520 | 5.80 | 1,300 | 8.40 | 6,580 |
| 2.50 | 80 | 4.10 | 555 | 6.00 | 1,507 | 8.60 | 6,930 |
| 2.60 | 96 | 4.20 | 590 | 6.20 | 1,748 | 8.80 | 7,300 |
| 2.70 | 110 | 4.30 | 620 | 6.40 | 2,024 | 9.00 | 7,685 |
| 2.80 | 133 | 4.40 | 650 | 6.60 | 2,350 | 9.20 | 8,100 |
| 2.90 | 164 | 4.50 | 685 | 6.80 | 2,720 | 9.40 | 8,530 |
| 3.00 | 196 | 4.60 | 718 | 7.00 | 3,144 | 9.60 | 8,990 |
| 3.20 | 264 | 4.70 | 750 | 7.20 | 3,630 | 9.80 | 9,480 |
| 3.40 | 330 | 4.80 | 780 | 7.40 | 4,200 | 10.00 | 10,000 |

*Rating table for Solomon River at Beloit, Kansas.*

[This table is applicable only from June 20, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.80 | 60 | 3.40 | 95 | 4.00 | 165 | 4.60 | 560 |
| 2.90 | 63 | 3.50 | 102 | 4.10 | 195 | 4.70 | 630 |
| 3.00 | 66 | 3.60 | 109 | 4.20 | 260 | 4.80 | 700 |
| 3.10 | 72 | 3.70 | 117 | 4.30 | 330 | 4.90 | 770 |
| 3.20 | 80 | 3.80 | 128 | 4.40 | 410 | 5.00 | 840 |
| 3.30 | 88 | 3.90 | 141 | 4.50 | 485 | | |

*Estimated monthly discharge of Solomon River at Beloit, Kansas.*

[Drainage area, 5,539 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| July | *a* 21,000 | 159 | 2,202 | 135,396 | 0.460 | 0.400 |
| August | *a* 24,000 | 172 | 1,629 | 100,164 | 0.34 | 0.29 |
| September | 615 | 14 | 156 | 9,283 | 0.032 | 0.028 |
| October | 62 | 7 | 28 | 1,722 | 0.006 | 0.005 |
| November | 26 | 7 | 23 | 1,369 | 0.005 | 0.004 |
| December | 250 | 7 | 114 | 7,010 | 0.024 | 0.021 |

*a* Estimated

*Estimated monthly discharge of Solomon River at Beloit, Kansas*—Continued.

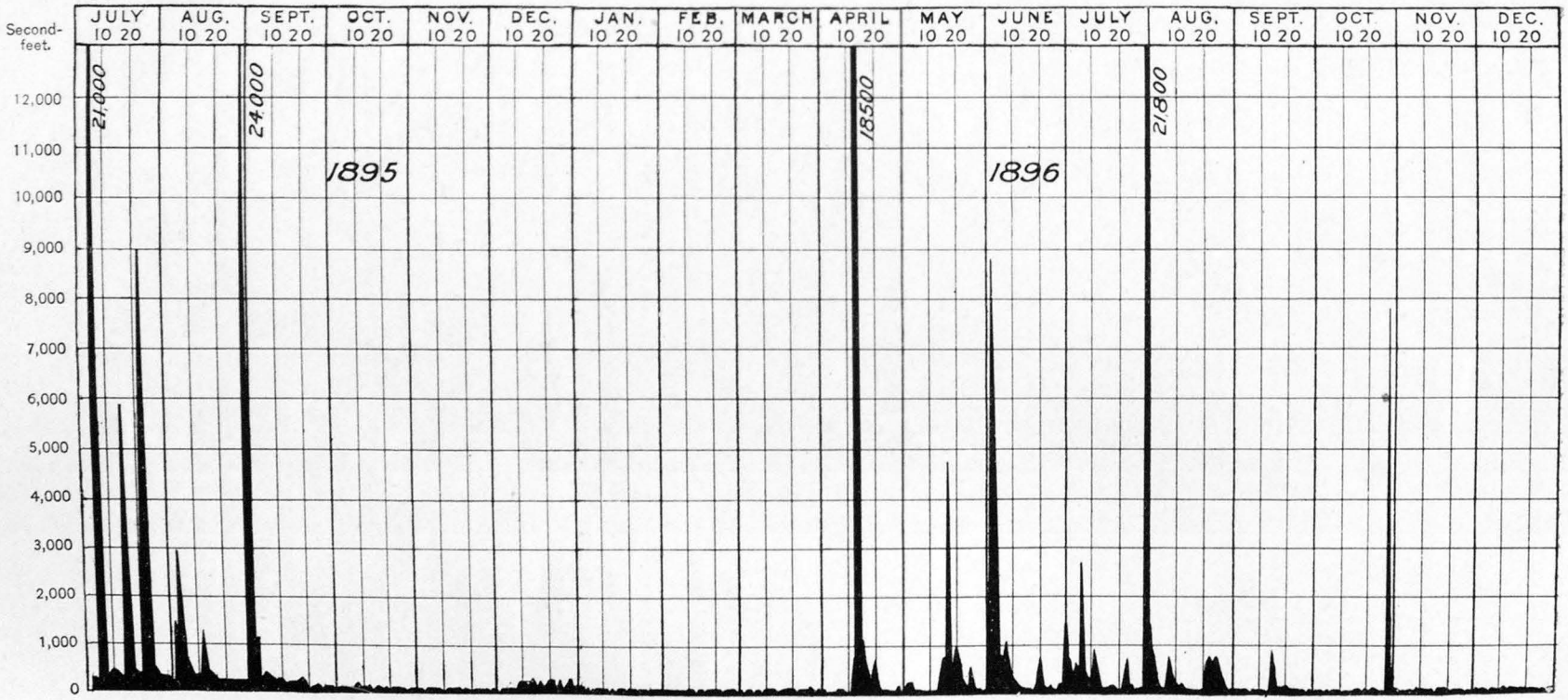
| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 121 | 5 | 88 | 5,411 | 0.018 | 0.016 |
| February | 121 | 19 | 103 | 5,925 | 0.020 | 0.018 |
| March | 123 | 8 | 94 | 5,780 | 0.019 | 0.017 |
| April | *a* 18,500 | 8 | 1,658 | 98,658 | 0.334 | 0.300 |
| May | 4,700 | 72 | 429 | 26,378 | 0.089 | 0.077 |
| June | 8,740 | 104 | 852 | 50,698 | 0.172 | 0.154 |
| July | *a* 21,800 | 108 | 1,238 | 76,122 | 0.255 | 0.226 |
| August | 803 | 92 | 354 | 21,767 | 0.073 | 0.065 |
| September | 960 | 28 | 130 | 7,735 | 0.026 | 0.023 |
| October | 6,760 | 10 | 302 | 18,569 | 0,062 | 0.055 |
| November | 117 | 34 | 76 | 4,522 | 0.015 | 0.013 |
| December | 124 | 38 | 92 | 5,657 | 0.019 | 0.017 |
| Per annum | *a* 21,800 | 5 | 451 | 327,222 | 11.02 | 0.083 |

*a* Estimated.

## BEVERLY STATION ON SALINE RIVER.

This station was established by Mr. Arthur P. Davis April 18, 1895, at the iron highway bridge one-half mile southwest of town. The present observer is Mr. Jerome Wilson, who took charge February 18, 1896, Charles Reid, the former observer, having moved away. Mr. Wilson lives about one-half mile from the station. The gage is an inclined timber, fastened to trestles which are set in the ground and well loaded down with rock. This is graduated up to 18 feet, and one of the iron cylinder bridge piers is then graduated up to 30 feet. The bench mark is the top of the lower iron strut at the north end connecting the two south piers. Its elevation is 18.95 feet above the zero of the gage. This gage was put in August 8, 1895, being brought over from the north bank, as the high water of July had settled the first, as reported in report for 1895. The water is cutting out the north piers, and quite an amount of work will be done here this winter to change the current back toward the south bank, which may damage this gage.

This station is in the Minneapolis quadrangle. Its latitude is 39° 1′ and longitude 97° 59′. The drainage area is 2,730 square miles, and is partly mapped upon the Beloit, Mankato, Smith Center, Phillipsburg, and Norton atlas sheets. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 58.




DISCHARGE OF SOLOMON RIVER AT BELOIT, KANSAS, 1895–96.

*List of discharge measurements made on Saline River at Beverly, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 18 | A. P. Davis | 28 | *a* 1.50 | 16 | 1.35 | 22 |
| 2 | June 8 | W. G. Russell | 19 | *a* 9.90 | 448 | 2.77 | 1,238 |
| 3 | July 22 | do | 19 | 6.10 | 129 | 1.76 | 226 |
| 4 | Aug. 22 | do | 19 | 4.70 | 50 | 1.52 | 76 |
| 5 | Sept. 21 | do | 19 | 3.85 | 30 | 0.42 | 13 |
| 6 | Nov. 12 | do | 19 | 4.30 | 52 | 1.09 | 56 |
| 7 | Dec. 14 | do | 28 | 4.60 | 60 | 1.19 | 70 |
| 8 | Dec. 23 | do | 19 | 4.10 | 44 | 0.57 | 25 |
| | 1896. | | | | | | |
| 9 | Jan. 16 | W. G. Russell | *b* 28 | 4.10 | 47 | 0.69 | 33 |
| 10 | Jan. 28 | do | 28 | 4.05 | 40 | 0.77 | 31 |
| 11 | Feb. 14 | do | 28 | 4.25 | 48 | 0.96 | 46 |
| 12 | Apr. 14 | do | 28 | 9.70 | 249 | 2.79 | 693 |
| 13 | May 15 | do | 28 | 5.75 | 112 | 1.83 | 204 |
| 14 | June 6 | do | 28 | 9.20 | 250 | 2.69 | 674 |
| 15 | July 11 | do | 28 | 7.50 | 174 | 2.82 | 493 |
| 16 | Aug. 13 | do | 28 | 4.80 | 78 | 1.23 | 96 |
| 17 | Sept. 1 | do | *c* 55 | 4.60 | 76 | 1.00 | 76 |
| 18 | Sept. 25 | do | 55 | 4.40 | 73 | 0.78 | 56 |
| 19 | Oct. 21 | do | 55 | 4.30 | 70 | 0.69 | 48 |
| 20 | Nov. 5 | do | 55 | 4.90 | 88 | 1.22 | 107 |

*a* Old gage before injury by flood. *b* Haskell meter. *c* Price large meter.

*Rating table for Saline River at Beverly, Kansas.*

[This table is applicable only from January 1, 1896, to September 1, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.00 | 30 | 5.50 | 167 | 7.00 | 380 | 8.50 | 592 |
| 4.10 | 33 | 5.60 | 181 | 7.10 | 400 | 8.60 | 603 |
| 4.20 | 41 | 5.70 | 195 | 7.20 | 420 | 8.70 | 614 |
| 4.30 | 49 | 5.80 | 212 | 7.30 | 443 | 8.80 | 626 |
| 4.40 | 56 | 5.90 | 223 | 7.40 | 467 | 8.90 | 638 |
| 4.50 | 65 | 6.00 | 234 | 7.50 | 493 | 9.00 | 650 |
| 4.60 | 76 | 6.10 | 246 | 7.60 | 502 | 9.10 | 661 |
| 4.70 | 85 | 6.20 | 258 | 7.70 | 511 | 9.20 | 674 |
| 4.80 | 96 | 6.30 | 270 | 7.80 | 520 | 9.30 | 677 |
| 4.90 | 103 | 6.40 | 284 | 7.90 | 529 | 9.40 | 681 |
| 5.00 | 113 | 6.50 | 298 | 8.00 | 539 | 9.50 | 685 |
| 5.10 | 122 | 6.60 | 314 | 8.10 | 549 | 9.60 | 689 |
| 5.20 | 132 | 6.70 | 330 | 8.20 | 559 | 9.70 | 693 |
| 5.30 | 143 | 6.80 | 346 | 8.30 | 570 | | |
| 5.40 | 154 | 6.90 | 362 | 8.40 | 581 | | |

*Estimated monthly discharge of Saline River at Beverly, Kansas.*

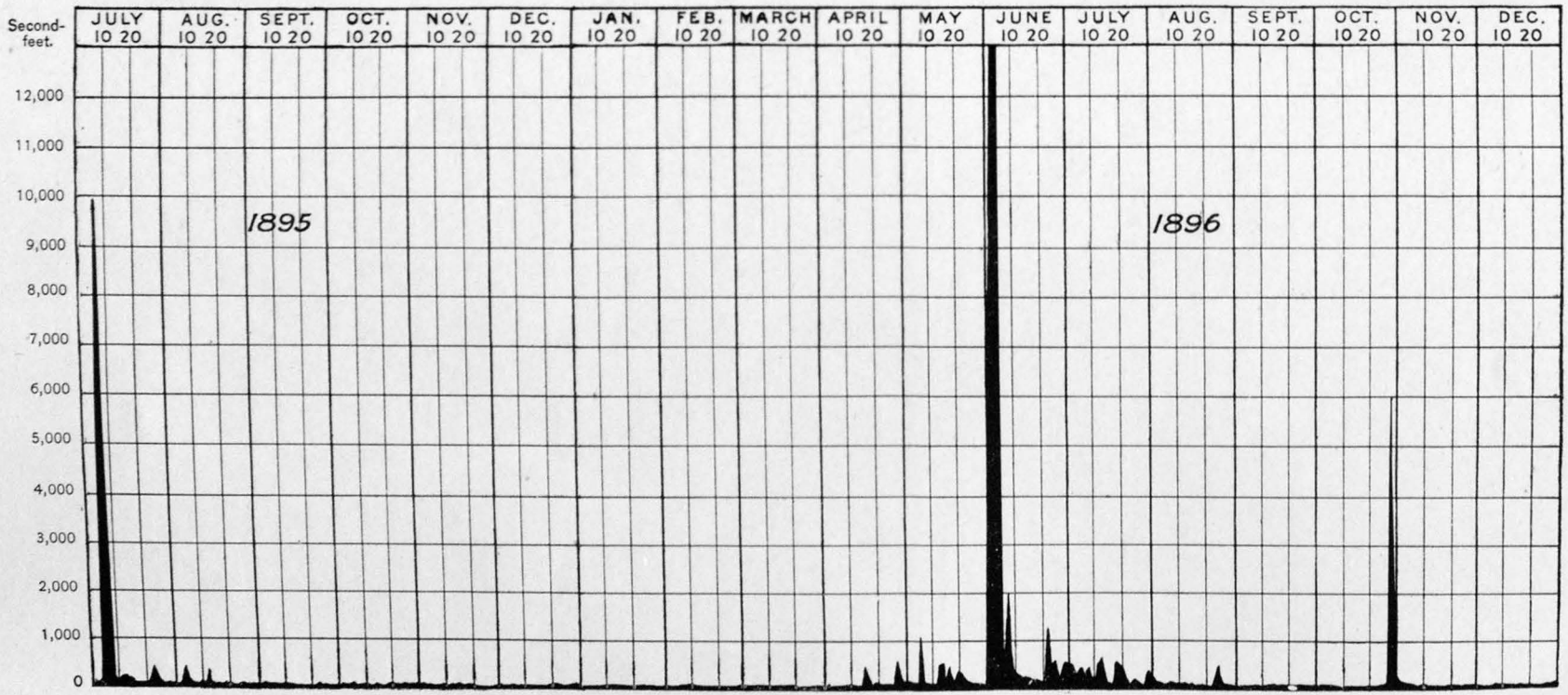
[Drainage area, 2,730 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches | Second feet per square mile. |
| 1895. | | | | | | |
| July | a10,000 | 73 | 574 | 35,294 | 0.20 | 0.18 |
| August | 339 | 58 | 101 | 6,210 | 0.035 | 0.031 |
| September | 92 | 9 | 38 | 2,261 | 0.012 | 0.011 |
| October | 58 | 6 | 27 | 1,660 | 0.009 | 0.008 |
| November | 62 | 9 | 33 | 1,964 | 0.010 | 0.009 |
| December | 57 | 13 | 33 | 2,029 | 0.011 | 0.010 |
| 1896. | | | | | | |
| January | 76 | 26 | 52 | 3,197 | 0.022 | 0.019 |
| February | 96 | 33 | 51 | 2,934 | 0.020 | 0.018 |
| March | 65 | 33 | 49 | 3,013 | 0.020 | 0.018 |
| April | 693 | 37 | 151 | 8,986 | 0.062 | 0.055 |
| May | 3,000 | 45 | 313 | 19,245 | 0.132 | 0.114 |
| June | a16,000 | 167 | 2,291 | 136,324 | 0.936 | 0.839 |
| July | 679 | 103 | 286 | 17,586 | 0.120 | 0.104 |
| August | 493 | 41 | 107 | 6,579 | 0.045 | 0.037 |
| September | 90 | 33 | 58 | 3,451 | 0.024 | 0.021 |
| October | a6,130 | 31 | 260 | 15,987 | 0.109 | 0.095 |
| November | 188 | 41 | 75 | 4,463 | 0.031 | 0.027 |
| December | 98 | 31 | 62 | 3,505 | 0.002 | 0.002 |
| Per annum | a16,000 | 26 | 313 | 225,270 | 1.523 | 0.112 |

a Estimated.

## ELLSWORTH STATION ON SMOKY HILL RIVER.

This station was established by Mr. Arthur P. Davis April 17, 1895, at the highway bridge on Douglas avenue, Ellsworth, Kansas, in the Ellsworth quadrangle. The observer is Robert Martin, who lives about 100 yards north of the bridge. The gage is an inclined ash timber spiked to a post driven in the bed of the river and bolted to an iron post of the bridge pier. The graduations are in feet and tenths to 4.5 feet on the timber, and continued on the bridge pier. The measurements are taken from the bridge, the initial point being at the north end. The bench mark is a nail driven in the base of a large box elder tree near the southeast corner of the bridge, 90 feet from the gage. Its elevation is 13.07 feet above the zero of the gage. Another gage was put in July 25, 1896, as the channel had left this gage; it is timber plank bolted to the bridge pier 90 feet north of the first gage and




DISCHARGE OF SALINE RIVER AT BEVERLY, KANSAS, 1895–96.

only about 4 feet long, as the water reaches the first gage at less than that height. A second gage was established October 23, 1895. It was spiked to the east or downstream pile of the fourth bent from the south end of the Frisco railroad bridge, west or upstream from the old gage 2,536 feet, and was placed at the same elevation as the old gage. The difference of water height October 23 was 1.44 feet, giving a slope of 0.000568. The channel is nearly straight above and below the bridge, and the bed is sandy and shifting, and is moving northward toward the left bank. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 58.

*List of discharge measurements made on Smoky Hill River at Ellsworth, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 16 | A. P. Davis..... | 28 | 1.50 | ..... | 0.84 | 12 |
| | Apr. 27 | .....do ..... | Floats. | ..... | ..... | 0.33 | *a* 188 |
| 2 | June 5 | W. G. Russell.... | 19 | 9.05 | 1,854 | 2.91 | 5,402 |
| 3 | July 3 | .....do ..... | 19 | 2.60 | 115 | 1.89 | 217 |
| 4 | Aug. 21 | .....do ..... | 19 | 2.10 | 77 | 1.34 | 104 |
| 5 | Sept. 20 | .....do ..... | 19 | 1.50 | 28 | 0.94 | 26 |
| 6 | Oct. 23 | .....do ..... | 19 | 1.35 | 21 | 0.84 | 17 |
| 7 | Dec. 6 | .....do ..... | 19 | 1.35 | 19 | 0.94 | 18 |
| 8 | Dec. 28 | .....do ..... | 19 | 1.30 | 19 | 0.95 | 18 |
| | 1896. | | | | | | |
| 9 | Jan. 22 | W. G. Russell... | *b* 3 | 1.42 | 26 | 1.00 | 26 |
| 10 | Mar. 19 | .....do ..... | 3 | 1.24 | 18 | 0.88 | 16 |
| 11 | Apr. 13 | .....do ..... | 3 | 3.04 | 221 | 1.75 | 387 |
| 12 | June 9 | .....do ..... | 3 | 3.55 | 277 | 2.20 | 609 |
| 13 | June 25 | .....do ..... | 3 | 2.50 | 138 | 1.68 | 232 |
| 14 | June 29 | .....do ..... | 3 | 3.40 | 296 | 1.73 | 511 |
| 15 | July 18 | .....do ..... | 3 | 3.05 | 242 | 1.78 | 431 |
| 16 | July 25 | .....do ..... | 3 | 2.00 | 81 | 1.58 | 128 |
| 17 | Aug. 19 | .....do ..... | *c* 55 | 1.56 | 53 | 1.49 | 79 |
| 18 | Aug. 25 | .....do ..... | 55 | 1.60 | 49 | 1.76 | 87 |
| 19 | Sept. 22 | .....do ..... | 55 | 1.68 | 63 | 1.63 | 102 |
| 20 | Oct. 26 | .....do ..... | 55 | 1.30 | 30 | 1.22 | 37 |
| 21 | Nov. 2 | .....do ..... | 55 | 1.80 | 82 | 1.85 | 153 |
| 22 | Nov. 20 | .....do ..... | 55 | 1.20 | 33 | 1.04 | 34 |
| 23 | Dec. 21 | .....do ..... | 55 | 1.20 | 32 | 1.14 | 37 |

*a* Smoky Hill River at Junction City. *b* Small Price meter. *c* Large Price meter.

*Rating table for Smoky Hill River at Ellsworth, Kansas.*

[This table is applicable only from January 1, 1896, to June 30, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.25 | 16 | 2.20 | 163 | 3.00 | 372 | 3.80 | 723 |
| 1.50 | 49 | 2.30 | 183 | 3.10 | 446 | 3.90 | 773 |
| 1.60 | 87 | 2.40 | 206 | 3.20 | 478 | 4.00 | 828 |
| 1.70 | 106 | 2.50 | 232 | 3.30 | 512 | 4.10 | 887 |
| 1.80 | 113 | 2.60 | 255 | 3.40 | 550 | 4.20 | 951 |
| 1.90 | 120 | 2.70 | 280 | 3.50 | 589 | 4.30 | 1,017 |
| 2.00 | 128 | 2.80 | 308 | 3.60 | 631 | 4.40 | 1,091 |
| 2.10 | 144 | 2.90 | 339 | 3.70 | 676 | | |

*Estimated monthly discharge of Smoky Hill River at Ellsworth, Kansas.*

[Drainage area, 7,980 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second feet per square mile. |
| 1895. | | | | | | |
| April 17 to 30 | 14 | 11 | 12 | 336 | 0.001 | 0.002 |
| May | 20 | 9 | 11 | 676 | 0.001 | 0.001 |
| June | 4,900 | 10 | 690 | 41,058 | 0.10 | 0.09 |
| July | 21,000 | 202 | 1,438 | 88,420 | 0.22 | .19 |
| August | 344 | 65 | 186 | 11,437 | 0.03 | 0.025 |
| September | 135 | 19 | 44 | 2,618 | 0.007 | 0.006 |
| October | 22 | 14 | 18 | 1,107 | 0.003 | 0.002 |
| November | 19 | 12 | 18 | 1,071 | 0.003 | 0.002 |
| December | 22 | 11 | 17 | 1,045 | 0.003 | 0.002 |
| 1896. | | | | | | |
| January | 57 | 17 | 25 | 1,537 | 0.004 | 0.003 |
| February | 49 | 18 | 26 | 1,496 | 0.004 | 0.003 |
| March | 21 | 14 | 18 | 1,107 | 0.002 | 0.002 |
| April | 800 | 14 | 130 | 7,736 | 0.018 | 0.016 |
| May | 116 | 18 | 62 | 3,812 | 0.009 | 0.008 |
| June | 1,713 | 72 | 313 | 18,625 | 0.044 | 0.039 |
| July | 951 | 119 | 230 | 14,142 | 0.033 | 0.029 |
| August | 372 | 66 | 115 | 7,071 | 0.016 | 0.014 |
| September | 117 | 50 | 72 | 4,284 | 0.010 | 0.009 |
| October | 255 | 25 | 54 | 3,320 | 0.008 | 0.007 |
| November | 122 | 20 | 54 | 3,213 | 0.008 | 0.007 |
| December | 43 | 18 | 34 | 2,337 | 0.005 | 0.004 |
| Per annum | 1,713 | 14 | 95 | 68,680 | 1.61 | 0.012 |

## KANSAS RIVER.

The Kansas River, properly so called, is formed by the junction, near Fort Riley, of the Republican and Smoky Hill rivers. The principal tributary below this point is Blue River, upon which measurements have been continued. Observations have also been taken at two points on the main stream.

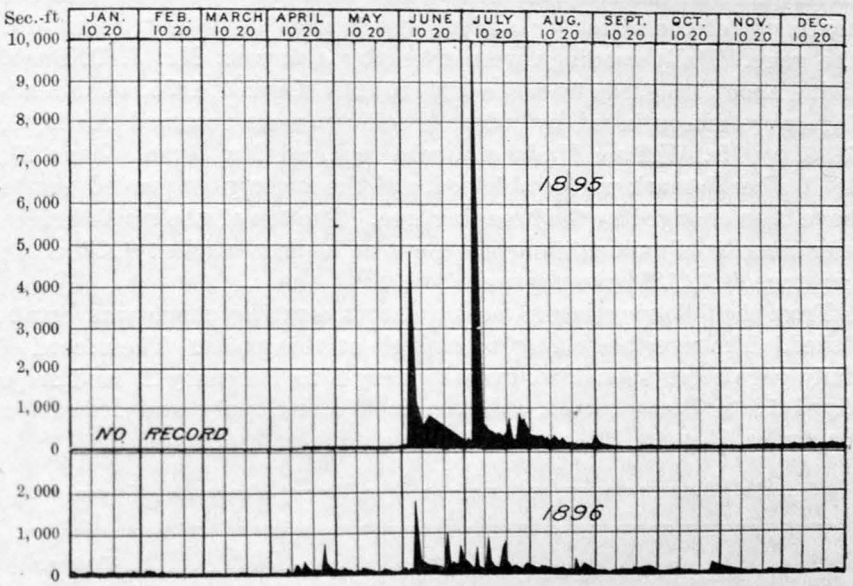



FIG. 30.—Discharge of Smoky Hill River at Ellsworth, Kansas, 1895–96.

## MANHATTAN STATION ON BLUE RIVER.

The Blue River, or, as it is sometimes called in distinction from one of its tributaries, Big Blue River, flows into Kansas River from the north, about 20 miles below the junction of the Smoky Hill and Republican rivers, in the town of Manhattan. The stream and its water powers are described by Prof. Dwight Porter in his report in Volume 17, Tenth Census, pages 60 to 65.

A station was established on the Blue River at the county bridge, 4 miles north of Manhattan. It is described in Bulletin 140, page 144. This point is beyond the influence of backwater from the Kansas, and all but about 50 of the 9,490 square miles of drainage area is represented in the discharge. The station was established by Mr. Arthur P. Davis, April 12, 1895, and was placed in charge of Prof. O. P. Hood, of the Kansas State Agricultural College. It is in the Junction City quadrangle, in latitude 39° 14′ and longitude 96° 35′. The drainage area is mapped on the Junction City, Marysville, Seneca, Washington, Grand Island, and Stromsburg atlas sheets.

The gage consists of three sections, a lower section being an ash

stick driven into the bottom of the river and bolted to an overhanging cottonwood tree 30 feet east of the bridge. It is marked from 2.10 to 11.30 feet. An oak board spiked to the inclined tree and marked from 11.30 to 17 feet furnished the center section. In May, 1896, during a high south wind, this cottonwood tree was broken off in the length of the middle section. A new middle section was then placed on the north side of the south bridge pier. This consists of an oak stick bolted to the pier and marked from 11.30 to 17 feet. A similar stick on the south side of the same pier, and marked from 17 to 30 feet, completes the gage. Daily readings were taken by a farmer, Mr. J. D. Bush, living about 100 yards from the bridge, until March 1, 1896, when readings were discontinued by order. Readings were resumed April 16, 1896, by Mr. William Hudspeth, who replaced Mr. Bush. June 27, 1896, a bench mark was established, and the lower gage proved not to have been changed by the breaking tree. The top of the south bridge pier immediately above the upper gage, at a place marked "X" in the capstone, is 32.135 above datum.

From the following meter measurements a rating curve was established. The river bed changes but little at this point. The record of daily gage heights for 1896, from January 1 to February 29 and from April 16 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 59.

*List of discharge measurements made on Blue River at Manhattan, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 12 | A. P. Davis..... | 28 | 3.60 | 367 | 1.48 | 542 |
| 2 | July 11 | O. P. Hood..... | 4 | 3.70 | 304 | 1.38 | 450 |
| 3 | Aug. 17 | .....do ..... | *a* 4 | 6.90 | 1,077 | ..... | ..... |
| 4 | Aug. 24 | .....do ..... | 4 | 5.70 | 966 | 1.61 | 1,512 |
| | 1896. | | | | | | |
| 5 | Apr. 16 | O. P. Hood..... | 4 | 4.00 | 396 | 1.39 | 617 |
| 6 | Apr. 20 | .....do ..... | 4 | 10.07 | 1,837 | 2.52 | 4,769 |
| 7 | Apr. 29 | .....do ..... | 4 | 5.35 | 679 | 1.71 | 1,207 |
| 8 | May 6 | .....do ..... | 4 | 11.75 | 2,331 | 2.49 | 5,757 |
| 9 | June 11 | .....do ..... | 4 | 3.70 | 305 | 1.38 | 450 |
| 10 | June 23 | .....do ..... | 4 | 5.87 | 607 | 2.07 | 1,385 |
| 11 | June 27 | .....do ..... | 4 | 11.58 | 2,071 | 2.83 | 6,499 |
| 12 | July 6 | .... do ..... | 4 | 9.60 | 1,717 | 2.19 | 3,759 |
| 13 | July 28 | .....do ..... | 4 | 5.30 | 621 | 1.88 | 1,173 |
| 14 | Aug. 15 | .....do ..... | 4 | 10.90 | 1,755 | 2.82 | 4,943 |
| 15 | Oct. 31 | .....do ..... | 55 | 11.75 | 2,152 | 3.29 | 7,098 |

*a* Instrument failed.

*Rating table for Blue River at Manhattan, Kansas.*

[This table is applicable only from April 12, 1895, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.00 | 214 | 4.50 | 830 | 7.00 | 2,055 | 9.50 | 3,838 |
| 2.10 | 229 | 4.60 | 868 | 7.10 | 2,115 | 9.60 | 3,922 |
| 2.20 | 245 | 4.70 | 907 | 7.20 | 2,176 | 9.70 | 4,007 |
| 2.30 | 262 | 4.80 | 946 | 7.30 | 2,238 | 9.80 | 4,093 |
| 2.40 | 280 | 4.90 | 986 | 7.40 | 2,301 | 9.90 | 4,180 |
| 2.50 | 299 | 5.00 | 1,028 | 7.50 | 2,365 | 10.00 | 4,268 |
| 2.60 | 320 | 5.10 | 1,071 | 7.60 | 2,430 | 10.10 | 4,357 |
| 2.70 | 341 | 5.20 | 1,115 | 7.70 | 2,496 | 10.20 | 4,447 |
| 2.80 | 363 | 5.30 | 1,161 | 7.80 | 2,563 | 10.30 | 4,538 |
| 2.90 | 385 | 5.40 | 1,208 | 7.90 | 2,630 | 10.40 | 4,630 |
| 3.00 | 408 | 5.50 | 1,255 | 8.00 | 2,698 | 10.50 | 4,724 |
| 3.10 | 431 | 5.60 | 1,303 | 8.10 | 2,767 | 10.60 | 4,820 |
| 3.20 | 454 | 5.70 | 1,354 | 8.20 | 2,837 | 10.70 | 4,918 |
| 3.30 | 478 | 5.80 | 1,404 | 8.30 | 2,908 | 10.80 | 5,019 |
| 3.40 | 502 | 5.90 | 1,456 | 8.40 | 2,980 | 10.90 | 5,122 |
| 3.50 | 527 | 6.00 | 1,508 | 8.50 | 3,053 | 11.00 | 5,228 |
| 3.60 | 552 | 6.10 | 1,561 | 8.60 | 3,127 | 11.10 | 5,337 |
| 3.70 | 578 | 6.20 | 1,615 | 8.70 | 3,202 | 11.20 | 5,449 |
| 3.80 | 605 | 6.30 | 1,670 | 8.80 | 3,278 | 11.30 | 5,565 |
| 3.90 | 633 | 6.40 | 1,725 | 8.90 | 3,355 | 11.40 | 5,685 |
| 4.00 | 662 | 6.50 | 1,775 | 9.00 | 3,433 | 11.50 | 5,809 |
| 4.10 | 692 | 6.60 | 1,825 | 9.10 | 3,512 | 11.60 | 5,937 |
| 4.20 | 724 | 6.70 | 1,881 | 9.20 | 3,592 | 11.70 | 6,069 |
| 4.30 | 758 | 6.80 | 1,938 | 9.30 | 3,673 | 11.80 | 6,205 |
| 4.40 | 793 | 6.90 | 1,996 | 9.40 | 3,755 | 11.90 | 6,345 |

*Estimated monthly discharge of Blue River at Manhattan, Kansas.*

[Drainage area, 9,490 square miles.]

| Month. | Discharge in second-feet | | | Total in acre feet. | Run-off | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| April 14 to 30 | 605 | 502 | 548 | 18,479 | 0.04 | 0.06 |
| May | 986 | 431 | 552 | 33,941 | 0.07 | 0.06 |
| June | 7,500 | 552 | 1,604 | 95,444 | 0.19 | 0.17 |
| July | 2,301 | 527 | 756 | 46,485 | 0.10 | 0.09 |
| August | 9,900 | 478 | 2,036 | 125,190 | 0.24 | 0.21 |
| September | 8,550 | 552 | 1,207 | 71,822 | 0.15 | 0.13 |
| October | 552 | 385 | 495 | 30,436 | 0.06 | 0.05 |
| November | 605 | 385 | 531 | 31,597 | 0.07 | 0.06 |
| December | 605 | 502 | 577 | 35,478 | 0.07 | 0.06 |
| 1896. | | | | | | |
| January | 605 | 515 | 568 | 34,925 | 0.07 | 0.06 |
| February | 619 | 502 | 567 | 32,614 | 0.06 | 0.06 |
| March | | | | | | |
| April 16 to 30 | 5,283 | 1,115 | 2,196 | 65,340 | 0.13 | 0.23 |
| May | 13,725 | 1,328 | 4,800 | 295,142 | 0.59 | 0.51 |
| June | 19,425 | 677 | 4,594 | 273,362 | 0.55 | 0.49 |
| July | 21,975 | 888 | 5,494 | 337,815 | 0.67 | 0,58 |
| August | 12,375 | 1,007 | 2,659 | 163,497 | 0.31 | 0.28 |
| September | 4,724 | 868 | 1,621 | 96,456 | 0.19 | 0.17 |
| October | 7,725 | 363 | 1,179 | 72,494 | 0.13 | 0.12 |
| November | 4,724 | 527 | 1,189 | 70,751 | 0.14 | 0.13 |
| December | 1,028 | 408 | 786 | 48,329 | 0.09 | 0.08 |

## LECOMPTON STATION ON KANSAS RIVER.

This station is located in Lecompton, Kansas, at the ferry. It is in the Oskaloosa quadrangle, in latitude 39° 4′ and longitude 95° 23′. The greater part of the drainage area is mapped on the same sheets as those listed under the Lawrence station. The river here, though quite wide for ordinary stages of water, is less than 150 feet when the water is low, and affords a good place to measure the flow under these conditions. Mr. Green, who operates the ferry, put in a gage in 1894. It consists of a board marked to feet and inches and fastened to oak post set in ground and braced to shore. It is impossible to measure the discharge of river at Lawrence when the gage there reads less than 1 foot, as the mean velocity is so small. At such a time it can easily be measured at Lecompton, and the discharge is practically the

same at the two places when low, very little water entering the river between these points.

Two measurements of discharge were made here in 1895, one on October 5, the other on October 25. The water has not been low enough to make a discharge measurement advisable here this season. The ferryman, Mr. Peter Long, has served as observer from January 1

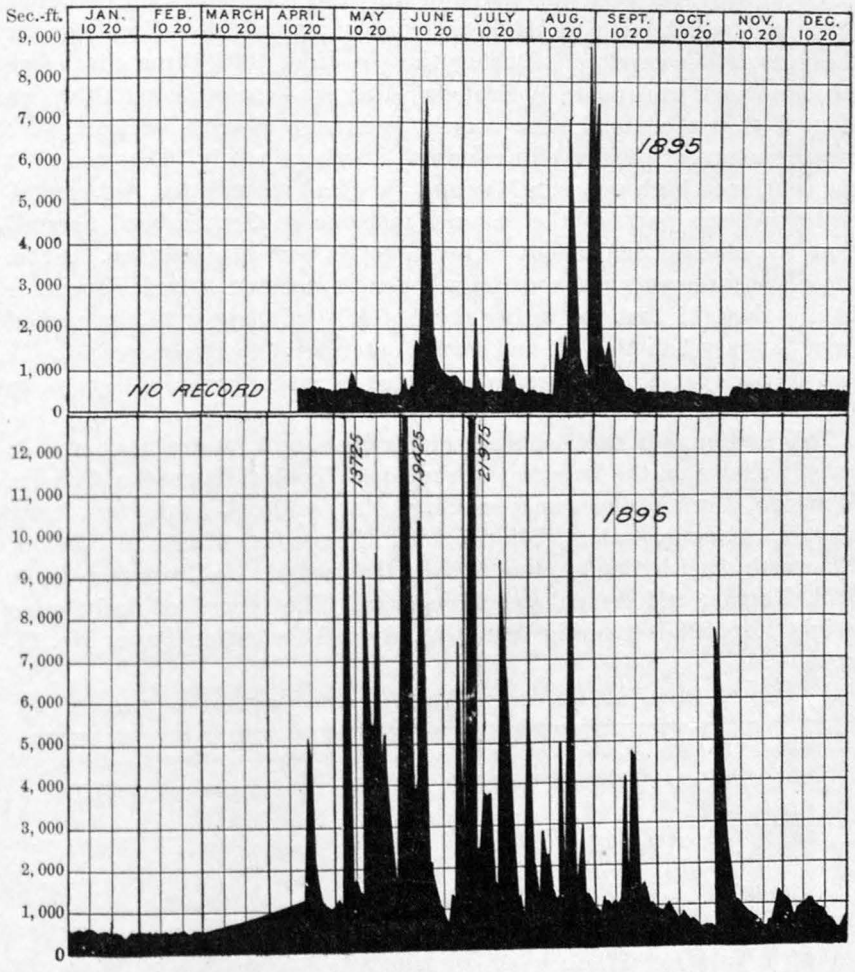



FIG. 31.—Discharge of Blue River at Manhattan, Kansas, 1895–96.

to October 31. Observations were then discontinued until spring, as the ice interferes with taking the readings. The record of daily gage heights is given in Water-Supply and Irrigation Paper No. 11, page 59.

## LAWRENCE STATION ON KANSAS RIVER.

This station is described on page 145 of Bulletin No. 140. The gage consists of a vertical board marked to feet and tenths and fastened to the south pier of the carriage bridge, about 50 feet up the river from the crest of dam. The zero of the gage is on a level with a large stone

in the crest of dam. There is also a short vertical board fastened by the side of this one for reading the level of the water when it stands below the zero of the gage. The channel is about 690 feet wide, broken by four piers. There is a flume on the south side of dam 60 feet wide and 7 feet deep. The observer is Mr. J. D. Bowersock.

Eight measurements of the discharge of the river were made by Prof. E. C. Murphy, between the dates of July 19, 1895, and September 4, 1895, from which a rating table was constructed and the discharge for the year 1895 computed. During the season of 1896 three discharge measurements were made by Professor Murphy—one on April 21, which showed that there had been very little change in cross section since measurements of the preceding season; another on July 10 showed that the continued high water in May and June had scoured the bed considerably in some parts of the channel, and one on September 1 showed that the channel had about returned to its normal condition. From these measurements and soundings taken September 28 and November 14 it is thought that the rating table of 1895 will apply to the period from January 1 to May 15, and from September 1 to December 31. A new rating table has been constructed for the period May 15 to August 31.

This station is in the Lawrence quadrangle, and its drainage area is largely shown on the Lawrence, Oskaloosa, Topeka, Hiawatha, Seneca, Wamego, Parkerville, Junction City, Marysville, Washington, Clay Center, Abilene, Salina, Minneapolis, Concordia, Mankato, Beloit, Ellsworth, Smith Center, Red Cloud, Holdredge, Phillipsburg, Ellis, Hill, Norton, and Arapahoe atlas sheets. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 60.

*List of discharge measurements made on Kansas River at Lawrence, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square (feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 19 | E. C. Murphy.... | 6 | 2.70 | 5,632 | 1.60 | 8,994 |
| 2 | July 27 | .....do ..... | 19 | 1.90 | 5,335 | 1.20 | 6,411 |
| 3 | Aug. 6 | .....do ..... | 17 | 1.10 | 4,705 | 0.64 | 3,025 |
| 4 | Aug. 22 | .....do ..... | 17 | 4.10 | 6,529 | 2.76 | 17,945 |
| 5 | Aug. 24 | .....do ..... | 17 | 2.35 | 5,443 | 1.44 | 7,869 |
| 6 | Aug. 27 | .....do ..... | 17 | 1.47 | 4,991 | 0.86 | 4,277 |
| 7 | Sept. 3 | .....do ..... | 17 | 3.24 | 6,058 | 2.14 | 12,935 |
| 8 | Sept. 4 | .....do ..... | 17 | 2.63 | 5,716 | 1.74 | 9,960 |
| 9 | Nov. 1 | .....do ..... | 17 | 0.20 | ..... | 1.35 | 376 |
| | 1896. | | | | | | |
| 10 | April 20 | E. C. Murphy.... | 10 | 3.00+ | 5,731 | 2.00 | 11,446 |
| 11 | July 10 | .....do ..... | 10 | 2.20 | 5,476 | 1.77 | 9,694 |
| 12 | Sept. 1 | .....do ..... | 10 | 1.30 | 4,696 | 0.90 | 4,240 |

*Rating table for Kansas River at Lawrence, Kansas, based on discharge measurements made during 1895.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 787 | 1.80 | 5,623 | 3.60 | 14,890 | 5.30 | 26,620 |
| 0.10 | 863 | 1.90 | 6,051 | 3.70 | 15,500 | 5.40 | 27,400 |
| 0.20 | 967 | 2.00 | 6,490 | 3.80 | 16,120 | 5.50 | 28,190 |
| 0.30 | 1,098 | 2.10 | 6,940 | 3.90 | 16,750 | 5.60 | 28,990 |
| 0.40 | 1,255 | 2.20 | 7,400 | 4.00 | 17,390 | 5.70 | 29,800 |
| 0.50 | 1,437 | 2.30 | 7,870 | 4.10 | 18,040 | 5.80 | 30,620 |
| 0.60 | 1,643 | 2.40 | 8,350 | 4.20 | 18,700 | 5.90 | 31,450 |
| 0.70 | 1,872 | 2.50 | 8,840 | 4.30 | 19,370 | 6.00 | 32,290 |
| 0.80 | 2,123 | 2.60 | 9,440 | 4.40 | 20,050 | 6.10 | 33,140 |
| 0.90 | 2,395 | 2.70 | 9,850 | 4.50 | 20,740 | 6.20 | 34,000 |
| 1.00 | 2,687 | 2.80 | 10,370 | 4.60 | 21,440 | 6.30 | 34,870 |
| 1.10 | 2,998 | 2.90 | 10,900 | 4.70 | 22,150 | 6.40 | 35,750 |
| 1.20 | 3,327 | 3.00 | 11,440 | 4.80 | 22,870 | 6.50 | 36,640 |
| 1.30 | 3,673 | 3.10 | 11,990 | 4.90 | 23,600 | 6.60 | 37,540 |
| 1.40 | 4,035 | 3.20 | 12,550 | 5.00 | 24,340 | 6.70 | 38,450 |
| 1.50 | 4,412 | 3.30 | 13,120 | 5.10 | 25,090 | 6.80 | 39,370 |
| 1.60 | 4,803 | 3.40 | 13,700 | 5.20 | 25,850 | 6.90 | 40,300 |
| 1.70 | 5,207 | 3.50 | 14,290 | | | | |

*Rating table for Kansas River at Lawrence, Kansas.*

[This table is applicable only from May 15, 1896, to August 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 787 | 1.60 | 5,786 | 3.10 | 13,637 | 4.60 | 23,443 |
| 0 10 | 868 | 1.70 | 6,276 | 3.20 | 14,203 | 4.70 | 24,213 |
| 0.20 | 987 | 1.80 | 6,775 | 3.30 | 14,778 | 4.80 | 24,998 |
| 0.30 | 1,143 | 1.90 | 7,281 | 3.40 | 15,363 | 4.90 | 25,798 |
| 0.40 | 1,335 | 2.00 | 7,792 | 3.50 | 15,959 | 5.00 | 26,613 |
| 0.50 | 1,562 | 2.10 | 8,306 | 3.60 | 16,567 | 5.10 | 27,443 |
| 0.60 | 1,821 | 2.20 | 8,822 | 3.70 | 17,188 | 5.20 | 28,298 |
| 0.70 | 2,111 | 2.30 | 9,340 | 3.80 | 17,823 | 5.30 | 29,158 |
| 0.80 | 2,430 | 2.40 | 9,861 | 3.90 | 18,473 | 5.40 | 30,033 |
| 0.90 | 2,776 | 2.50 | 10,385 | 4.00 | 19,138 | 5.50 | 30,923 |
| 1.00 | 3,147 | 2.60 | 10,913 | 4.10 | 19,818 | 5.60 | 31,828 |
| 1.10 | 3,541 | 2.70 | 11,446 | 4.20 | 20,513 | 5.70 | 32,748 |
| 1.20 | 3,956 | 2.80 | 11,984 | 4.30 | 21,223 | 5.80 | 33,683 |
| 1.30 | 4,390 | 2.90 | 12,528 | 4.40 | 21,948 | 5.90 | 34,633 |
| 1.40 | 4,841 | 3.00 | 13,079 | 4.50 | 22,688 | 6.00 | 35,598 |
| 1.50 | 5,307 | | | | | | |

*Estimated monthly discharge of Kansas River at Lawrence, Kansas.*

[Drainage area, 59,841 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| March | 1,643 | 967 | 1,364 | 83,869 | 0.026 | 0.023 |
| April | 1,872 | 967 | 1,372 | 81,639 | 0.026 | 0.023 |
| May | 1,437 | 787 | 1,074 | 66,038 | 0.021 | 0.018 |
| June | 20,050 | 967 | 5,927 | 352,681 | 0.110 | 0.099 |
| July | 10,370 | 2,395 | 5,663 | 348,207 | 0.120 | 0.095 |
| August | 28,190 | 4,035 | 11,319 | 695,982 | 0.220 | 0.190 |
| September | 20,050 | 1,255 | 4,998 | 297,401 | 0.093 | 0.084 |
| October | 1,346 | 967 | 1,090 | 67,022 | 0.021 | 0.018 |
| November | 1,346 | 863 | 1,044 | 62,122 | 0.019 | 0.017 |
| December | 1,255 | 700 | 1,012 | 62,226 | 0.020 | 0.017 |
| 1896. | | | | | | |
| January | 1,540 | 698 | 973 | 59,827 | 0.018 | 0.016 |
| February | 1,540 | 1,255 | 1,400 | 80,529 | 0.025 | 0.023 |
| March | 1,437 | 825 | 1,230 | 75,630 | 0.024 | 0.021 |
| April | 12,550 | 1,176 | 4,447 | 264,615 | 0.082 | 0.074 |
| May | 34,158 | 4,223 | 13,944 | 857,389 | 0.260 | 0.230 |
| June | 38,583 | 5,546 | 14,839 | 882,980 | 0.280 | 0.250 |
| July | 53,308 | 5,546 | 23,408 | 1,439,311 | 0.450 | 0.390 |
| August | 22,688 | 3,956 | 8,935 | 549,395 | 0.170 | 0.150 |
| September | 12,550 | 2,123 | 4,436 | 263,960 | 0.082 | 0.074 |
| October | 7,170 | 1,437 | 1,960 | 120,516 | 0.038 | 0.033 |
| November | 11,440 | 2,123 | 3,724 | 221,593 | 0.069 | 0.062 |
| December | 3,327 | 2,123 | 2,477 | 152,306 | 0.047 | 0.041 |
| Per annum | 53,308 | 825 | 6,814 | 4,968,051 | 1.545 | 0.114 |

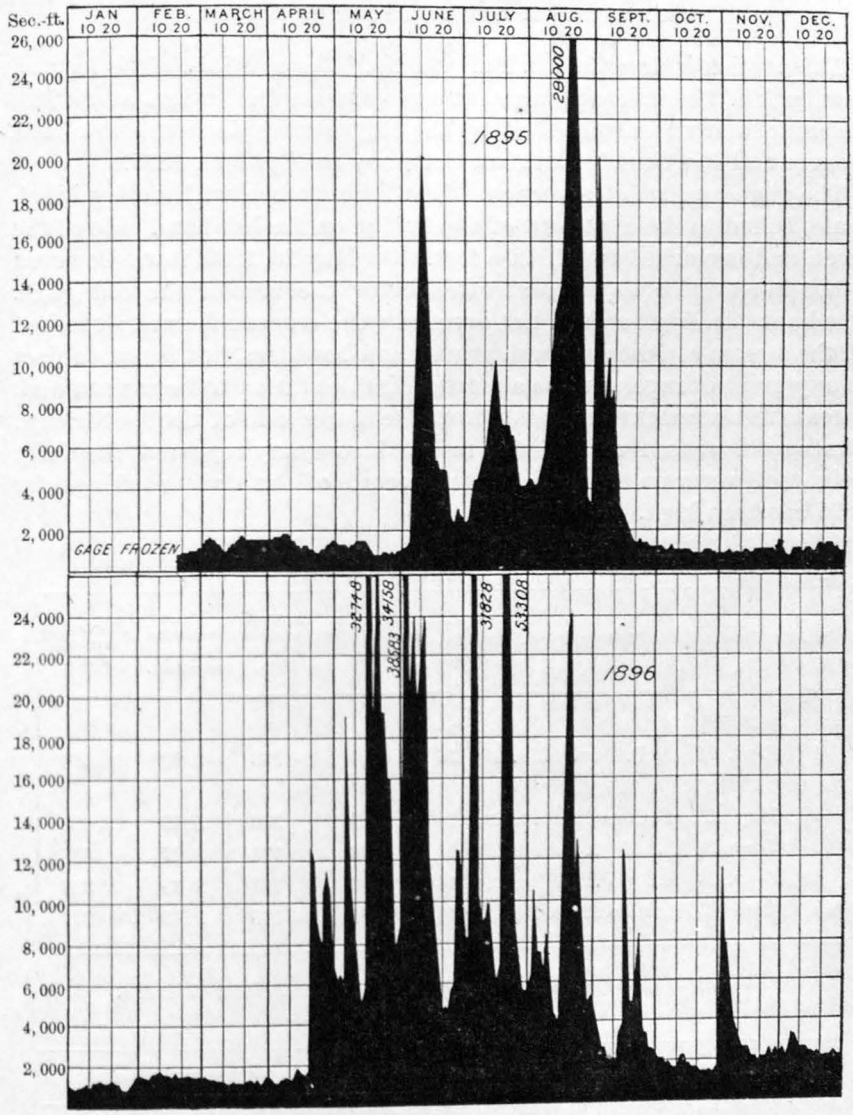



FIG. 32.—Discharge of Kansas River at Lawrence, Kansas, 1895–96.

## ARKANSAS BASIN.

The Arkansas River rises in the Rocky Mountain region of central Colorado near the city of Leadville. Several stations have been maintained on the main stream and a few on tributaries, as shown in the following pages.

### ARKANSAS RIVER.

A table of drainage areas of this stream is given in Bulletin 140, page 154. Five stations have been maintained on this river during a part or the whole of 1896.

## SALIDA STATION ON ARKANSAS RIVER.

This station is described in Bulletin No. 140, page 155. It is located just back of the railroad yards, at a suspension footbridge, at Salida, Colorado, and was established by the engineering department of the Denver and Rio Grande Railroad Company on April 11, 1895.

The gage consists of a vertical 4 by 6 inch timber, with a 2 by 6 inch scale, bolted to the abutment of the bridge on the left-hand side of the river, and is marked to 0.10 of a foot. On May 26, 1896, it was lowered 1 foot in elevation, as low water fell below the zero of the old gage. The banks are high and do not overflow; the current is swift; the bed of the stream consists of sand, gravel, and bowlders, but is not subject to any great changes, and is a most desirable station to be maintained. Stream measurements are made from the lower side of the footbridge. During the season of 1895 the railroad company reported the daily height of water on the gage, but no record of the daily readings for 1896 has been kept.

*List of discharge measurements made on Arkansas River at Salida, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 27 | A. P. Davis..... | 55 | 0.60 | 162 | 2.90 | 463 |
| | 1896. | | | | | | |
| 2 | May 26 | F. Cogswell ..... | 14 | 3.10 | 362 | 5.59 | 2,023 |
| 3 | June 24 | .....do ..... | 14 | 1.40 | 194 | 3.29 | 638 |
| 4 | Sept. 29 | .....do ..... | 14 | 1.00 | 151 | 2.33 | 352 |
| 5 | Oct. 27 | .....do ..... | 14 | 0.80 | 136 | 2.33 | 317 |

*Estimated monthly discharge of Arkansas River at Salida, Colorado.*

[Drainage area, 1,160 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| April 11 to 30..... | 1,846 | 495 | 1,117 | 44,320 | 0.71 | 0.96 |
| May ..... | 2,462 | 968 | 1,545 | 94,998 | 1.53 | 1.33 |
| June ..... | 2,242 | 1,244 | 1,599 | 95,147 | 1.54 | 1.38 |
| July ..... | 1,626 | 819 | 1,159 | 71,264 | 1.15 | 1.00 |
| August..... | 1,285 | 708 | 860 | 52,879 | 0.85 | 0.74 |
| September ..... | 819 | 429 | 537 | 31,954 | 0.53 | 0.46 |
| October ..... | 402 | 402 | 402 | 24,718 | 0.39 | 0.35 |

*Rating table for Arkansas River at Salida, Colorado, for 1895 and 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 190 | 1.05 | 383 | 2.10 | 1,162 | 3.15 | 2,066 |
| 0.05 | 195 | 1.10 | 402 | 2.15 | 1,203 | 3.20 | 2,110 |
| 0.10 | 200 | 1.15 | 429 | 2.20 | 1,244 | 3.25 | 2,154 |
| 0.15 | 205 | 1.20 | 456 | 2.25 | 1,285 | 3.30 | 2,198 |
| 0.20 | 210 | 1.25 | 495 | 2.30 | 1,326 | 3.35 | 2,242 |
| 0.25 | 216 | 1.30 | 534 | 2.35 | 1,368 | 3.40 | 2,286 |
| 0.30 | 222 | 1.35 | 578 | 2.40 | 1,410 | 3.45 | 2,330 |
| 0.35 | 229 | 1.40 | 622 | 2.45 | 1,453 | 3.50 | 2,374 |
| 0.40 | 236 | 1.45 | 665 | 2.50 | 1,496 | 3.55 | 2,418 |
| 0.45 | 243 | 1.50 | 708 | 2.55 | 1,539 | 3.60 | 2,462 |
| 0.50 | 250 | 1.55 | 745 | 2.60 | 1,582 | 3.65 | 2,506 |
| 0.55 | 259 | 1.60 | 782 | 2.65 | 1,626 | 3.70 | 2,550 |
| 0.60 | 268 | 1.65 | 819 | 2.70 | 1,670 | 3.75 | 2,594 |
| 0.65 | 277 | 1.70 | 856 | 2.75 | 1,714 | 3.80 | 2,638 |
| 0.70 | 286 | 1.75 | 893 | 2.80 | 1,758 | 3.85 | 2,682 |
| 0.75 | 296 | 1.80 | 930 | 2.85 | 1,802 | 3.90 | 2,726 |
| 0.80 | 307 | 1.85 | 968 | 2.90 | 1,846 | 3.95 | 2,770 |
| 0.85 | 319 | 1.90 | 1,006 | 2.95 | 1,890 | 4.00 | 2,814 |
| 0.90 | 332 | 1.95 | 1,044 | 3.00 | 1,934 | | |
| 0.95 | 348 | 2.00 | 1,082 | 3.05 | 1,978 | | |
| 1.00 | 364 | 2.05 | 1,122 | 3.10 | 2,022 | | |

CANYON STATION ON ARKANSAS RIVER.

This station was described in Bulletin No. 131, page 35, and in Bulletin No. 140, page 156. It is located at the Hot Springs Hotel, 1½ miles west of Canyon, Colorado, in the Canyon quadrangle, about 500 yards below the mouth of Grape Creek, in latitude 38° 26′, longitude 105° 15′, and was established in April, 1889. During the flood of August 30, 1896, the original gage rods were washed out and a new one has since been placed on left bank of river just below the foot-bridge, consisting of an inclined 4-inch by 4-inch by 16 foot timber bolted to a small juniper tree and to posts set in the ground. It is marked to vertical 0.10 foot, the space between the marks being 0.223 foot. A vertical rod is also fastened to the juniper tree for extreme high water. Both banks are high and not liable to overflow. The current is swift, and the cross section is not subject to any notable changes, except at extreme high and low water stages. Stream measurements are made from the lower side of the suspension footbridge leading to the hotel. The observer is Dr. J. L. Prentiss. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 60.

*List of discharge measurements made on Arkansas River at Canyon, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 23 | Sept. 22 | F. H. Newell | 24 | 2.45 | 129 | 2.26 | 291 |
| | 1894. | | | | | | |
| 24 | May 15 | F. H. Newell | 24 | 4.20 | 329 | 7.28 | 2,395 |
| 25 | May 18 | do | 24 | 3.80 | 290 | 6.71 | 1,940 |
| 26 | June 18 | do | 24 | 4.80 | 385 | 6.19 | 2,387 |
| 27 | Sept. 20 | A. P. Davis | 21 | 2.65 | 140 | 2.86 | 395 |
| 28 | Oct. 15 | do | 21 | 2.40 | 125 | 2.56 | 319 |
| | 1895. | | | | | | |
| 29 | May 31 | A. P. Davis | 55 | 4.35 | 343 | 7.10 | 2,434 |
| 30 | June 13 | do | 55 | 4.50 | 356 | 6.73 | 2,397 |
| 31 | Oct. 4 | do | 61 | 2.70 | 157 | 3.70 | 585 |
| | 1896. | | | | | | |
| 32 | July 31 | F. Cogswell | 14 | 2.40 | 129 | 3.21 | 414 |
| 33 | Aug. 30 | do | 14 | 2.00 | 82 | 2.47 | 203 |
| 34 | Sept. 16 | do | 14 | 2.05 | 98 | 2.56 | 251 |
| 35 | Oct. 31 | do | 14 | 2.20 | 101 | 2.80 | 289 |
| 36 | Nov. 14 | C. C. Babb | 63 | 2.55 | 97 | 3.03 | 294 |

*Rating table for Arkansas River at Canyon, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.80 | 144 | 2.55 | 489 | 3.30 | 1,024 | 4.05 | 1,844 |
| 1.85 | 159 | 2.60 | 520 | 3.35 | 1,069 | 4.10 | 1,914 |
| 1.90 | 174 | 2.65 | 552 | 3.40 | 1,114 | 4.15 | 1,988 |
| 1.95 | 192 | 2.70 | 584 | 3.45 | 1,161 | 4.20 | 2,062 |
| 2.00 | 214 | 2.75 | 617 | 3.50 | 1,208 | 4.25 | 2,143 |
| 2.05 | 235 | 2.80 | 650 | 3.55 | 1,258 | 4.30 | 2,224 |
| 2.10 | 256 | 2.85 | 685 | 3.60 | 1,308 | 4.35 | 2,314 |
| 2.15 | 277 | 2.90 | 720 | 3.65 | 1,361 | 4.40 | 2,404 |
| 2.20 | 298 | 2.95 | 755 | 3.70 | 1,414 | 4.45 | 2,496 |
| 2.25 | 321 | 3.00 | 790 | 3.75 | 1,470 | 4.50 | 2,588 |
| 2.30 | 344 | 3.05 | 827 | 3.80 | 1,526 | 4.55 | 2,683 |
| 2.35 | 371 | 3.10 | 864 | 3.85 | 1,586 | 4.60 | 2,778 |
| 2.40 | 398 | 3.15 | 903 | 3.90 | 1,646 | 4.65 | 2,876 |
| 2.45 | 428 | 3.20 | 942 | 3.95 | 1,710 | 4.70 | 2,974 |
| 2.50 | 458 | 3.25 | 983 | 4.00 | 1,774 | | |

*Estimated monthly discharge of Arkansas River at Canyon, Colorado.*

[Drainage area, 3,060 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 398 | 298 | 344 | 21,149 | 0.13 | 0.11 |
| February | 458 | 298 | 361 | 20,049 | 0.13 | 0.12 |
| March | 584 | 398 | 471 | 28,960 | 0.17 | 0.15 |
| April | 1,774 | 458 | 868 | 51,650 | 0.31 | 0.28 |
| May | 2,404 | 790 | 1,506 | 92,600 | 0.56 | 0.49 |
| June | 2,588 | 1,308 | 1,900 | 113,058 | 0.69 | 0.62 |
| July | 2,224 | 1,024 | 1,413 | 86,882 | 0.53 | 0.46 |
| August | 2,143 | 790 | 1,095 | 67,328 | 0.41 | 0.36 |
| September | 942 | 458 | 635 | 37,786 | 0.23 | 0.21 |
| October | 827 | 398 | 505 | 31,051 | 0.20 | 0.17 |
| November | 520 | 398 | 499 | 29,693 | 0.18 | 0.16 |
| December | 520 | 256 | 444 | 27,301 | 0.17 | 0.15 |
| Per annum | 2,588 | 256 | 837 | 607,507 | 3.71 | 0.27 |
| 1896. | | | | | | |
| January | 489 | 428 | 454 | 27,915 | 0.17 | 0.15 |
| February | 520 | 371 | 438 | 25,194 | 0.15 | 0.14 |
| March | 942 | 344 | 472 | 29,022 | 0.17 | 0.15 |
| April | 864 | 398 | 558 | 32,965 | 0.20 | 0.18 |
| May | 2,775 | 650 | 1,276 | 78,458 | 0.48 | 0.42 |
| June | 2,496 | 398 | 959 | 57,065 | 0.35 | 0.31 |
| July | 1,988 | 235 | 538 | 33,080 | 0.21 | 0.18 |
| August | 2,876 | 144 | 395 | 24,287 | 0.15 | 0.13 |
| September | 520 | 192 | 313 | 18,625 | 0.11 | 0.10 |
| October | 344 | 235 | 285 | 17,524 | 0.10 | 0.09 |
| November | 344 | 124 | 267 | 15,888 | 0.10 | 0.09 |
| December | 1,258 | 218 | 579 | 35,601 | 0.22 | 0.19 |
| Per annum | 2,876 | 124 | 544 | 395,624 | 2.41 | 0.18 |

## PUEBLO STATION ON ARKANSAS RIVER.

This station is described in Bulletin 140, page 158. It is at the city of Pueblo, in the Pueblo quadrangle, 2 miles above the mouth of Fountain Creek, in latitude 38° 16′ and longitude 104° 36′. It was established in September, 1894. The drainage area is 4,600 square miles, and is partly mapped on the Spanish Peaks, Walsenburg, Pueblo, Colorado Springs, Castle Rock, Pikes Peak, Canyon, Huerfano Park, and Leadville atlas sheets. There are two gage rods. The main one,

at Santa Fé avenue bridge, consists of a vertical 6 by 6 inch timber and a 1 by 6 inch scale, bolted to the abutment of the Denver and Rio Grande Railroad bridge on left-hand side of river, marked to tenths of a foot. There is also a short vertical rod, for extreme low water, spiked to a pile about 20 feet out in the stream, reading same as the main gage. The 12-foot mark of this gage is opposite the top of the large capstone. The rod at Victoria avenue bridge consists of inclined 4 by 4 inch timbers fastened to posts set in right bank of stream, marked to vertical tenths of a foot, the space between the marks being 0.242 of a foot. This rod was placed in June, 1895, for the purpose of noting the change in the slope of the water surface.

Stream measurements are made from lower side of the Main street bridge. The river is confined by the city levees, and the bed is sandy and constantly changing, filling in at low water and scouring out during high water. Considerable trouble has been experienced in getting the velocity at the bottom of the river, owing to the clogging of the meter by the moving sand. The observer is R. L. Holden. The daily gage heights for 1896 are given in Water-Supply and Irrigation Paper No. 11, page 61.

*List of discharge measurements made on Arkansas River at Pueblo, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Apr. 24 | P. J. Preston..... | ..... | ..... | 165 | 1.95 | 322 |
| 2 | Sept. 19 | A. P. Davis ..... | 21 | 0.35 | 151 | 2.50 | 378 |
| 3 | Oct. 13 | .....do ..... | 22 | 0.39 | 157 | 2.36 | 370 |
| | 1895. | | | | | | |
| 4 | Feb. 6 | A. P. Davis ..... | 24 | 0.40 | 150 | 2.75 | 411 |
| 5 | May 20 | .....do ..... | 28 | 1.65 | 300 | 4.78 | 1,435 |
| 6 | June 11 | .....do ..... | 55 | 2.80 | 401 | 6.89 | 2,758 |
| 7 | Sept. 5 | F. Cogswell ..... | 14 | 0.70 | 170 | 3.35 | 570 |
| | 1896. | | | | | | |
| 8 | Mar. 22 | F. Cogswell ..... | 14 | 0.50 | 173 | 2.70 | 470 |
| 9 | Apr. 28 | .....do ..... | 14 | 1.30 | 249 | 4.09 | 1,016 |
| 10 | May 27 | .....do ..... | 14 | 2.00 | 340 | 4.65 | 1,682 |
| 11 | June 5 | .....do ..... | 14 | 1.65 | 298 | 4.71 | 1,403 |
| 12 | July 10 | .....do ..... | 14 | 0.30 | 135 | 2.48 | 335 |
| 13 | July 30 | .....do ..... | 14 | 0.50 | 187 | 2.73 | 510 |
| 14 | Aug. 18 | .....do ..... | 14 | 0.00 | 118 | 1.72 | 203 |
| 15 | Aug. 19 | .....do ..... | 14 | 0.85 | 195 | 2.74 | 534 |
| 16 | Aug. 19 | .....do ..... | Floats. | 10.00 | 1,500 | 11.00 | 16,500 |
| 17 | Sept. 16 | .....do ..... | 14 | 0.30 | 121 | 2.43 | 294 |
| 18 | Oct. 30 | .....do ..... | 14 | 0.35 | 128 | 2.50 | 320 |
| 19 | Nov. 13 | C. C. Babb..... | 63 | 0.31 | 121 | 2.46 | 298 |

*Rating table for Arkansas River at Pueblo, Colorado.*

[This table is applicable only from September 19, 1894, to August 18, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 203 | 0.95 | 776 | 1.90 | 1,618 | 2.85 | 2,835 |
| 0.05 | 227 | 1.00 | 812 | 1.95 | 1,675 | 2.90 | 2,904 |
| 0.10 | 251 | 1.05 | 850 | 2.00 | 1,732 | 2.95 | 2,974 |
| 0.15 | 276 | 1.10 | 888 | 2.05 | 1,790 | 3.00 | 3,044 |
| 0.20 | 301 | 1.15 | 926 | 2.10 | 1,848 | 3.05 | 3,112 |
| 0.25 | 327 | 1.20 | 964 | 2.15 | 1,910 | 3.10 | 3,180 |
| 0.30 | 354 | 1.25 | 1,004 | 2.20 | 1,972 | 3.15 | 3,245 |
| 0.35 | 383 | 1.30 | 1,044 | 2.25 | 2,034 | 3.20 | 3,310 |
| 0.40 | 412 | 1.35 | 1,085 | 2.30 | 2,096 | 3.25 | 3,374 |
| 0.45 | 442 | 1.40 | 1.126 | 2.35 | 2,159 | 3.30 | 3,438 |
| 0.50 | 472 | 1.45 | 1,172 | 2.40 | 2,222 | 3.35 | 3,501 |
| 0.55 | 504 | 1.50 | 1,218 | 2.45 | 2,287 | 3.40 | 3,564 |
| 0.60 | 536 | 1.55 | 1,264 | 2.50 | 2,352 | 3.45 | 3,624 |
| 0.65 | 568 | 1.60 | 1,310 | 2.55 | 2,421 | 3.50 | 3,684 |
| 0.70 | 601 | 1.65 | 1,357 | 2.60 | 2,490 | 3.55 | 3,737 |
| 0.75 | 635 | 1.70 | 1,404 | 2.65 | 2,559 | 3.60 | 3,790 |
| 0.80 | 670 | 1.75 | 1,455 | 2 70 | 2,628 | 3.65 | 3,842 |
| 0.85 | 705 | 1.80 | 1,506 | 2.75 | 2,697 | 3.70 | 3,894 |
| 0.90 | 740 | 1.85 | 1,562 | 2.80 | 2,766 | | |

*Rating table for Arkansas River at Pueblo, Colorado.*

[This table is applicable only from August 19, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 203 | 0.65 | 441 | 1.25 | 733 | 1.85 | 1,039 |
| 0.05 | 219 | 0.70 | 463 | 1.30 | 758 | 1.90 | 1,064 |
| 0.10 | 235 | 0.75 | 486 | 1.35 | 784 | 1.95 | 1,089 |
| 0.15 | 251 | 0.80 | 510 | 1.40 | 810 | 2.00 | 1,114 |
| 0.20 | 268 | 0.85 | 534 | 1.45 | 836 | 2.05 | 1,139 |
| 0.25 | 285 | 0.90 | 558 | 1.50 | 862 | 2.10 | 1,164 |
| 0.30 | 303 | 0.95 | 583 | 1.55 | 888 | 2.15 | 1,189 |
| 0.35 | 321 | 1.00 | 608 | 1.60 | 914 | 2.20 | 1,214 |
| 0.40 | 340 | 1.05 | 633 | 1.65 | 939 | 2.25 | 1,239 |
| 0.45 | 359 | 1.10 | 658 | 1.70 | 964 | 2.30 | 1,264 |
| 0.50 | 378 | 1.15 | 683 | 1.75 | 989 | 2.35 | 1,289 |
| 0.55 | 399 | 1.20 | 708 | 1.80 | 1,014 | 2.40 | 1,314 |
| 0.60 | 420 | | | | | | |

*Estimated monthly discharge of Arkansas River at Pueblo, Colorado.*

[Drainage area, 4,600 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1894. | | | | | | |
| September 19 to 30 | 412 | 301 | 356 | 8,472 | 0.03 | 0.08 |
| October | 472 | 354 | 420 | 25,825 | 0.10 | 0.09 |
| November | 442 | 412 | 413 | 24,576 | 0.10 | 0.09 |
| December | 412 | 301 | 374 | 22,996 | 0.09 | 0.08 |
| 1895. | | | | | | |
| January | 740 | 327 | 460 | 28,284 | 0.12 | 0.10 |
| February | 670 | 327 | 476 | 26,435 | 0.11 | 0.10 |
| March | 412 | 301 | 357 | 21,951 | 0.09 | 0.08 |
| April | 1,790 | 301 | 744 | 44,271 | 0.18 | 0.16 |
| May | 2,490 | 601 | 1,561 | 95,982 | 0.39 | 0.34 |
| June | 3,564 | 1,455 | 2,152 | 128,053 | 0.53 | 0.47 |
| July | 5,000 | 1,044 | 1,900 | 116,826 | 0.47 | 0.41 |
| August | 3,112 | 568 | 1,275 | 78,397 | 0.32 | 0.28 |
| September | 888 | 383 | 494 | 29,395 | 0.12 | 0.11 |
| October | 705 | 412 | 551 | 33,881 | 0.14 | 0.12 |
| November | 601 | 472 | 530 | 31,537 | 0.13 | 0.12 |
| December | 568 | 327 | 462 | 28,407 | 0.12 | 0.10 |
| Per annum | 5,000 | 301 | 914 | 663,419 | 2.72 | 0.20 |
| 1896. | | | | | | |
| January | 601 | 383 | 519 | 31,912 | 0.13 | 0.11 |
| February | 536 | 354 | 456 | 26,229 | 0.11 | 0.10 |
| March | 472 | 301 | 396 | 24,349 | 0.10 | 0.09 |
| April | 1,172 | 276 | 470 | 27,967 | 0.11 | 0.10 |
| May | 2,352 | 472 | 1,101 | 67,698 | 0.28 | 0.24 |
| June | 2,096 | 412 | 895 | 53,257 | 0.21 | 0.19 |
| July | 2,835 | 301 | 633 | 38,921 | 0.16 | 0.14 |
| August | 3,438 | 203 | 489 | 30,067 | 0.13 | 0.11 |
| September | 441 | 219 | 309 | 18,387 | 0.08 | 0.07 |
| October | 340 | 268 | 293 | 18,015 | 0.07 | 0.04 |
| November | 486 | 235 | 314 | 18,684 | 0.08 | 0.07 |
| December | 420 | 268 | 333 | 20,474 | 0.08 | 0.07 |
| Per annum | 3,438 | 203 | 517 | 375,960 | 1.54 | 0.11 |

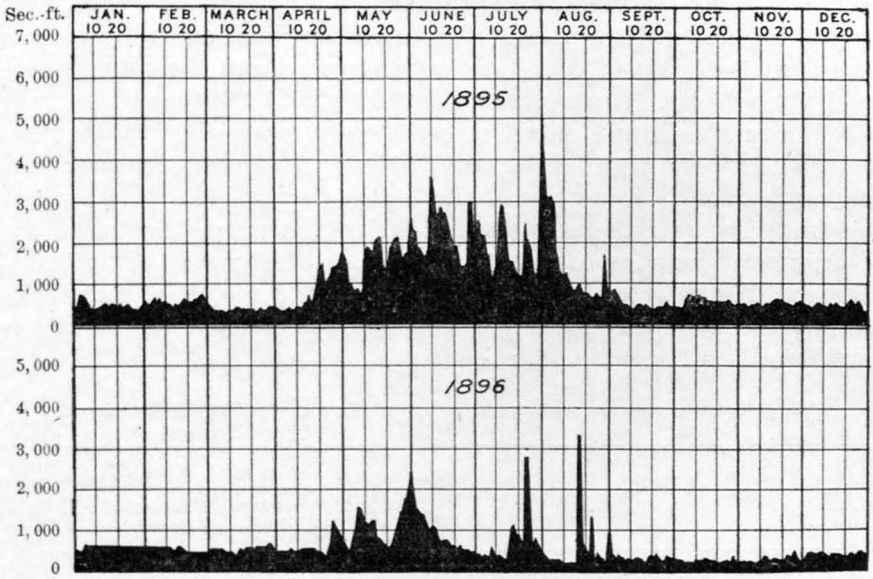



FIG. 33.—Discharge of Arkansas River at Pueblo, Colorado, 1895–96.

## LITTLE FOUNTAIN CREEK, EL PASO COUNTY, COLORADO.

Mr. M. E. Sullivan has made some examination of this creek in connection with the proposed water supply for the city of Pueblo. On June 12, 1895, the discharge at the mouth of the canyon was found to be 64 cubic feet per second, not including the underflow. On January 4, 1897, the discharge was 7.5 cubic feet per second. Drift brush and other watermarks indicate that the flood volume sometimes amounts to over 1,000 cubic feet per second. These floods occur usually in March, according to the testimony of residents of that vicinity, and continue three or four days together.

In January, 1897, a series of pits were dug to bed rock at the point where the north and south outcropping ledge crosses the mouth of the canyon. It is proposed to build a masonry dam 120 feet high at this point, forming a storage reservoir of about 5,000 acre-feet capacity to supply the city of Pueblo. In sinking these pits it was found that bed rock was covered to the depth of from 12 to 24 feet with very large bowlders and gravel, and that the underflow along bed rock between these bowlders was large. The upper or western end of the watershed of Little Fountain Creek is full of springs.

## TRINIDAD STATION ON PURGATOIRE RIVER.

This station is located at the Las Animas street bridge in the city of Trinidad, Colorado, at the extreme western boundary of the El Moro quadrangle, and was established on May 1, 1896. It is in latitude 37° 05′ and longitude 104° 30′. The gage consists of a vertical 2 by 6 inch plank, graduated to vertical tenths of a foot, and is fastened

with iron bands to the downstream side of a cylindrical bridge pier, on the right side of the river. The banks are high and not liable to overflow; the bed is of gravel and small stones, and the water moves with fair velocity. During the flood of July 25, 1896, the channel was filled in with sand and gravel near the gage, materially changing the relation between gage height and discharge. Stream measurements are made from the lower side of the bridge during high water, and at low water by wading some 400 feet below the gage. Sufficient discharge measurements have not been made to estimate the daily discharge. The observer is Mr. J. N. Turner. The record of daily gage heights for 1896 from May 1 to November 30 is given in Water-Supply and Irrigation Paper No. 11, page 61.

*List of discharge measurements made on Purgatoire River at Trinidad, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 24 | A. P. Davis..... | 55 | ..... | 54 | 1.60 | 86 |
| | 1896. | | | | | | |
| 2 | Apr. 27 | F. Cogswell..... | 14 | 3.20 | 40 | 2.18 | 88 |
| 3 | June 4 | .....do ..... | 14 | 3.15 | 38 | 1.90 | 72 |
| 4 | July 11 | .....do ..... | 14 | 3.20 | 38 | 1.74 | 66 |
| 5 | Sept. 14 | .....do ..... | 14 | 3.50 | 24 | 1.25 | 30 |
| 6 | Oct. 12 | .....do ..... | 14 | 3.70 | 39 | 1.23 | 48 |
| 7 | Nov. 16 | C. C. Babb..... | 63 | 3.60 | 22 | 1.09 | 24 |

## HUTCHINSON STATION ON ARKANSAS RIVER.

This station was established May 13, 1895, by Mr. Arthur P. Davis. It is at the wagon bridge at the south end of Main street, Hutchinson, Kansas, in the Hutchinson quadrangle, in latitude 38° 02.5′, longitude 97° 56′. The drainage area is about 34,000 square miles, and is partly mapped on Lyons, Great Bend, Pratt, Kinsley, Larned, Ness City, Spearville, Dodge, Garden, Albany, Granada, Lamar, Kit Carson, Two Buttes, Mount Carrizo, Higbee, Las Animas, Arroyo, Limon, Sanborn, Catlin, Timpas, Mesa de Maya, El Mora, Apishapa, Nepesta, Big Springs, Colorado Springs, Pueblo, Walsenburg, Trinidad, Huerfano Park, and Canyon City atlas sheets. The observer is Daniel Lauer, who lives about 100 yards from the station. The main gage consists of an oak timber painted white, graduated in feet and tenths and spiked to an oak pile a few feet above the bridge, driven as a protection to the bridge pier from ice and drift. The figures and marks below 3 feet on this gage having become obscure, a new gage of plank 3 feet long was painted and graduated like the other and driven in front

and spiked to this with the graduations coinciding. There are two bench marks; one is the upper cross piece of the pier guard, having an elevation of 8.35 feet above zero; the second is the top of the iron doorsill, next to the river, of the first brick building. Its elevation is 8.12 feet above zero of the gage. Measurements are made from the bridge, and at low water may be made by wading. The channel is generally straight, both above and below for some distance, and is sandy and very shifting. At very low stage the water is in several channels and crooked. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 62.

*List of discharge measurements made on Arkansas River at Hutchinson, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 13 | A. P. Davis..... | 19 | 1.30 | ..... | 0.90 | 10 |
| 2 | June 20 | W. G. Russell..... | 19 | 3.40 | 749 | 1.98 | 1,471 |
| 3 | July 27 | .....do ..... | 19 | 5.65 | 3,127 | 3.93 | 12,300 |
| 4 | Aug. 31 | .....do ..... | 19 | 2.73 | 557 | 1.86 | 1,037 |
| 5 | Oct. 1 | .....do ..... | 19 | 1.60 | 71 | 0.80 | 57 |
| 6 | Nov. 13 | .....do ..... | 19 | 1.50 | 63 | 0.73 | 46 |
| 7 | Dec. 20 | .....do ..... | 19 | 2.15 | 94 | 1.33 | 125 |
| 8 | Dec. 31 | .....do ..... | 19 | 1.75 | 76 | 0.64 | 49 |
| | 1896. | | | | | | |
| 9 | Jan. 17 | W. G. Russell..... | *a* 3 | 2.35 | 299 | 1.65 | 494 |
| 10 | Jan. 29 | .....do ..... | 3 | 2.80 | 440 | 1.79 | 791 |
| 11 | Feb. 13 | .....do ..... | 3 | 2.15 | 178 | 1.74 | 308 |
| 12 | Apr. 15 | .....do ..... | 3 | 1.67 | 70 | 1.10 | 78 |
| 13 | June 30 | .....do ..... | 3 | 1.60 | 82 | 1.13 | 93 |
| 14 | July 14 | .....do ..... | 3 | 1.40 | 29 | 0.98 | 28 |
| 15 | July 31 | .....do ..... | 3 | 1.80 | 98 | 1.39 | 137 |
| 16 | Aug. 21 | .....do ..... | *b* 55 | 1.40 | 43 | 1.21 | 52 |
| 17 | Sept. 24 | .....do ..... | 55 | 1.30 | 30 | 0.85 | 25 |
| 18 | Oct. 22 | .....do ..... | 55 | 1.55 | 59 | 1.56 | 93 |
| 19 | Nov. 4 | .....do ..... | 55 | 1.60 | 62 | 1.60 | 99 |
| 20 | Dec. 9 | .....do ..... | 3 | 1.60 | 52 | 1.00 | 52 |

*a* Price acoustic meter. *b* Price large meter.

*Rating table for Arkansas River at Hutchinson, Kansas.*

[This table is applicable only from January 1, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet.* |
| 1.30 | 25 | 1.80 | 143 | 2.30 | 440 | 2.80 | 791 |
| 1.40 | 28 | 1.90 | 178 | 2.40 | 520 | 2.90 | 878 |
| 1.50 | 51 | 2.00 | 222 | 2.50 | 578 | 3.00 | 977 |
| 1.60 | 93 | 2.10 | 276 | 2.60 | 641 | 3.10 | 1,082 |
| 1.70 | 115 | 2.20 | 346 | 2.70 | 712 | 3.20 | 1,200 |

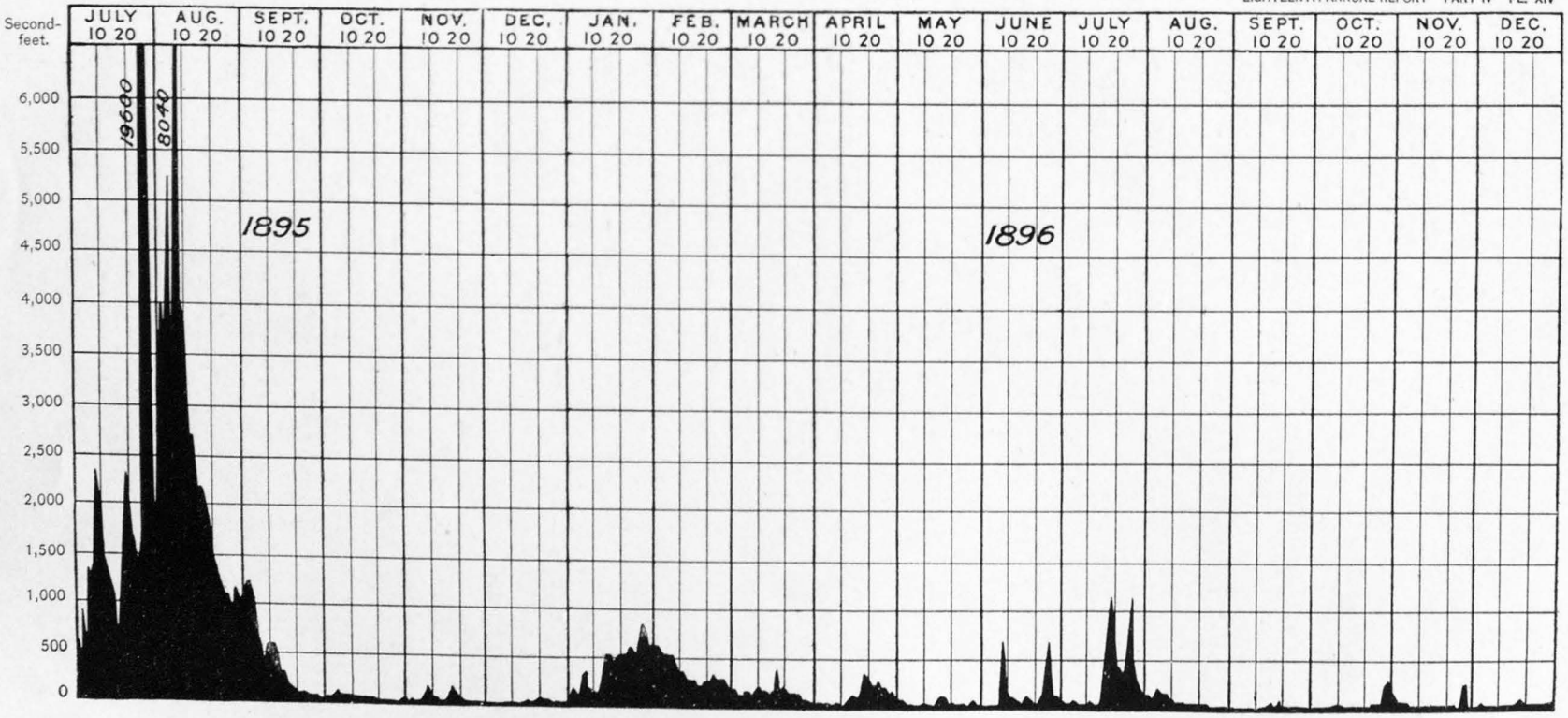
*Estimated monthly discharge of Arkansas River at Hutchinson, Kansas.*

[Drainage area, 34,000 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| May 13 to 31 | 42 | 22 | 27 | 1,026 | 0.001 | 0.001 |
| June | 1,618 | 33 | 900 | 53,554 | 0.03 | 0.03 |
| July | 19,600 | 444 | 3,848 | 236,606 | 0.13 | 0.11 |
| August | 8,040 | 958 | 2,712 | 166,755 | 0.09 | 0.08 |
| September | 1,203 | 57 | 375 | 22,314 | 0.012 | 0.001 |
| October | 84 | 37 | 56 | 3,443 | 0.002 | 0.002 |
| November | 57 | 29 | 43 | 2,559 | 0.001 | 0.001 |
| December | 159 | 37 | 71 | 4,366 | 0.002 | 0.002 |
| 1896. | | | | | | |
| January | 878 | 143 | 426 | 26,194 | 0.014 | 0.012 |
| February | 578 | 178 | 347 | 19,960 | 0.011 | 0.010 |
| March | 391 | 51 | 153 | 9,407 | 0.005 | 0.004 |
| April | 346 | 38 | 129 | 7,677 | 0.004 | 0.003 |
| May | 115 | 25 | 54 | 3,320 | 0.002 | 0.002 |
| June | 676 | 25 | 164 | 9,759 | 0.005 | 0.005 |
| July | 1,138 | 28 | 251 | 15,433 | 0.009 | 0.008 |
| August | 178 | 25 | 69 | 4,243 | 0.002 | 0.002 |
| September | 81 | 16 | 27 | 1,607 | 0.001 | 0.001 |
| October | 249 | 25 | 52 | 3,197 | 0.002 | 0.002 |
| November | 222 | 39 | 79 | 4,701 | 0.003 | 0.002 |
| December | 110 | 39 | 52 | 3,197 | 0.002 | 0.002 |
| Per annum | 1,138 | 16 | 150 | 108,695 | 0.060 | 0.004 |

## VERDIGRIS AND NEOSHO RIVERS.

These streams drain a portion of southern Kansas, and unite with the Arkansas River near each other, a few miles above Fort Gibson.




DISCHARGE OF ARKANSAS RIVER AT HUTCHINSON, KANSAS, 1895-96.

## LIBERTY STATION ON VERDIGRIS RIVER.

This station is described on page 162 of Bulletin No. 140, and is at a wagon bridge about 250 feet below McTaggart's milldam, about 3 miles southwest of the town of Liberty, Kansas, in the Independence quadrangle, in latitude 37° 07′ and longitude 95° 36′. The drainage area is 3,067 square miles. It is mapped on Independence, Fredonia, Emporia, Eureka, Sedan, El Dorado, Cottonwood Falls, Parkerville, Newton, and Abilene atlas sheets. The gage is in two parts; a vertical board marked to feet and tenths, fastened to flume which serves to give ordinary heights, and horizontal marks one-half foot apart on the corner of wheelhouse. The zero of gage is 12.46 feet below the heads of three large nails in flume. The channel is here about 150 to 300 feet wide, depending on height of water, and is broken by two piers. The bed is rock and gravel and subject to very little change. The river rises here sometimes to a height of 35 feet and floods the country on both sides of it.

Three measurements of the discharge were made by Prof. E. C. Murphy between the dates of August 2, 1895, and November 15, 1895, and six more between the dates of April 15 and September 26, 1896. These measurements, together with three made in 1897, form the basis of a rating curve. They show very little change of bed and a slow change in mean velocity with depth of water. Mr. J. G. Kaull, who served as observer in 1895, has left this vicinity, and Mr. A. C. McTaggart has served as observer in his place. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 62.

*List of discharge measurements made on Verdigris River at Liberty, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 2 | E. C. Murphy | 19 | 2.40 | 130 | 0.88 | 107 |
| 2 | Sept. 7 | do | 17 | 3.44 | 278 | 1.59 | 443 |
| 3 | Nov. 15 | do | 17 | 2.70 | 188 | 1.16 | 218 |
| | 1896. | | | | | | |
| 4 | Apr. 15 | E. C. Murphy | 10 | 3.40 | 250 | 1.47 | 368 |
| 5 | May 26 | do | 10 | 20.00 | 3,516 | 4.14 | 14,574 |
| 6 | May 27 | do | 10 | 19.50 | 3,465 | 3.97 | 13,756 |
| 7 | July 8 | do | 10 | 3.70 | 304 | 2.25 | 684 |
| 8 | Sept. 25 | do | 10 | 2.55 | 132 | 1.29 | 170 |
| 9 | Sept. 26 | do | 10 | 2.70 | 150 | 1.52 | 229 |
| | 1897. | | | | | | |
| 10 | Apr. 2 | E. C. Murphy | 19 | 6.55 | 691 | 3.70 | 2,558 |
| 11 | Apr. 3 | do | 19 | 5.87 | 584 | 3.43 | 2,002 |
| 12 | Apr. 30 | do | 19 | 16.00 | 2,917 | 3.55 | 10,367 |

*Rating table for Verdigris River at Liberty, Kansas.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 0 | 5.10 | 1,472 | 9.20 | 4,784 | 13.30 | 8,146 |
| 1.10 | 6 | 5.20 | 1,544 | 9.30 | 4,866 | 13.40 | 8,228 |
| 1.20 | 12 | 5.30 | 1,616 | 9.40 | 4,948 | 13.50 | 8,310 |
| 1.30 | 18 | 5.40 | 1,688 | 9.50 | 5,030 | 13.60 | 8,392 |
| 1.40 | 24 | 5.50 | 1,760 | 9.60 | 5,112 | 13.70 | 8,474 |
| 1.50 | 30 | 5.60 | 1,840 | 9.70 | 5,194 | 13.80 | 8,556 |
| 1.60 | 38 | 5.70 | 1,920 | 9.80 | 5,276 | 13.90 | 8,638 |
| 1.70 | 46 | 5.80 | 2,000 | 9.90 | 5,358 | 14.00 | 8,720 |
| 1.80 | 54 | 5.90 | 2,080 | 10.00 | 5,440 | 14.10 | 8,802 |
| 1.90 | 62 | 6.00 | 2,160 | 10.10 | 5,522 | 14.20 | 8,884 |
| 2.00 | 70 | 6.10 | 2,242 | 10.20 | 5,604 | 14.30 | 8,966 |
| 2.10 | 88 | 6.20 | 2,324 | 10.30 | 5,686 | 14.40 | 9,048 |
| 2.20 | 106 | 6.30 | 2,406 | 10.40 | 5,768 | 14.50 | 9,130 |
| 2.30 | 124 | 6.40 | 2,488 | 10.50 | 5,850 | 14.60 | 9,212 |
| 2.40 | 142 | 6.50 | 2,570 | 10.60 | 5,932 | 14.70 | 9,294 |
| 2.50 | 160 | 6.60 | 2,652 | 10.70 | 6,014 | 14.80 | 9,376 |
| 2.60 | 192 | 6.70 | 2,734 | 10.80 | 6,096 | 14.90 | 9,458 |
| 2.70 | 224 | 6.80 | 2,816 | 10.90 | 6,178 | 15.00 | 9,540 |
| 2.80 | 256 | 6.90 | 2,896 | 11.00 | 6,260 | 15.10 | 9,622 |
| 2.90 | 288 | 7.00 | 2,980 | 11.10 | 6,342 | 15.20 | 9,704 |
| 3.00 | 320 | 7.10 | 3,062 | 11.20 | 6,424 | 15.30 | 9,786 |
| 3.10 | 360 | 7.20 | 3,144 | 11.30 | 6,506 | 15.40 | 9,868 |
| 3.20 | 400 | 7.30 | 3,226 | 11.40 | 6,588 | 15.50 | 9,950 |
| 3.30 | 440 | 7.40 | 3,308 | 11.50 | 6,670 | 15.60 | 10,032 |
| 3.40 | 480 | 7.50 | 3,390 | 11.60 | 6,752 | 15.70 | 10,114 |
| 3.50 | 520 | 7.60 | 3,472 | 11.70 | 6,834 | 15.80 | 10,196 |
| 3.60 | 570 | 7.70 | 3,554 | 11.80 | 6,916 | 15.90 | 10,278 |
| 3.70 | 620 | 7.80 | 3,636 | 11.90 | 6,998 | 16.00 | 10,360 |
| 3.80 | 670 | 7.90 | 3,718 | 12.00 | 7,080 | 16.10 | 10,442 |
| 3.90 | 720 | 8.00 | 3,800 | 12.10 | 7,162 | 16.20 | 10,524 |
| 4.00 | 770 | 8.10 | 3,882 | 12.20 | 7,244 | 16.30 | 10,606 |
| 4.10 | 830 | 8.20 | 3,964 | 12.30 | 7,326 | 16.40 | 10,688 |
| 4.20 | 890 | 8.30 | 4,046 | 12.40 | 7,408 | 16.50 | 10,770 |
| 4.30 | 950 | 8.40 | 4,128 | 12.50 | 7,490 | 16.60 | 10,856 |
| 4.40 | 1,010 | 8.50 | 4,210 | 12.60 | 7,572 | 16.70 | 10,942 |
| 4.50 | 1,070 | 8.60 | 4,292 | 12.70 | 7,654 | 16.80 | 11,028 |
| 4.60 | 1,136 | 8.70 | 4,374 | 12.80 | 7,736 | 16.90 | 11,114 |
| 4.70 | 1,202 | 8.80 | 4,456 | 12.90 | 7,818 | 17.00 | 11,200 |
| 4.80 | 1,268 | 8.90 | 4,538 | 13.00 | 7,900 | 17.10 | 11,290 |
| 4.90 | 1,334 | 9.00 | 4,620 | 13.10 | 7,982 | 17.20 | 11,380 |
| 5.00 | 1,400 | 9.10 | 4,702 | 13.20 | 8,064 | 17.30 | 11,470 |

*Rating table for Verdigris River at Liberty, Kansas*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 17.40 | 11,560 | 19.10 | 13,370 | 20.80 | 15,594 | 22.50 | 18,110 |
| 17.50 | 11,650 | 19.20 | 13,490 | 20.90 | 15,742 | 22.60 | 18,258 |
| 17.60 | 11,750 | 19.30 | 13,610 | 21.00 | 15,890 | 22.70 | 18,406 |
| 17.70 | 11,850 | 19.40 | 13,730 | 21.10 | 16,038 | 22.80 | 18,554 |
| 17.80 | 11,950 | 19.50 | 13,850 | 21.20 | 16,186 | 22.90 | 18,702 |
| 17.90 | 12,050 | 19.60 | 13,976 | 21.30 | 16,334 | 23.00 | 18,850 |
| 18.00 | 12,150 | 19.70 | 14,102 | 21.40 | 16,482 | 23.10 | 18,998 |
| 18.10 | 12,256 | 19.80 | 14,228 | 21.50 | 16,630 | 23.20 | 19,146 |
| 18.20 | 12,362 | 19.90 | 14,354 | 21.60 | 16,778 | 23.30 | 19,294 |
| 18.30 | 12,468 | 20.00 | 14,470 | 21.70 | 16,926 | 23.40 | 19,442 |
| 18.40 | 12,574 | 20.10 | 14,606 | 21.80 | 17,074 | 23.50 | 19,590 |
| 18.50 | 12,680 | 20.20 | 14,742 | 21.90 | 17,222 | 23.60 | 19,738 |
| 18.60 | 12,794 | 20.30 | 14,878 | 22.00 | 17,370 | 23.70 | 19,886 |
| 18.70 | 12,908 | 20.40 | 15,014 | 22.10 | 17,518 | 33.80 | 20,034 |
| 18.80 | 13,022 | 20.50 | 15,150 | 22.20 | 17,666 | 23.90 | 20,182 |
| 18.90 | 13,136 | 20.60 | 15,298 | 22.30 | 17,814 | 24.00 | 20,330 |
| 19.00 | 13,250 | 20.70 | 15,446 | 22.40 | 17,962 | | |

*Estimated monthly discharge of Verdigris River at Liberty, Kansas.*

[Drainage area, 3,067 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 1,136 | 480 | 673 | 41,381 | 0.24 | 0.21 |
| February | 770 | 320 | 461 | 26,517 | 0.16 | 0.15 |
| March | 400 | 256 | 312 | 19,184 | 0.12 | 0.10 |
| April | 3,882 | 256 | 721 | 42,902 | 0.27 | 0.24 |
| May | 19,960 | 224 | 4,219 | 259,418 | 1.59 | 1.38 |
| June | 16,867 | 360 | 2,200 | 130,909 | 0.80 | 0.72 |
| July | 10,770 | 224 | 1,751 | 107,665 | 0.66 | 0 57 |
| August | 288 | 62 | 111 | 6,825 | 0.04 | 0.04 |
| September | 460 | 46 | 126 | 7,498 | 0.04 | 0.04 |
| October | 8,720 | 54 | 625 | 38,430 | 0.23 | 0.20 |
| November | 9,130 | 208 | 1,082 | 64,383 | 0.39 | 0.35 |
| December | 1,010 | 288 | 493 | 30,314 | 0.18 | 0.16 |
| Per annum | 19,960 | 46 | 1,065 | 775,426 | 4.72 | 0.35 |

### IOLA STATION ON NEOSHO RIVER.

This station is described on page 163 of Bulletin 140. It is at a highway bridge 1 mile west of the city of Iola, Kansas, in the Iola quadrangle, latitude 37° 55′, longitude 95° 25′. The area drained is 3,670 square miles, and is mapped on Fredonia, Garnett, Burlington, Emporia, Eskridge, Cottonwood Falls, Parkerville, Abilene, and Newton sheets. The gage is in two parts; one part, a vertical board marked to feet and tenths and fastened to flume, serves to give ordinary heights; the other is a smooth stone wall, near by, having horizontal lines on it one-half foot apart, for use when the water is high. The zero is 13.30 feet below the heads of three large nails driven into crosspiece of flume. On October 16 a new gage was fastened on top of the old one with their zeros coinciding—the marks having washed off the old one. Mr. Elias Bruner continues to serve as observer.

Four measurements of the discharge were made by Prof. E. C. Murphy between the dates of July 30 and November 15, 1895, and four more between the dates of April 14 and October 16, 1896. These measurements, together with three made in 1897, form the basis of a rating table. They show that the velocity is very little at low water and increases rapidly as the depth increases, a mean velocity of 11.1 feet per second being found for a gage reading 16.8 feet. The cross section changes somewhat, due to driftwood digging out stone from the dam during moderate floods, and these being washed downstream by high floods. The measurements are made from a carriage bridge about 90 feet below a milldam. The river is here 190 feet wide, confined between high masonry walls. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 63.

*List of discharge measurements made on Neosho River at Iola, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 30 | E. C. Murphy | 19 | 2.75 | 448 | 0.57 | 257 |
| 2 | Aug. 3 | do | 19 | 3.10 | 531 | 0.98 | 521 |
| 3 | Sept. 6 | do | 17 | 2.80 | 453 | 0.79 | 358 |
| 4 | Nov. 15 | do | 17 | 2.40 | 474 | 0.56 | 267 |
| | 1896. | | | | | | |
| 5 | Apr. 14 | E. C. Murphy | 10 | 3.40 | 680 | 0.97 | 664 |
| 6 | May 26 | do | (*a*) | 16.80 | 3,112 | 11.16 | 34,722 |
| 7 | July 8 | do | 10 | 3.50 | 704 | 1.23 | 863 |
| 8 | Oct. 16 | do | 17 | 2.25 | 85 | 0.87 | *b* 73 |
| | 1897. | | | | | | |
| 9 | Mar. 19 | do | 17 | 3.15 | 647 | 0.87 | 566 |
| 10 | Apr. 1 | do | 19 | 4.60 | 931 | 2.20 | 2,049 |
| 11 | Apr. 2 | do | 19 | 4.35 | 883 | 1.98 | 1,752 |

*a* Surface floats. *b* Measurement, a little below station, with boat and cable.

*Rating table for Neosho River at Iola, Kansas.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.00 | 0 | 6.30 | 4,740 | 10.60 | 16,110 | 14.90 | 29,440 |
| 2.10 | 10 | 6.40 | 4,945 | 10.70 | 16,420 | 15.00 | 29,750 |
| 2.20 | 20 | 6.50 | 5,150 | 10.80 | 16,730 | 15.10 | 30,060 |
| 2.30 | 50 | 6.60 | 5,355 | 10.90 | 17,040 | 15.20 | 30,370 |
| 2.40 | 75 | 6.70 | 5,565 | 11.00 | 17,350 | 15.30 | 30,680 |
| 2.50 | 100 | 6.80 | 5,775 | 11.10 | 17,660 | 15.40 | 30,990 |
| 2.60 | 125 | 6.90 | 5,985 | 11.20 | 17,970 | 15.50 | 31,300 |
| 2.70 | 160 | 7.00 | 6,200 | 11.30 | 18,280 | 15.60 | 31,610 |
| 2.80 | 200 | 7.10 | 6,415 | 11.40 | 18,590 | 15.70 | 31,920 |
| 2.90 | 250 | 7.20 | 6,630 | 11.50 | 18,900 | 15.80 | 32,230 |
| 3.00 | 300 | 7.30 | 6,850 | 11.60 | 19,210 | 15.90 | 32,540 |
| 3.10 | 350 | 7.40 | 7,070 | 11.70 | 19,520 | 16.00 | 32,850 |
| 3.20 | 410 | 7.50 | 7,300 | 11.80 | 19,830 | 16.10 | 33,160 |
| 3.30 | 480 | 7.60 | 7,530 | 11.90 | 20,140 | 16.20 | 33,470 |
| 3.40 | 560 | 7.70 | 7,770 | 12.00 | 20,450 | 16.30 | 33,780 |
| 3.50 | 650 | 7.80 | 8,010 | 12.10 | 20,760 | 16.40 | 34,090 |
| 3.60 | 740 | 7.90 | 8,250 | 12.20 | 21,070 | 16.50 | 34,400 |
| 3.70 | 850 | 8.00 | 8,500 | 12.30 | 21,380 | 16.60 | 34,710 |
| 3.80 | 960 | 8.10 | 8,750 | 12.40 | 21,690 | 16.70 | 35,020 |
| 3.90 | 1,080 | 8.20 | 9,010 | 12.50 | 22,000 | 16.80 | 35,330 |
| 4.00 | 1,200 | 8.30 | 9,270 | 12.60 | 22,310 | 16.90 | 35,640 |
| 4.10 | 1,320 | 8.40 | 9,530 | 12.70 | 22,620 | 17.00 | 35,950 |
| 4.20 | 1,440 | 8.50 | 9,800 | 12.80 | 22,930 | 17.10 | 36,260 |
| 4.30 | 1,560 | 8.60 | 10,070 | 12.90 | 23,240 | 17.20 | 36,570 |
| 4.40 | 1,690 | 8.70 | 10,350 | 13.00 | 23,550 | 17.30 | 36,880 |
| 4.50 | 1,820 | 8.80 | 10,630 | 13.10 | 23,860 | 17.40 | 37,190 |
| 4.60 | 1,950 | 8.90 | 10,910 | 13.20 | 24,170 | 17.50 | 37,500 |
| 4.70 | 2,080 | 9.00 | 11,200 | 13.30 | 24.480 | 17.60 | 37,810 |
| 4.80 | 2,220 | 9.10 | 11,490 | 13.40 | 24,790 | 17.70 | 38,120 |
| 4.90 | 2,360 | 9.20 | 11,790 | 13.50 | 25,100 | 17.80 | 38,430 |
| 5.00 | 2,500 | 9.30 | 12,090 | 13.60 | 25,410 | 17.90 | 38,740 |
| 5.10 | 2,650 | 9.40 | 12,390 | 13.70 | 25,720 | 18.00 | 39,050 |
| 5.20 | 2,800 | 9.50 | 12,700 | 13.80 | 26,030 | 18.10 | 39,360 |
| 5.30 | 2,950 | 9.60 | 13,010 | 13.90 | 26,340 | 18.20 | 39,670 |
| 5.40 | 3,100 | 9.70 | 13,320 | 14.00 | 26,650 | 18.30 | 39,980 |
| 5.50 | 3,250 | 9.80 | 13,630 | 14.10 | 26,960 | 18.40 | 40,290 |
| 5.60 | 3,400 | 9.90 | 13,940 | 14.20 | 27,270 | 18.50 | 40,600 |
| 5.70 | 3,550 | 10.00 | 14,250 | 14.30 | 27,580 | 18.60 | 40,910 |
| 5.80 | 3,710 | 10.10 | 14,560 | 14.40 | 27,890 | 18.70 | 41,220 |
| 5.90 | 3,970 | 10.20 | 14,870 | 14.50 | 28,200 | 18.80 | 41,530 |
| 6.00 | 4,150 | 10.30 | 15,180 | 14.60 | 28,510 | 18.90 | 41,840 |
| 6.10 | 4,340 | 10.40 | 15,490 | 14.70 | 28,820 | 19.00 | 42,150 |
| 6.20 | 4,540 | 10.50 | 15,800 | 14.80 | 29,130 | | |

*Estimated monthly discharge of Neosho River at Iola, Kansas.*

[Drainage area, 3,670 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 275 | 100 | 125 | 7,686 | 0.03 | 0.03 |
| February | 275 | 75 | 114 | 6,557 | 0.03 | 0.03 |
| March | 125 | 20 | 61 | 3,751 | 0.02 | 0.02 |
| April | 15,025 | 50 | 2,708 | 161,137 | 0.82 | 0.74 |
| May | 45,560 | 160 | 10,273 | 631,666 | 3.23 | 2.80 |
| June | 5,048 | 250 | 905 | 53,851 | 0.28 | 0.25 |
| July | 7,890 | 125 | 1,278 | 78,581 | 0.40 | 0.35 |
| August | 300 | 10 | 58 | 3,566 | 0.02 | 0.02 |
| September | 10 | 0 | 6 | 357 | 0.002 | 0.002 |
| October | 225 | 0 | 11 | 676 | 0.003 | 0.003 |
| November | 2,290 | 5 | 245 | 14,578 | 0.07 | 0.07 |
| December | 445 | 20 | 88 | 5,411 | 0.02 | 0.02 |
| Per annum | 45,560 | 0 | 1,322 | 967,817 | 4.925 | 0.36 |

## MEDICINE AND CIMARRON RIVERS.

These streams drain a portion of southwestern Kansas, and flow in a general southeasterly direction into the Arkansas River. They are referred to in Bulletin 140, page 164.

### KIOWA STATION ON MEDICINE RIVER.

This station is described in Bulletin 140, page 165. It is located at the wagon bridge 3 miles east and one-half mile north of the town of Kiowa, in latitude 37° 3′ and longitude 98° 29.5′, in the Anthony quadrangle. The drainage area is about 1,300 square miles, and is mapped on the Anthony, Medicine Lodge, Coldwater, and Kinsley atlas sheets. The station was established by Mr. Arthur P Davis, May 6, 1895, with Mr. James M. Fisher as observer, who lives one-half mile south of the station. The gage was first fastened to a bridge piling near the right bank, but the channel changed to the left bank, leaving the gage on dry land. It was then changed to a piling near the left bank and placed at the same elevation as before. The channel then moved back near the center of the bridge, when a second gage was put in this channel at the same elevation as the other. The bench mark is the top of the plate or cap of the pile to which the first gage was spiked and at an elevation of 11.1 feet above the zero of the gage. At low water meas-

urements can be made by wading and at high water from the bridge, the initial point being the south end of the bridge on the right bank of the stream. During August, September, and October, 1896, Mr. Fisher, the observer, took measurements about every ten days and forwarded them to Mr. W. G. Russell for computation. This station was discontinued October 31, 1896. The record of daily gage heights for 1896, from January 1 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 63.

*List of discharge measurements made on Medicine River at Kiowa, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 6 | A. P. Davis | 19 | 2.35 | 24 | 0.91 | 22 |
| 2 | June 21 | W. G. Russell | 19 | 2.40 | 49 | 1.34 | 66 |
| 3 | July 25 | do | 19 | 3.20 | 173 | 1.70 | 294 |
| 4 | Sept. 1 | do | 19 | 2.60 | 38 | 1.06 | 40 |
| 5 | Oct. 29 | do | 19 | 2.40 | 23 | 0.68 | 15 |
| 6 | Dec. 21 | do | 19 | 2.65 | 45 | 1.22 | 54 |
| | 1896. | | | | | | |
| 7 | May 22 | W. G. Russell | 3 | 3.62 | 111 | 1.13 | 126 |
| 8 | Aug. 1 | do | 3 | 2.50 | 30 | 1.11 | 34 |
| 9 | Aug. 3 | do | 3 | 2.40 | 28 | 1.14 | 32 |
| 10 | Aug. 10 | J. M. Fisher | 3 | 1.90 | 5 | 0.74 | 4 |
| 11 | Aug. 18 | do | 3 | 1.80 | 2 | 0.67 | 1 |
| 12 | Aug. 22 | do | 3 | 1.70 | 1 | 0.52 | 0.5 |
| 13 | Aug. 28 | do | 3 | 1.40 | ..... | ..... | Dry. |
| 14 | Sept. 21 | do | 3 | 2.50 | 31 | 1.15 | 36 |
| 15 | Sept. 28 | do | 3 | 2.10 | 6 | 0.75 | 5 |
| 16 | Oct. 5 | do | 3 | 2.20 | 9 | 0.78 | 7 |
| 17 | Oct. 12 | do | 3 | 2.40 | 23 | 1.00 | 23 |
| 18 | Oct. 19 | do | 3 | 2.30 | 17 | 0.92 | 15 |
| 19 | Oct. 23 | do | 3 | 2.80 | 61 | 1.12 | 68 |
| 20 | Oct. 29 | do | 3 | 3.00 | 105 | 1.23 | 130 |

*Rating table for Medicine River at Kiowa, Kansas, constructed by W. G. Russell.*

[This table is applicable only from January 1 1896, to October 31, 1896.]

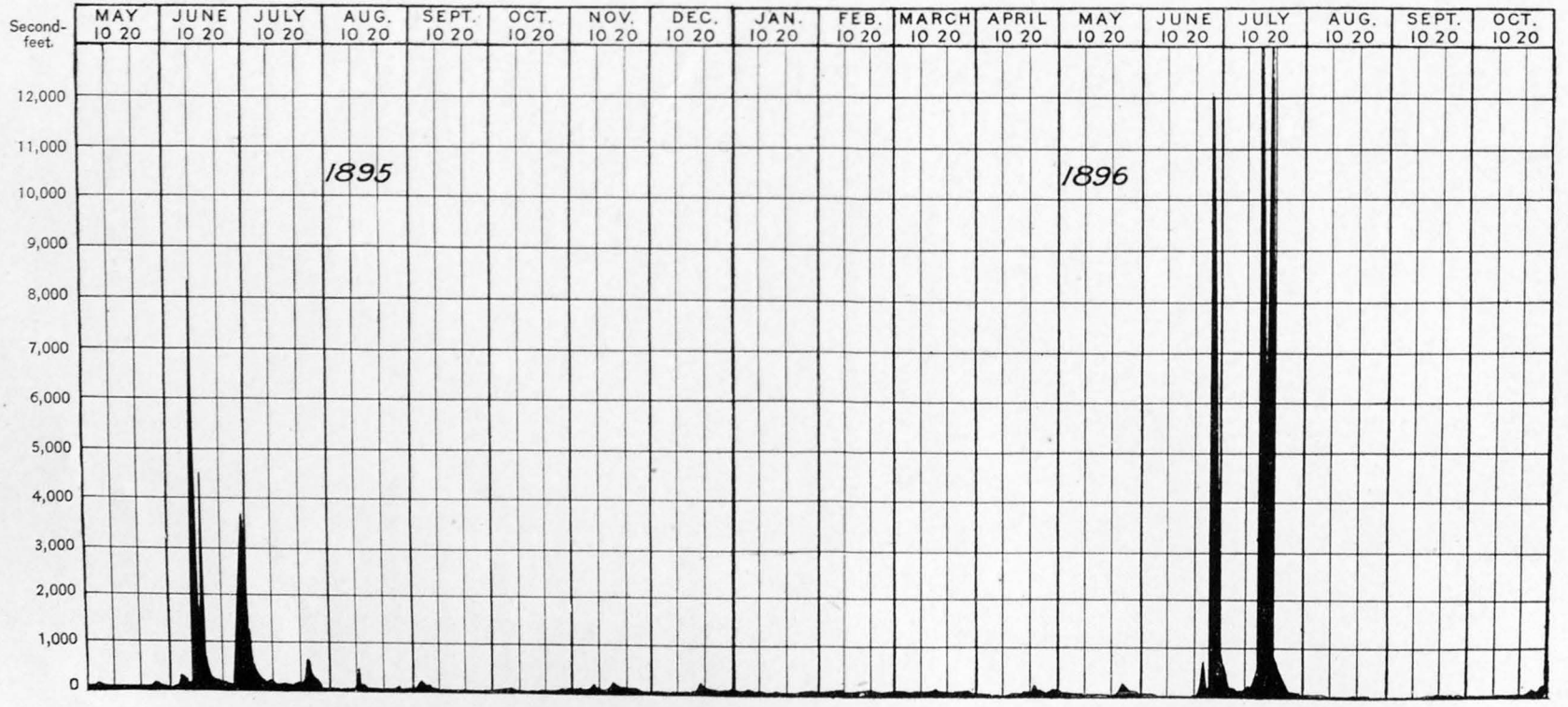
| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.40 | 0 | 2.70 | 55 | 3 80 | 585 | 4.90 | 4,000 |
| 1.70 | 1 | 2.80 | 68 | 3.90 | 700 | 5.00 | 4,800 |
| 1.80 | 1 | 2.90 | 98 | 4.00 | 790 | 5.10 | 5,750 |
| 1.90 | 4 | 3.00 | 130 | 4.10 | 940 | 5.20 | 6,900 |
| 2.00 | 4 | 3.10 | 156 | 4.20 | 1,130 | 5 30 | 8,270 |
| 2.10 | 5 | 3.20 | 187 | 4.30 | 1,350 | 5.40 | 9,920 |
| 2.20 | 7 | 3.30 | 240 | 4.40 | 1,620 | 5.50 | 11,860 |
| 2.30 | 15 | 3.40 | 288 | 4.50 | 1,940 | 5.60 | 14,200 |
| 2.40 | 23 | 3.50 | 345 | 4.60 | 2,320 | 5.70 | 17,050 |
| 2.50 | 36 | 3.60 | 410 | 4.70 | 2,780 | 5.80 | 20,400 |
| 2.60 | 44 | 3.70 | 490 | 4.80 | 3,330 | 5.90 | 24,600 |

*Estimated monthly discharge of Medicine River at Kiowa, Kansas.*

[Drainage area, 1,300 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| May 6 to 31 | 67 | 10 | 20 | 1,040 | 0.014 | 0.015 |
| June | 2,000 | 12 | 378 | 22,493 | 0.32 | 0.29 |
| July | 1,190 | 12 | 170 | 10,453 | 0.15 | 0.13 |
| August | 427 | 8 | 30 | 1,845 | 0.026 | 0.023 |
| September | 110 | 5 | 20 | 1,190 | 0.017 | 0.015 |
| October | 32 | 5 | 15 | 922 | 0.013 | 0.011 |
| November | 154 | 14 | 49 | 2,916 | 0.042 | 0.037 |
| December | 156 | 12 | 26 | 1,599 | 0.023 | 0.020 |
| 1896. | | | | | | |
| January | 68 | 36 | 46 | 2,828 | 0.038 | 0.035 |
| February | 55 | 23 | 42 | 2,416 | 0.035 | 0.032 |
| March | 55 | 15 | 33 | 2,029 | 0.027 | 0.025 |
| April | 171 | 4 | 40 | 2,380 | 0.034 | 0.031 |
| May | 187 | 5 | 32 | 1,968 | 0.026 | 0.024 |
| June | *a* 11,860 | 0 | 899 | 53,494 | 0.772 | 0.704 |
| July | *a* 24,600 | 36 | 1,784 | 109,694 | 1.47 | 1.36 |
| August | 23 | 0 | 6 | 369 | 0.005 | 0.005 |
| September | 19 | 0 | 4 | 238 | 0.004 | 0.003 |
| October | 130 | 5 | 34 | 2,091 | 0.027 | 0.025 |

*a* Estimated.




DISCHARGE OF MEDICINE RIVER AT KIOWA, KANSAS, 1895-96.

## ARKALON STATION ON CIMARRON RIVER.

This station is located one-half mile north of Arkalon, a station of the Chicago, Rock Island and Pacific Railway, and at the railroad bridge crossing the river. It was established by Mr. Arthur P. Davis, May 14, 1895. The observer is G. W. Siever, railroad agent at Arkalon, who reads the gage twice each day. The gage consists of a vertical plank spiked to the bridge piling on the west and upstream side, and is graduated to feet and tenths. The bench mark is the top of the sill at the northwest corner of the windmill tower of the railroad water tank and southwest of the gage, and at an elevation of 14.43 feet above the zero of the gage. The bed of this stream is sandy, and at low water stream is very crooked. At ordinary stages it can be easily measured by wading, and at high water can be measured from the bridge, the initial point being the north or left bank of the river. The flow in this stream is, in general, very uniform and of small amount. Readings at this station were discontinued October 31, 1896. No meter measurements have been made in 1896. The record of daily gage heights for 1896, from January 1 to October 31, is given in Water-Supply and Irrigation Paper No. 11, page 64.

*List of discharge measurements made on Cimarron River at Arkalon, Kansas.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 14 | A. P. Davis..... | 19 | 2.50 | 13 | 1.31 | 17 |
| 2 | June 24 | W. G. Russell..... | 19 | 2.70 | 13 | 1.30 | 16 |
| 3 | July 23 | .....do ..... | 19 | 7.00 | 178 | 1.79 | 317 |
| 4 | Aug. 29 | .....do ..... | 19 | 2.30 | 10 | 1.55 | 16 |
| 5 | Oct. 3 | .....do ..... | 19 | 2.35 | 16 | 0.98 | 16 |

*Rating table for Cimarron River at Arkalon, Kansas, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.30 | 16 | 3.80 | 42 | 5.30 | 108 | 6.80 | 279 |
| 2.40 | 17 | 3.90 | 45 | 5.40 | 116 | 6.90 | 298 |
| 2.50 | 18 | 4.00 | 48 | 5.50 | 123 | 7.00 | 319 |
| 2.60 | 19 | 4.10 | 51 | 5.60 | 131 | 7.10 | 340 |
| 2.70 | 21 | 4.20 | 54 | 5.70 | 140 | 7.20 | 361 |
| 2.80 | 22 | 4.30 | 57 | 5.80 | 149 | 7.30 | 384 |
| 2.90 | 24 | 4.40 | 61 | 5.90 | 159 | 7.40 | 409 |
| 3.00 | 26 | 4.50 | 65 | 6.00 | 170 | 7.50 | 436 |
| 3.10 | 27 | 4.60 | 69 | 6.10 | 181 | 7.60 | 465 |
| 3.20 | 29 | 4.70 | 74 | 6.20 | 192 | 7.70 | 496 |
| 3.30 | 31 | 4.80 | 79 | 6.30 | 203 | 7.80 | 528 |
| 3.40 | 33 | 4.90 | 84 | 6.40 | 214 | 7.90 | 562 |
| 3.50 | 35 | 5.00 | 89 | 6.50 | 228 | 8.00 | 599 |
| 3.60 | 37 | 5.10 | 95 | 6.60 | 244 | 8.10 | 638 |
| 3.70 | 39 | 5.20 | 102 | 6.70 | 261 | 8.20 | 680 |

*Estimated monthly discharge of Cimarron River at Arkalon, Kansas.*

[Drainage area, 5,200 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| May 14 to 31 | 22 | 18 | 18 | 648 | 0.002 | 0.003 |
| June | 170 | 19 | 47 | 2,797 | 0.01 | 0.009 |
| July | 659 | 14 | 149 | 9,162 | 0.033 | 0.028 |
| August | 170 | 16 | 30 | 1,845 | 0.007 | 0.006 |
| September | 19 | 16 | 17 | 1,012 | 0.004 | 0.003 |
| October | 18 | 16 | 17 | 1,045 | 0.004 | 0.003 |
| November | 18 | 17 | 17 | 1,012 | 0.004 | 0.003 |
| December | 18 | 17 | 17 | 1,045 | 0.004 | 0.003 |
| 1896. | | | | | | |
| January | 18 | 17 | 18 | 1,107 | 0.004 | 0.003 |
| February | 18 | 18 | 18 | 1,035 | 0.004 | 0.003 |
| March | 18 | 18 | 18 | 1,107 | 0.004 | 0.003 |
| April | 52 | 17 | 20 | 1,190 | 0.004 | 0.004 |
| May | 18 | 17 | 18 | 1,107 | 0.004 | 0.003 |
| June | 18 | 16 | 17 | 1,012 | 0.004 | 0.003 |
| July | 23 | 16 | 17 | 1,045 | 0.004 | 0.003 |
| August | 17 | 16 | 17 | 1,045 | 0.004 | 0.003 |
| September | 16 | 16 | 16 | 952 | 0.003 | 0.003 |
| October | 18 | 16 | 17 | 1,045 | 0.004 | 0.003 |

## CANADIAN RIVER.

The Canadian River is the largest tributary of the Arkansas, and might properly be considered as draining an independent basin. It is described in Bulletin 140, on page 167. Comparatively few measurements of the discharge of the stream have been made, although among the mountains and foothills in northeastern New Mexico irrigation has developed to a large extent. A single gaging station has been established, which is upon Mora River, one of the most important mountain feeders of the main stream.

### WATROUS STATION ON MORA RIVER.

This station has been described on page 40 of Bulletin No. 131. During 1895 observations of river height have been maintained and occasional measurements made, as shown by the accompanying list. The bed of the stream is very changeable, so that computations of discharge can not be made with accuracy except by continued series of soundings and by frequent discharge measurements. It has not been possible to construct a rating table. The station has been discontinued. A record of daily gage heights, not published, was kept at this point from January 1 to February 29.

*List of discharge measurements made on Mora River at Watrous, New Mexico.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Oct. 4 | A. P. Davis..... | 21 | 1.68 | 33 | 1.05 | 35 |
| | 1895. | | | | | | |
| 2 | May 18 | A. P. Davis..... | 28 | 1.50 | 20 | 0.89 | 18 |
| 3 | July 15 | P. E. Harroun..... | 25 | 2.00 | 156 | 0.85 | 131 |
| 4 | Sept. 4 | .....do ..... | 25 | 2.30 | 106 | 1.49 | 160 |
| 5 | Sept. 30 | .....do ..... | 25 | 1.50 | 25 | 0.66 | 15 |
| 6 | Nov. 16 | .....do ..... | 25 | 1.90 | 46 | 0.86 | 39 |
| 7 | Dec. 13 | .....do ..... | 26 | 1.90 | 60 | 1.01 | 61 |

## RIO GRANDE BASIN.

This basin is referred to in Bulletin 140, page 169, and is described at some length in the Twelfth Annual Report of the United States Geological Survey, Part II, Irrigation, pages 240 to 290. The question as to the amount of water in the stream is of peculiar importance, not only as related to agriculture, but also from its bearing upon interstate and international distribution of water. A number of gaging stations have

been maintained along this river for several years, the oldest continuous records being at Del Norte, near the headwaters, and at Embudo, in northern New Mexico. An accurate measurement of the lower portion of this stream is attended with extreme difficulty, owing to the rapidly shifting character of the river bed.

### DEL NORTE STATION ON RIO GRANDE.

This station has been described in Bulletin No. 131, page 41, and in Bulletin No. 140, page 170. It is located about 2 miles above the town of Del Norte, Colorado, and was established in September, 1889. The gage consists of an inclined 2 by 6 inch plank, fastened to posts driven into the right bank of the river and marked to vertical tenths of a foot, the space between marks being 0.22 of a foot. Bench mark No. 1 is a large nail in the root of a tree 15 feet northwest of the end of the cable on left bank of river. Bench mark No. 2 is a large nail in the root of a tree 25 feet southwest of the end of the inclined gage. Both bench marks are 7.54 feet above the datum of the gage. While the banks are not high, the river has never been known to overflow. The current is swift; the bed is composed of small stones and the cross section does not change materially. Discharge measurements are made at low stage of water by wading and at high water from a box suspended from a §-inch wire cable fastened to a large cottonwood tree on the left bank and to a sand anchor on the right bank. The river does not fluctuate rapidly, and observations of the gage heights are taken on alternate days. The observer is Mr. J. S. Regan. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 64.

*List of discharge measurements made on Rio Grande at Del Norte, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 34 | June 13 | F. H. Newell..... | 24 | 2.68 | (*a*) | ..... | 968 |
| 35 | Sept. 27 | A. P. Davis ..... | 21 | 1.52 | 115 | 2.32 | 267 |
| | 1895. | | | | | | |
| 36 | June 14 | F. Cogswell ..... | 55 | 4.00 | 480 | 5.88 | 2,818 |
| 37 | Oct. 13 | .....do ..... | 14 | 1.80 | 164 | 2.53 | 414 |
| | 1896. | | | | | | |
| 38 | June 22 | F. Cogswell ..... | 14 | 1.90 | 183 | 2.68 | 492 |
| 39 | July 27 | .....do ..... | 14 | 1.70 | 154 | 2.50 | 385 |
| 40 | Sept. 28 | .....do ..... | 14 | 2.30 | 235 | 3.00 | 706 |
| 41 | Oct. 26 | .....do ..... | 14 | 1.80 | 166 | 2.68 | 445 |

*a* Measurements made at iron bridge, mill race, and canal, and total taken as discharge of river.

*Rating table for Rio Grande at Del Norte, Colorado, for 1895 and 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.20 | 108 | 2.10 | 594 | 3.00 | 1,172 | 3.90 | 2,428 |
| 1.25 | 134 | 2.15 | 622 | 3.05 | 1,212 | 3.95 | 2,591 |
| 1.30 | 160 | 2.20 | 650 | 3.10 | 1,252 | 4.00 | 2,754 |
| 1.35 | 187 | 2 25 | 680 | 3.15 | 1,294 | 4.05 | 2,829 |
| 1.40 | 214 | 2.30 | 710 | 3.20 | 1,336 | 4.10 | 2,904 |
| 1.45 | 241 | 2.35 | 740 | 3.25 | 1,382 | 4.15 | 2,979 |
| 1.50 | 268 | 2.40 | 770 | 3.30 | 1,428 | 4.20 | 3,054 |
| 1.55 | 295 | 2.45 | 800 | 3.35 | 1,478 | 4.25 | 3,129 |
| 1.60 | 322 | 2.50 | 830 | 3.40 | 1,528 | 4.30 | 3,204 |
| 1.65 | 349 | 2.55 | 862 | 3.45 | 1,583 | 4.35 | 3,279 |
| 1.70 | 376 | 2.60 | 894 | 3.50 | 1,638 | 4.40 | 3,354 |
| 1.75 | 403 | 2.65 | 927 | 3.55 | 1,702 | 4.45 | 3,429 |
| 1.80 | 430 | 2.70 | 960 | 3.60 | 1,766 | 4.50 | 3,504 |
| 1.85 | 457 | 2.75 | 993 | 3.65 | 1,838 | 4.55 | 3,579 |
| 1.90 | 484 | 2.80 | 1,026 | 3.70 | 1,910 | 4.60 | 3,654 |
| 1.95 | 511 | 2.85 | 1,061 | 3.75 | 2,032 | 4.65 | 3,729 |
| 2.00 | 538 | 2.90 | 1,096 | 3 80 | 2,154 | 4.70 | 3,804 |
| 2.05 | 566 | 2.95 | 1,134 | 3.85 | 2,291 | | |

*Estimated monthly discharge of Rio Grande at Del Norte, Colorado.*

[Drainage area, 1,400 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 894 | 680 | 801 | 49,252 | 0.66 | 0.57 |
| February | 1,061 | 894 | 953 | 52,927 | 0.73 | 0.68 |
| March | 960 | 403 | 638 | 39,229 | 0.53 | 0.46 |
| April | 3,129 | 650 | 1,883 | 112,047 | 1.50 | 1.34 |
| May | 3,129 | 1,382 | 2,116 | 130,108 | 1.74 | 1.51 |
| June | 3,804 | 1,172 | 2,209 | 131,445 | 1.76 | 1.58 |
| July | 1,252 | 770 | 958 | 58,905 | 0.79 | 0.69 |
| August | 960 | 566 | 720 | 44,271 | 0.60 | 0.52 |
| September | 566 | 376 | 454 | 27,015 | 0.36 | 0.32 |
| October | 484 | 403 | 435 | 26,747 | 0.36 | 0.31 |
| November | 403 | 322 | 353 | 21,005 | 0.28 | 0.25 |
| December | 1,212 | 403 | 1,008 | 61,980 | 0.83 | 0.72 |
| Per annum | 3,804 | 322 | 1,044 | 754,931 | 10.14 | 0.75 |

*Estimated monthly discharge of Rio Grande at Del Norte, Colorado*—Continued.

[Drainage area, 1,400 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 1,428 | 1,172 | 1,293 | 79,504 | 1.06 | 0.92 |
| February | 2,154 | 960 | 1,258 | 72,361 | 0.97 | 0.90 |
| March | 1,336 | 830 | 1,081 | 66,469 | 0.89 | 0.77 |
| April | 3,054 | 594 | 1,484 | 88,304 | 1.18 | 1.06 |
| May | 3,579 | 1,212 | 2,374 | 145,973 | 1.96 | 1.70 |
| June | 1,766 | 430 | 821 | 48,853 | 0.65 | 0.59 |
| July | 650 | 322 | 403 | 24,780 | 0.33 | 0.29 |
| August | 403 | 214 | 261 | 16,048 | 0.22 | 0.19 |
| September | 1,294 | 268 | 477 | 28,383 | 0.38 | 0.34 |
| October | 566 | 403 | 469 | 28,838 | 0.39 | 0.34 |
| November | 376 | 268 | 310 | 18,446 | 0.24 | 0.22 |
| December | 430 | 322 | 375 | 23,058 | 0.31 | 0.27 |
| Per annum | 3,579 | 214 | 884 | 641,017 | 8.58 | 0 63 |

## EMBUDO STATION ON RIO GRANDE.

This station is described in Bulletin 131, on page 53. It is located about 300 feet east of the railroad depot of Embudo. The observer is F. B. Hatfield, the station agent. Equipment consists of a five eighths inch cable and car with tagged wire. The gage is inclined, and consists of 4 by 4 timber, notched and marked every tenth of a foot vertically, and spiked to small hand-driven piles. The initial point of sounding is on the right bank. The left bank is steep and the right bank of more gentle slope. Three discharge measurements were made during the year 1896, which, taken in conjunction with those made in 1895, are used in constructing a rating table for estimates of daily discharge. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 65.

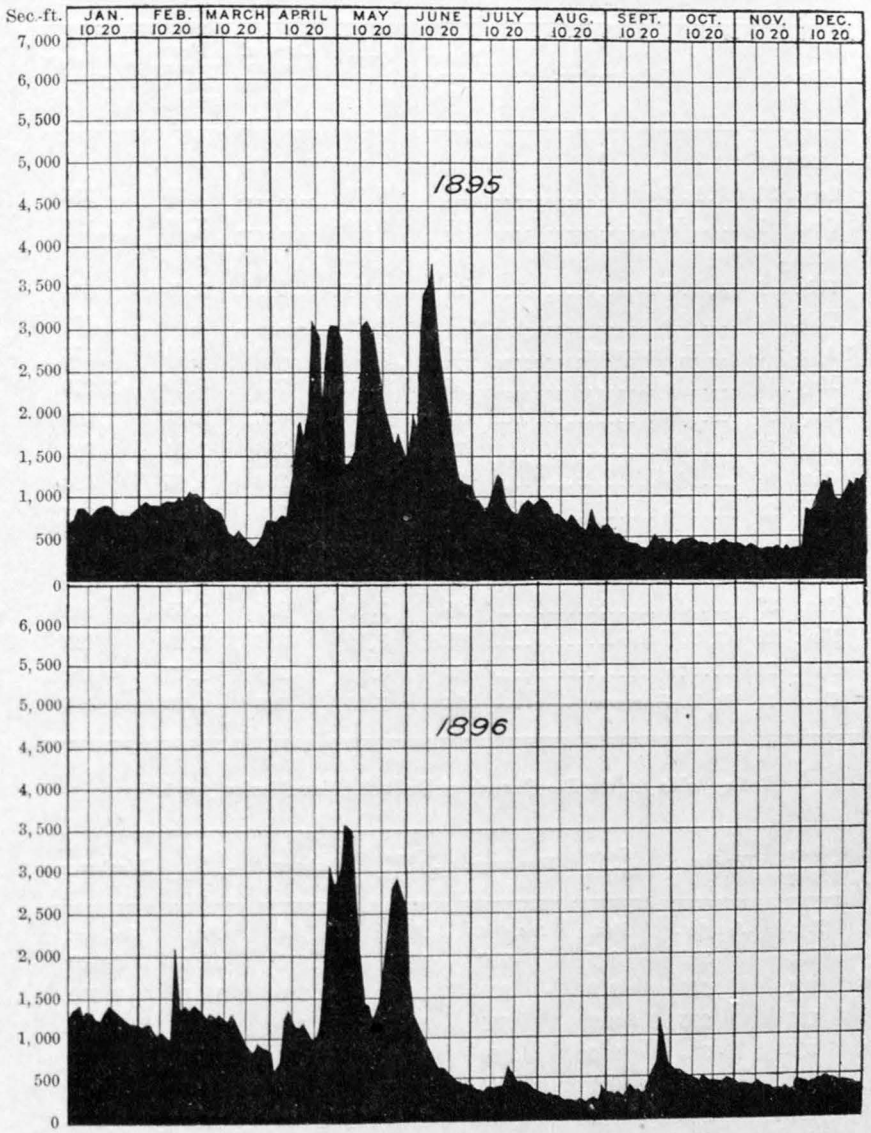



FIG. 34.—Discharge of Rio Grande at Del Norte, Colorado, 1895–96.

*List of discharge measurements made on Rio Grande at Embudo, New Mexico.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1894. | | | | | | |
| Sept. 30 | A. P. Davis | 21 | 7.70 | | 1.50 | 284 |
| Oct. 1 | do | 21 | 9.30 | | 3.25 | 1,138 |
| 1895. | | | | | | |
| Feb. 2 | A. P. Davis | 24 | 7.98 | | 2.23 | 464 |
| Feb. 4 | do | 24 | 8.01 | | 2.25 | 453 |
| Apr. 8 | P. E. Harroun | 25 | 9.40 | 399 | 2.94 | 1,175 |
| May 14 | do | 25 | 11.20 | 732 | 4.39 | 3,219 |
| July 27 | do | 25 | 9.90 | 436 | 3.88 | 1,669 |
| Aug. 19 | do | 25 | 8.80 | 388 | 2.34 | 908 |
| Oct. 26 | do | 25 | 8.10 | 299 | 1.65 | 494 |
| Nov. 28 | do | 25 | 8.40 | 388 | 1.82 | 617 |
| 1896. | | | | | | |
| Sept. 7 | P. E. Harroun | 26 | 7.30 | 228 | 0.94 | 213 |
| Oct. 29 | do | 26 | 7.80 | 221 | 1.55 | 342 |
| Nov. 20 | C. C. Babb | 63 | 8.11 | 236 | 1.85 | 436 |
| Nov. 21 | do | 63 | 8.11 | 243 | 1.77 | 431 |
| Dec. 14 | P. E. Harroun | 26 | 7.90 | 249 | 1.72 | 427 |

*Rating table for the Rio Grande at Embudo, New Mexico, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 7.3 | 210 | 8.7 | 750 | 10.1 | 1,870 | 11.4 | 3,520 |
| 7.4 | 240 | 8.8 | 800 | 10.2 | 1,980 | 11.5 | 3,660 |
| 7.5 | 275 | 8.9 | 850 | 10.3 | 2,100 | 11.6 | 3,800 |
| 7.6 | 310 | 9.0 | 900 | 10.4 | 2,220 | 11.7 | 3,940 |
| 7.7 | 345 | 9.1 | 960 | 10.5 | 2,350 | 11.8 | 4,080 |
| 7.8 | 380 | 9.2 | 1,020 | 10.6 | 2,470 | 11.9 | 4,220 |
| 7.9 | 420 | 9.3 | 1,090 | 10.7 | 2,590 | 12.0 | 4,360 |
| 8.0 | 460 | 9.4 | 1,160 | 10.8 | 2,720 | 12.1 | 4,520 |
| 8.1 | 500 | 9.5 | 1,240 | 10.9 | 2,850 | 12.2 | 4,660 |
| 8.2 | 540 | 9.6 | 1,330 | 11.0 | 2,980 | 12.3 | 4,800 |
| 8.3 | 580 | 9.7 | 1,430 | 11.1 | 3,110 | 12.4 | 4,940 |
| 8.4 | 620 | 9.8 | 1,540 | 11.2 | 3,240 | 12.5 | 5,090 |
| 8.5 | 660 | 9.9 | 1,650 | 11.3 | 3,380 | 12.6 | 5,240 |
| 8.6 | 700 | 10.0 | 1,760 | | | | |

EMBUDO GAGING STATION ON THE RIO GRANDE, NEW MEXICO.

*Estimated monthly discharge of Rio Grande at Embudo, New Mexico.*

[Drainage area, 7,000 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 660 | 460 | 532 | 32,712 | 0.09 | 0.08 |
| February | 640 | 480 | 551 | 31,694 | 0.09 | 0.08 |
| March | 2,100 | 580 | 957 | 58,844 | 0.16 | 0.14 |
| April | 2,720 | 1,200 | 1,797 | 106,929 | 0.29 | 0.26 |
| May | 2,980 | 850 | 1,598 | 98,259 | 0.26 | 0.23 |
| June | 990 | 210 | 367 | 21,838 | 0.06 | 0.05 |
| July | 1,380 | 210 | 299 | 18,385 | 0.04 | 0.04 |
| August | 310 | 210 | 249 | 15,310 | 0.03 | 0.03 |
| September | 580 | 210 | 228 | 13,570 | 0.03 | 0.03 |
| October | 1,090 | 275 | 349 | 21,459 | 0.06 | 0.05 |
| November | 660 | 210 | 395 | 23,504 | 0.07 | 0.06 |
| December | 500 | 380 | 414 | 25,456 | 0.07 | 0.06 |
| Per annum | 2,980 | 210 | 645 | 467,960 | 1.25 | 0.09 |

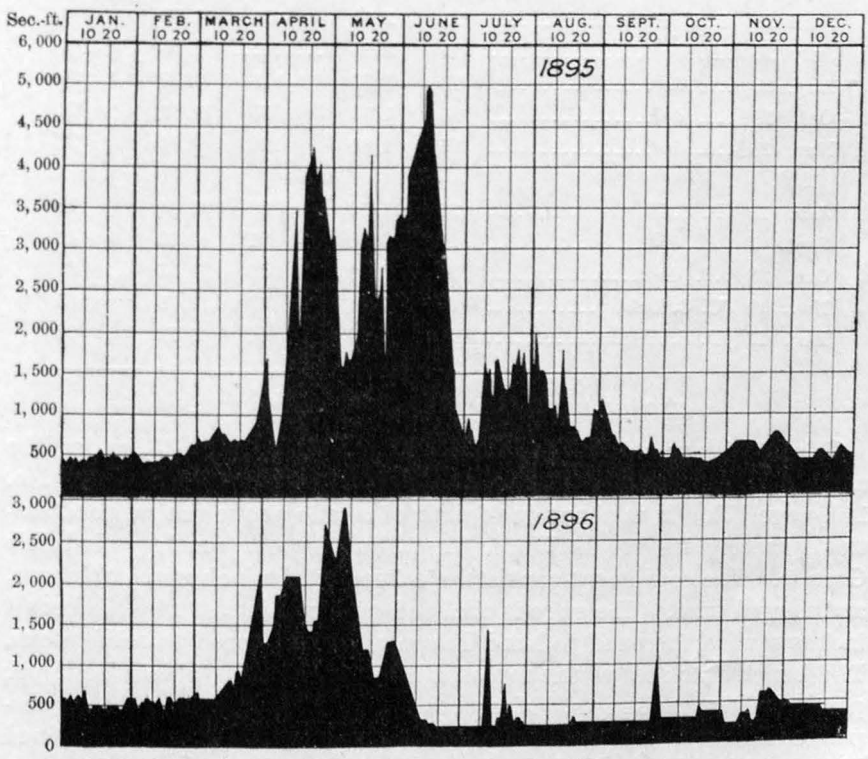



FIG. 35.—Discharge of Rio Grande at Embudo, New Mexico, 1895–96.

ABIQUIU STATION ON CHAMA RIVER.

This station is described in Bulletin 140, page 173. It is located about 200 yards above the town of Chama. The gage consists of two pieces of 4 by 4 timber laid on the slope of the river bank and spiked to hand-driven piles. The gaging equipment consists of five eighths inch cable, car, and tagged wire. The initial point for soundings is on the left bank. The channel is straight, both above and below the station, for a distance of about 300 feet, although at stages of very low water it is likely to divide and swing in the main bed. The right bank is steep and rocky, but the left bank is liable to overflow during an excessive flood. Four measurements of discharge were made during 1895, and five in 1896, but sufficient data has not been obtained to warrant the estimation of mean and total discharges, as the bed of the stream is of fine silt, and is very shifting and changeable. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 65.

*List of discharge measurements made on Chama River at Abiquiu, New Mexico.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet) |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| June 21 | P. E. Harroun | 25 | 2.50 | 254 | 1.59 | 404 |
| July 25 | do | 25 | 2.90 | | 1.33 | 206 |
| Aug. 18 | do | 25 | 1.30 | 118 | 1.77 | 209 |
| Oct. 29 | do | 25 | 1.10 | 55 | 1.31 | 72 |
| Nov. 26 | do | 25 | 1.80 | 120 | 0.64 | 77 |
| 1896. | | | | | | |
| Jan. 19 | P. E. Harroun | 26 | 1.50 | 89 | 1.44 | 129 |
| Sept. 5 | do | 26 | 2.20 | 71 | 0.70 | 47 |
| Oct. 28 | do | 26 | 2.30 | 49 | 1.03 | 51 |
| Nov. 19 | C. C. Babb | 63 | 2.27 | 59 | 1.10 | 65 |
| Dec. 12 | P. E. Harroun | 26 | 2.30 | 62 | 1.22 | 76 |

RIO GRANDE STATION ON RIO GRANDE.

This station was described in Bulletin No. 131, page 45, under the name of Water Tank Station. It is also mentioned in Bulletin No. 140, page 175. It is about one-fourth of a mile above the railroad station formerly known as Water Tank, but more recently called Rio Grande. The equipment consists of a five-eighths-inch wire cable, car, and tagged wire. The gage is inclined and consists of two timbers 4 inches square, fastened to hand-driven piles and wired to solid rocks. The bench mark is on the top of a bowlder, against which the upper portion of the gage rests. Measurements are made from the car suspended from the cable. The bed of the stream is rocky, and is confined between high banks. Eight discharge measurements were made in

RIO GRANDE GAGING STATION ON THE RIO GRANDE, NEW MEXICO

1895 and three in 1896, and from these a rating table has been constructed from which estimates of daily discharge have been made. The record of daily gage heights for 1896 for part of January and February and from March 4 to December 26 is given in Water-Supply and Irrigation Paper No. 11, page 66.

*List of discharge measurements made on Rio Grande at Rio Grande, New Mexico.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Feb. 1 | P. E. Harroun | 24 | 4.60 | ..... | 3.11 | 652 |
| Apr. 19 | .....do | 25 | 9.80 | 790 | 6.55 | 5,174 |
| May 11 | .....do | 25 | 8.00 | 725 | 5.86 | 4,249 |
| June 5 | .....do | 25 | 9.10 | 1,141 | 5.86 | 6,689 |
| July 23 | .....do | 25 | 6.60 | 475 | 4.41 | 2,095 |
| Aug. 21 | .....do | 25 | 5.50 | 240 | 3.92 | 933 |
| Sept. 10 | .....do | 25 | 5.10 | 215 | 3.43 | 739 |
| Oct. 24 | .....do | 25 | 4.90 | 237 | 2.23 | 629 |
| Nov. 30 | .....do | 25 | 4.90 | 225 | 2.84 | 639 |
| 1896. | | | | | | |
| Sept. 4 | P. E. Harroun | 26 | 4.10 | 129 | 2.04 | 263 |
| Oct. 21 | .....do | 26 | 4.70 | 180 | 2.22 | 401 |
| Nov. 18 | C. C. Babb | 63 | 5.07 | 191 | 2.58 | 493 |
| Dec. 11 | P. E. Harroun | 26 | 5.10 | 224 | 2.65 | 594 |

*Rating table for the Rio Grande at Rio Grande, New Mexico, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.7 | 210 | 5.3 | 705 | 6.9 | 2,490 | 8.5 | 5,250 |
| 3.8 | 225 | 5.4 | 765 | 7.0 | 2,640 | 8.6 | 5,470 |
| 3.9 | 240 | 5.5 | 840 | 7.1 | 2,790 | 8.7 | 5,700 |
| 4.0 | 255 | 5.6 | 920 | 7.2 | 2,940 | 8.8 | 5,930 |
| 4.1 | 270 | 5.7 | 1,010 | 7.3 | 3,090 | 8.9 | 6,180 |
| 4.2 | 290 | 5.8 | 1,110 | 7.4 | 3,250 | 9.0 | 6,430 |
| 4.3 | 310 | 5.9 | 1,210 | 7.5 | 3,410 | 9.1 | 6,680 |
| 4.4 | 330 | 6.0 | 1,320 | 7.6 | 3,570 | 9.2 | 6,940 |
| 4.5 | 350 | 6.1 | 1,440 | 7.7 | 3,730 | 9.3 | 7,200 |
| 4.6 | 375 | 6.2 | 1,560 | 7.8 | 3,900 | 9.4 | 7,470 |
| 4.7 | 400 | 6.3 | 1,680 | 7.9 | 4,070 | 9.5 | 7,750 |
| 4.8 | 440 | 6.4 | 1,810 | 8.0 | 4,250 | 9.6 | 8,040 |
| 4.9 | 480 | 6.5 | 1,940 | 8.1 | 4,430 | 9.7 | 8,330 |
| 5.0 | 530 | 6.6 | 2,070 | 8.2 | 4,620 | 9.8 | 8,630 |
| 5.1 | 590 | 6.7 | 2,210 | 8.3 | 4,820 | 9.9 | 8,930 |
| 5.2 | 645 | 6.8 | 2,350 | 8.4 | 5,030 | 10.0 | 9,240 |

*Estimated monthly discharge of Rio Grande at Rio Grande, New Mexico, for 1896.*

[Drainage area, 11,250 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | ..... | ..... | *a* 600 | 36,893 | 0.06 | 0.05 |
| February | ..... | ..... | *a* 600 | 34,512 | 0.05 | 0.05 |
| March 4 to 31 | 3,015 | 675 | 1,355 | 75,264 | 0.12 | 0.12 |
| April | 5,140 | 1,810 | 3,483 | 207,253 | 0.35 | 0.31 |
| May | 5,250 | 1,265 | 2,704 | 166,263 | 0.28 | 0.24 |
| June | 1,680 | 255 | 535 | 31,835 | 0.06 | 0.05 |
| July | 920 | 255 | 412 | 25,333 | 0.04 | 0.04 |
| August | 310 | 210 | 243 | 14,942 | 0.02 | 0.02 |
| September | 735 | 255 | 299 | 17,792 | 0.03 | 0.03 |
| October | 617 | 350 | 461 | 28,346 | 0.04 | 0.04 |
| November | 617 | 310 | 498 | 29,633 | 0.04 | 0.04 |
| December | 645 | 330 | 488 | 30,006 | 0.04 | 0.04 |

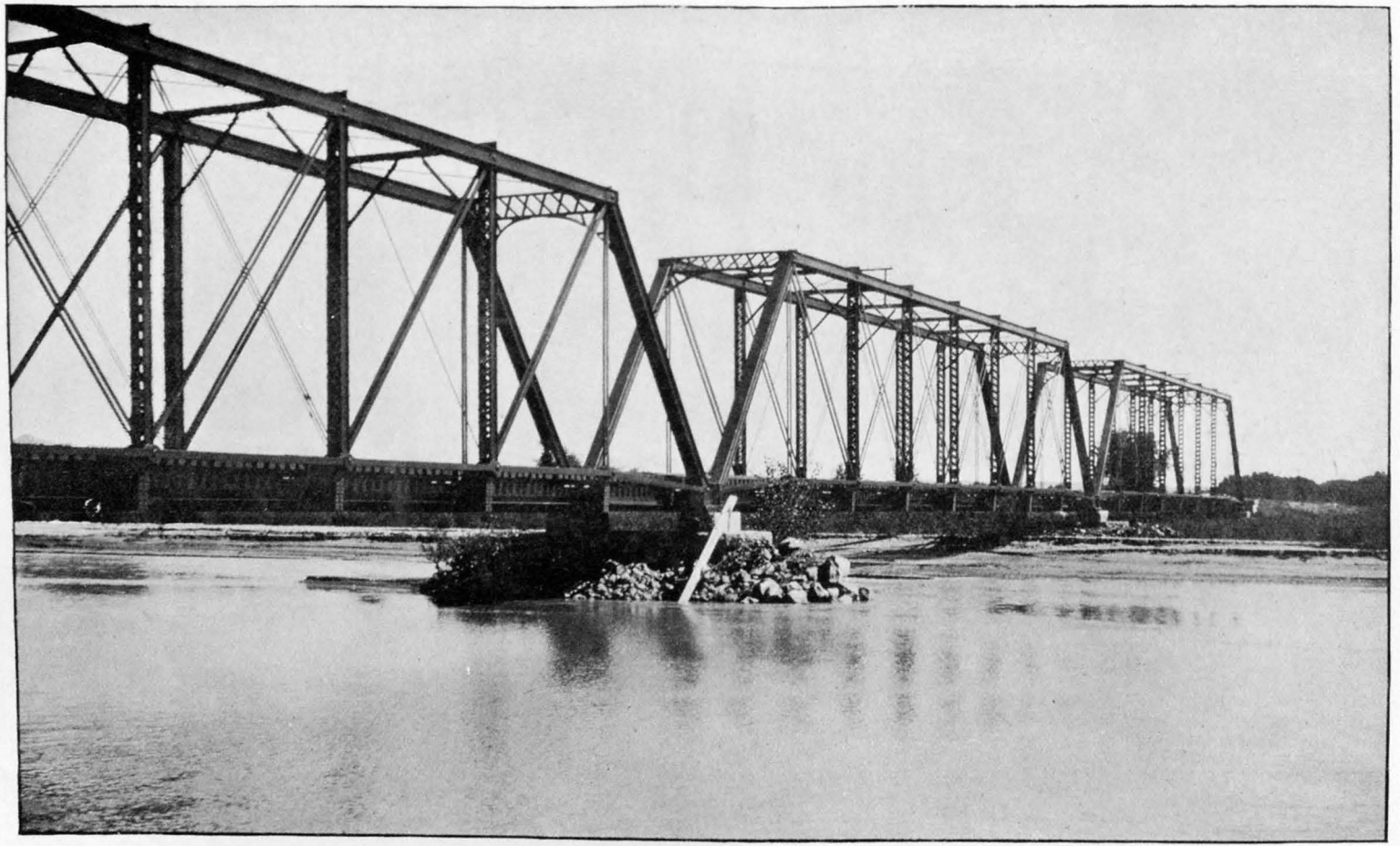
*a* Estimated.

## SAN MARCIAL STATION ON RIO GRANDE.

This station is described in Bulletin No. 140, page 177, and the locality is described in Bulletin No. 131, page 46. The inclined wooden gage was broken off by floating drift, and a wire gage reading from same datum was substituted for it. The observer is H. S. Lohman.

The channel is sandy and shifting.

Eight measurements were made at this point during 1895, one being on the 22d of April, when for a gage height of 9.4 a discharge of 7,800 cubic feet per second was obtained. This was a greater discharge than had occurred previously in that year, and was probably the maximum for the entire year. The discharge for May was lower than for April, reaching a minimum between 2,000 and 3,000 second-feet on the 10th. During June the discharge varied between 2,000 and 5,000 second-feet, while July furnished both a higher maximum and a lower minimum than either May or June. The discharge for August was somewhat similar to that for July, while in September the discharge declined until on the 20th the river was practically dry and remained so for over a week. On the 29th a slight rise occurred, but the discharge remained small throughout October. It gradually increased throughout November, and in December discharged from 500 to 700 cubic feet per second.



SAN MARCIAL GAGING STATION ON THE RIO GRANDE, NEW MEXICO.

Five measurements of discharge were made in 1896, the total quantity of water carried being far less than in the previous year. These measurements, together with six made during the early part of 1897, have been employed for the construction of a rating table from which

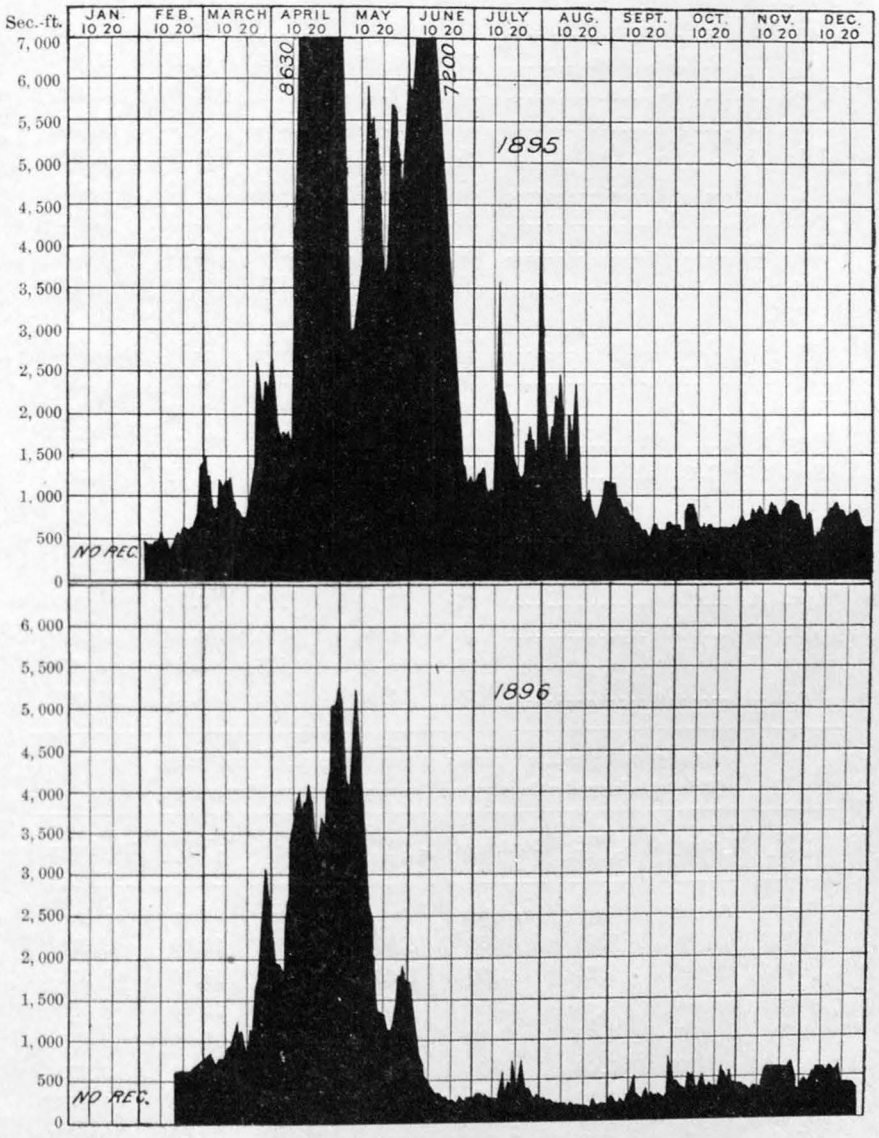



FIG. 36.—Discharge of Rio Grande at Rio Grande, New Mexico, 1895-96.

the discharge of 1896 has been estimated. The record of daily gage heights for 1896, from January 22 to December 26, is given in Water-Supply and Irrigation Paper No. 11, page 66.

*List of discharge measurements made on Rio Grande at San Marcial, New Mexico.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Jan. 29 | A. P. Davis | 24 | 6.40 | | 0.38 | 89 |
| Apr. 22 | P. E. Harroun | 25 | 9.50 | 1,286 | 6.07 | 7,804 |
| May 19 | do | 25 | 7.60 | 630 | 5.49 | 3,458 |
| June 1 | do | 25 | 8.60 | 1,144 | 4.12 | 4,714 |
| July 16 | do | 25 | 6.60 | 630 | 2.38 | 1,503 |
| Sept. 5 | do | 25 | 6.90 | 315 | 1.99 | 626 |
| Oct. 1 | do | 25 | 5.30 | 10 | 1.47 | 15 |
| Nov. 17 | do | 25 | 7.20 | 264 | 2.17 | 674 |
| Dec. 14 | do | 25 | 7.20 | 193 | 3.12 | 602 |
| 1896. | | | | | | |
| Jan. 10 | P. E. Harroun | 25 | 7.40 | 219 | 3.20 | 701 |
| Jan. 22 | do | 25 | 7.50 | 233 | 3.29 | 767 |
| Feb. 14 | do | 25 | 7.30 | 157 | 3.63 | 570 |
| May 28 | do | 25 | 7.00 | 124 | 1.64 | 203 |
| Nov. 23 | C. C. Babb | 63 | 7.10 | 211 | 1.72 | 364 |
| 1897. | | | | | | |
| Feb. 21 | P. E. Harroun | 26 | 7.40 | 165 | 2.08 | 344 |
| Mar. 24 | do | 26 | 7.50 | 192 | 2.49 | 478 |
| Apr. 9 | do | 26 | 7.50 | 212 | 3.77 | 800 |
| Apr. 20 | do | 26 | 8.50 | 664 | 4.77 | 3,165 |
| May 5 | do | 26 | 10.20 | 2,025 | 4.28 | 8,679 |
| May 19 | do | 26 | 10.00 | 1,760 | 5.91 | 10,403 |

*Rating table for Rio Grande at San Marcial, New Mexico.*

[This table is applicable only from January 1, 1896, to May 5, 1897.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 6.40 | 0 | 7.60 | 950 | 8.80 | 4,150 | 10.00 | 8,050 |
| 6.50 | 15 | 7.70 | 1,100 | 8.90 | 4,475 | 10.10 | 8,375 |
| 6.60 | 45 | 7.80 | 1,250 | 9.00 | 4,800 | 10.20 | 8,700 |
| 6.70 | 70 | 7.90 | 1,400 | 9.10 | 5,125 | 10.30 | 9,025 |
| 6.80 | 100 | 8.00 | 1,(00 | 9.20 | 5,450 | 10.40 | 9,350 |
| 6.90 | 150 | 8.10 | 1,900 | 9.30 | 5,775 | 10.50 | 9,675 |
| 7.00 | 240 | 8.20 | 2,200 | 9.40 | 6,100 | 10.60 | 10,000 |
| 7.10 | 350 | 8.30 | 2,525 | 9.50 | 6,425 | 10.70 | 10,325 |
| 7.20 | 460 | 8.40 | 2,850 | 9.60 | 6,750 | 10.80 | 10,650 |
| 7.30 | 580 | 8.50 | 3,175 | 9.70 | 7,075 | 10.90 | 10,975 |
| 7.40 | 700 | 8.60 | 3,500 | 9.80 | 7,400 | 11.00 | 11,300 |
| 7.50 | 820 | 8.70 | 3,825 | 9.90 | 7,725 | | |

*Estimated monthly discharge of Rio Grande at San Marcial, New Mexico.*

[Drainage area, 28,067 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| February | 1,755 | 280 | 986 | 53,760 | 0.04 | 0.04 |
| March | 3,115 | 1,350 | 2,096 | 128,879 | 0.08 | 0.07 |
| April | 7,800 | 2,180 | 4,689 | 279,014 | 0.19 | 0.17 |
| May | 6,265 | 2,095 | 3,625 | 222,892 | 0.15 | 0.13 |
| June | 5,958 | 1,080 | 3,922 | 233,375 | 0.16 | 0.14 |
| July | 7,339 | 960 | 2,431 | 149,476 | 0.10 | 0.09 |
| August | 6,265 | 1,210 | 2,913 | 179,113 | 0.12 | 0.10 |
| 1896. | | | | | | |
| February | 885 | 580 | 680 | 39,114 | 0.02 | 0.02 |
| March | 2,200 | 240 | 679 | 41,750 | 0.02 | 0.02 |
| April | 4,800 | 1,400 | 3,142 | 186,962 | 0.12 | 0.11 |
| May | 4,800 | 195 | 2,019 | 124,143 | 0.08 | 0.07 |
| June | 820 | 0 | 164 | 9,759 | 0.01 | 0.01 |
| July | 4,800 | 0 | 466 | 28,653 | 0.02 | 0.02 |
| August | 820 | 0 | 118 | 7,255 | 0.004 | 0.004 |
| September | 1,500 | 0 | 130 | 7,735 | 0.006 | 0.005 |
| October | 11,300 | 0 | 742 | 45,624 | 0.03 | 0.03 |
| November | 496 | 15 | 209 | 12,444 | 0.01 | 0.01 |
| December | 820 | 460 | 619 | 38,060 | 0.02 | 0.02 |

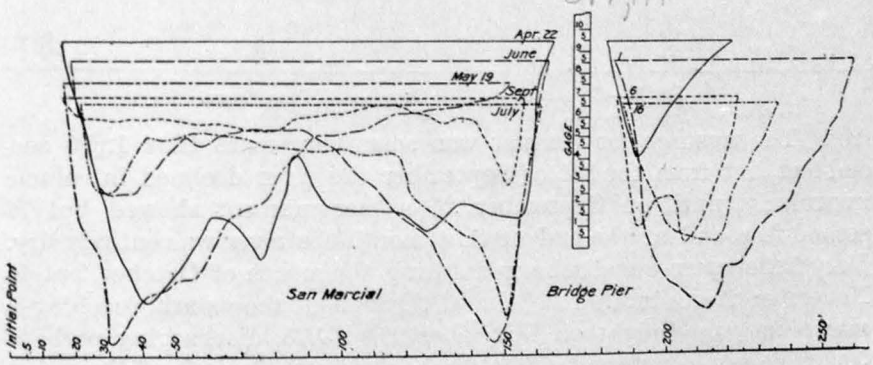



FIG 37.—Cross section of Rio Grande at San Marcial, New Mexico.

## EL PASO STATION ON RIO GRANDE.

This station was described in Bulletin No. 131, page 46. It is located opposite the pumping house of the smelter company, the engineman of which, Mr. C. T. Pelham, is the observer. Measurements are made

from a gaging car suspended from a half-inch steel cable. The gage is an inclined 4 by 6 inch timber, bolted to the solid rock. The bed of the stream here consists entirely of soft mud, constantly changing and shifting, and sufficient satisfactory data have not yet been obtained for constructing a rating curve.

Observations of gage height were begun on January 25, 1895, at which date the gage reading was 6.5 and the discharge 230 cubic feet per second. The reading fluctuated above and below this point during the month of February, and in March reached a maximum of 8.5, discharging considerably more water during March than in February. The discharge during the months of April, May, June, July, and August was in general much greater than in the month of March, but only one measurement of discharge was made, that on July 19, which showed a gage height of 8.15 and a discharge of 1,039 second-

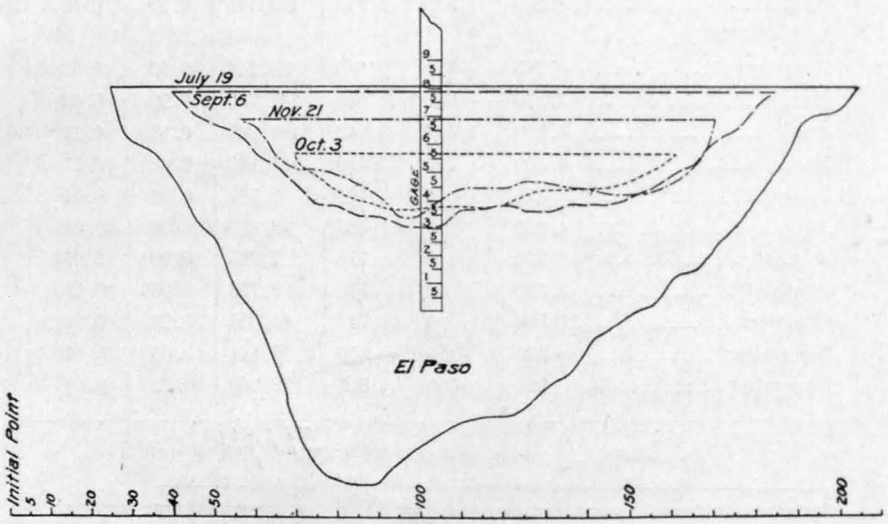
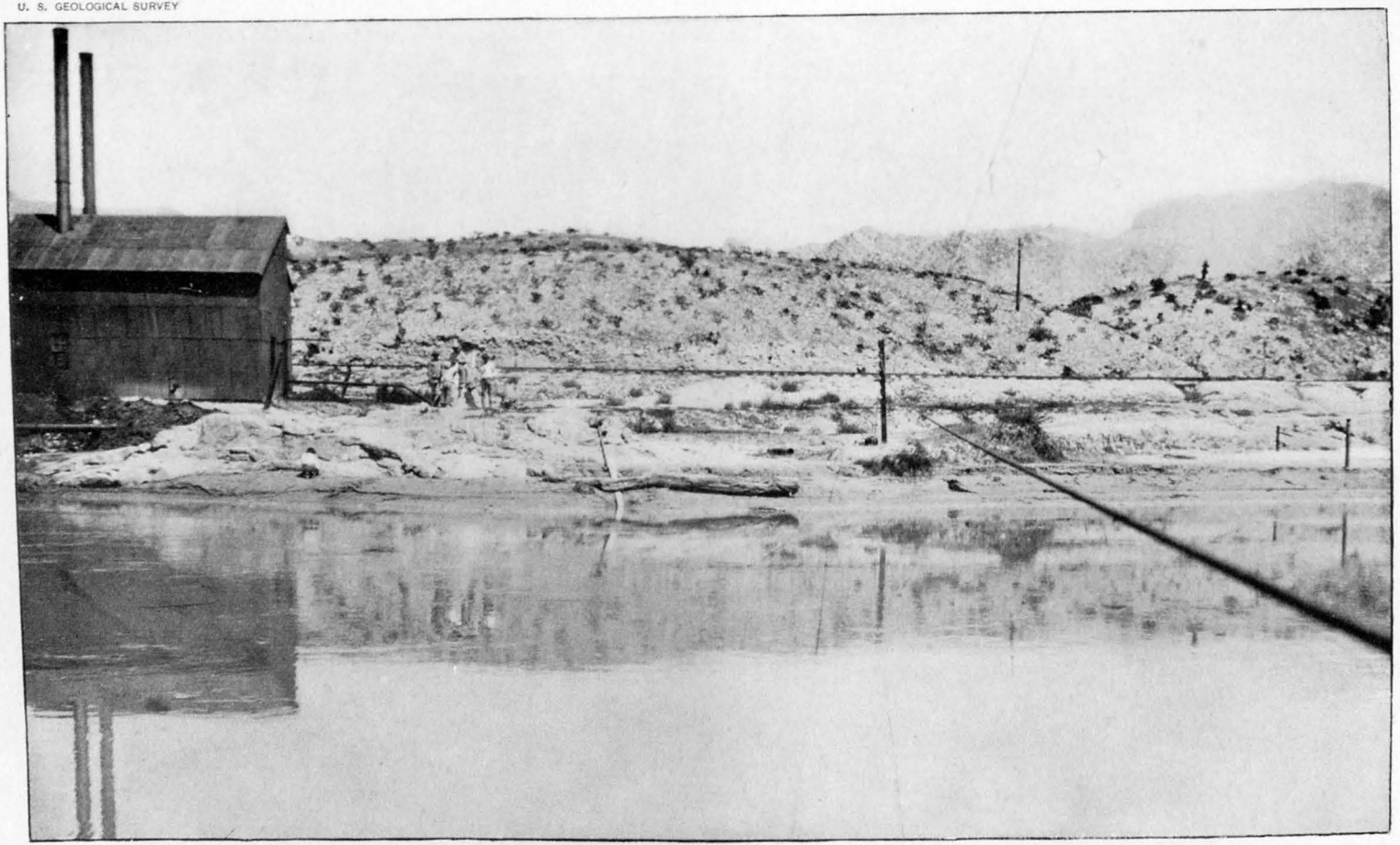



FIG. 38.—Cross section of Rio Grande at El Paso, Texas.

feet. The average for August was something more than 1,000 second-feet, but from the 1st of September the river declined in volume irregularly, until on September 25 a measurement showed but 76 second-feet, and at the end of that month the river was entirely dry. Very little water was discharged during the month of October, but in November it gradually rose almost throughout the month, reaching a maximum gage height on November 29 of 7.75, discharging perhaps 500 cubic feet per second. The discharge for the month of December fluctuated between 200 and 500 cubic feet per second.

Throughout 1896 the readings were continued. During the month of January the minimum gage reading was 5.85 on the 1st of the month, and the maximum 7.60 on January 17. A measurement made January 11, at gage height 6.15, gave a discharge of 150 second-feet. Another



EL PASO GAGING STATION ON THE RIO GRANDE, TEXAS.

measurement on January 23, at a gage reading of 7.30, gave a discharge of 379 second-feet. The range during the month was probably between 100 and 400 second-feet. February maintained a somewhat higher average than this, though the maximum was probably not so great. March was closely comparable with January.

The months of April and May gave the largest run off of any months of the year, with the possible exception of October. In the latter part of May and early June the volume of the river declined steadily, until June 20, when there was practically no running water at the station, which condition continued to the end of the month. A slight rise occurred early in July, but lasted only a few days, and the river was then nearly dry until July 17, when a heavy general rain occurred, raising the water to 8.38 feet on the gage. The river was further swollen on July 24, and then declined until August 24, when it was again dry and remained so most of the time until September 23, when it was again swollen by rain and increased in volume irregularly until the 16th, 17th, and 18th of October, when the greatest discharge of the year occurred, the gage reaching a maximum of 10.6 on October 16, and declining by October 30 to 7.25 feet. During November and December the discharge varied irregularly from about 50 second-feet to about 300.

The total discharge for 1896 was much less than for 1895. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 67.

*List of discharge measurements made on Rio Grande at El Paso, Texas.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Jan. 25 | A. P. Davis | 24 | 6.40 | 265 | 0.87 | 230 |
| July 19 | P. E. Harroun | 25 | 8.10 | 1,433 | 0.71 | 1,039 |
| Sept. 6 | ....do | 25 | 7.90 | 467 | 1.63 | 761 |
| Sept. 21 | A. P. Davis | 55 | 5.70 | 139 | 0.55 | 76 |
| Oct. 3 | P. E. Harroun | 55 | 5.70 | 115 | 0.23 | 26 |
| Nov. 21 | ....do | 55 | 6.90 | 254 | 1.55 | 392 |
| Dec. 4 | A. P. Davis | 61 | 7.50 | ..... | 1.37 | 423 |
| Dec. 16 | P. E. Harroun | 26 | 6.80 | 236 | 1.13 | 266 |
| Dec. 27 | C. C. Babb | 62 | 7.42 | ..... | 1.50 | 386 |
| 1896. | | | | | | |
| Jan. 11 | P. E. Harroun | 62 | 6.20 | 163 | 0.93 | 151 |
| Jan. 23 | ....do | 62 | 7.30 | 231 | 1.64 | 379 |
| Feb. 15 | ....do | 62 | 7.10 | 193 | 1.49 | 282 |
| Nov. 6 | ....do | 62 | 7.70 | 179 | 0.49 | 70 |
| Nov. 25 | C. C. Babb | 63 | 6.31 | 137 | 1.01 | 138 |

## COLORADO BASIN.

Topographically considered, this is the largest hydrographic basin lying wholly within the arid region, having a total area above the town of Yuma, Arizona, of over 225,000 square miles. The river discharges annually a large quantity of water, and supports a comparatively small extent of irrigation, owing to the fact that the main stream and most of its tributaries are situated so far below the level of the irrigable lands as to render their diversion extremely difficult or impracticable.

### GRAND RIVER.

This stream rises in the Rocky Mountain region, its main fork finding its source in Grand County, in northern Colorado. The entire area of its drainage basin above its junction with Green River is 26,167 square miles.

#### GRAND JUNCTION STATION ON GRAND RIVER.

This station is described in Bulletin No. 131, page 48, and in Bulletin No. 140, page 186. It is located at the wagon bridge across the Grand River near the pump house of the city waterworks, Grand Junction, Colorado, and was established on October 18, 1894. The river at this point discharges through two channels. The original gage rod consists of a vertical 4 by 6 inch timber, with 1 by 6 inch scale, bolted to the bridge abutment on right-hand side of the right channel, and is graduated to tenths of a foot. The discharge measurements made during 1894 and 1895 and gage heights to August 22, 1896, refer to this rod. The 12-foot mark is on a level with the top of the bridge abutment. The banks of the right channel are both liable to overflow at very high water; the bed is of sand, and the current very sluggish.

The dam of the city waterworks, just below this gage, went out in June, 1895, and has not been rebuilt. The cross section of the channel has materially changed since that date, and the discharge measurements made in 1894 and 1895 are not applicable for 1896. Gage rod No. 2 consists of a vertical 4 by 6 inch timber, with a 2 by 6 inch scale, bolted to the bridge pier on the right-hand side of the left channel, about 580 feet from rod No. 1. It was placed in position on August 23, 1896, and is graduated to tenths of a foot. It reads 3 feet higher than the old rod.

The right bank of the left channel is low and liable to overflow; the left is high and rocky; the bed is sandy; the water is deep and moves with considerable velocity. At high water it becomes necessary to guy the meter to a wire stretched across the channel above the bridge to prevent it from being swept downstream by the swift current. All discharge measurements in both channels are made from the upper side

of the bridge, but a sufficient number have not been obtained to construct a rating table. The observer is Mr. B. W. Vedder, engineer at the pumping station. The record of daily gage heights for 1896, from April 12 to December 31, are given in Water-Supply and Irrigation Paper No. 11, page 67.

*List of discharge measurements made on Grand River at Grand Junction, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Oct. 18 | A. P. Davis | 22 | 2.10 | 1,450 | 1.10 | 1,585 |
| | 1895. | | | | | | |
| 2 | June 27 | A. P. Davis | 55 | 4.03 | 2,860 | 5.77 | 16,500 |
| 3 | Oct. 1 | do | 61 | 0.82 | 1,009 | 2.04 | 2,059 |
| | 1896. | | | | | | |
| 4 | Aug. 20 | F. Cogswell | 14 | 3.00 | 623 | 1.65 | 1,023 |
| 5 | Sept. 20 | do | 14 | 3.90 | 940 | 1.81 | 1,694 |
| 6 | Oct. 17 | do | 14 | 3.60 | 916 | 1.68 | 1,542 |
| 7 | Nov. 10 | C. C. Babb | 63 | 3.35 | 680 | 2.20 | 1,497 |

## DOLORES STATION ON DOLORES RIVER.

This station was described in Bulletin No. 140, page 191. It is located about one-half mile above the railroad depot at Dolores, Colorado, and was established on June 23, 1895. The gage consists of a vertical 2 by 6 inch plank, bolted to the abutment of a foot bridge, on the left side of the river, and is graduated to tenths of a foot. The bench mark consists of a nail driven in the base of a cottonwood tree 18 feet southwesterly from the gage. It is 1.60 feet above the 14-foot mark.

The right bank is low; the left high; the water moves with good velocity, and the bed of the stream is composed of small stones. In June, 1896, a loose rock dam was built just below the gage, backing up the water from 0.20 to 0.30 of a foot. This dam, although only a temporary expedient to turn water into an irrigation ditch, is, from the nature of its construction, of a somewhat permanent character, and the present relation of discharge to gage height is not liable to change back to that of 1895. It has therefore been necessary to construct two rating tables for the discharge of 1896. Discharge measurements are made from the lower side of the foot bridge, except at a low stage of water, when they are made by wading. The observer is Mrs. Mary D. Smith. The record of daily gage heights for 1896, from March 1 to November 30, is given in Water-Supply and Irrigation Paper No. 11, page 68.

*List of discharge measurements made on Dolores River at Dolores, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 22 | F. Cogswell | 55 | 3.50 | 223 | 3.40 | 756 |
| 2 | Aug. 28 | do | 14 | 2.70 | 81 | 2.00 | 163 |
| 3 | Oct. 9 | do | 14 | 2.50 | 59 | 1.51 | 89 |
| 4 | Nov. 20 | do | 14 | 2.40 | 51 | 1.45 | 75 |
| | 1896. | | | | | | |
| 5 | May 13 | F. Cogswell | 14 | 3.50 | 171 | 3.23 | 553 |
| 6 | May 14 | do | 14 | 3.50 | 171 | 3.42 | 586 |
| 7 | June 17 | do | 14 | 3.00 | 103 | 1.73 | 179 |
| 8 | July 21 | do | 14 | 2.80 | 90 | 1.37 | 124 |
| 9 | Aug. 24 | do | 14 | 2.60 | 31 | 1.37 | 42 |
| 10 | Sept. 23 | do | 14 | 4.80 | 300 | 5.16 | 1,550 |
| 11 | Sept. 24 | do | 14 | 4.15 | 247 | 4.24 | 1,047 |
| 12 | Oct. 21 | do | 14 | 2.75 | 43 | 1.77 | 76 |

*Rating table for Dolores River at Dolores, Colorado.*

[This table is applicable only from January 1, 1896, to June 16, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.00 | 8 | 2.65 | 144 | 3.25 | 429 | 3.85 | 867 |
| 2.05 | 14 | 2.70 | 162 | 3.30 | 458 | 3.90 | 912 |
| 2.10 | 20 | 2.75 | 182 | 3.35 | 491 | 3.95 | 960 |
| 2.15 | 27 | 2.80 | 202 | 3.40 | 524 | 4.00 | 1,008 |
| 2.20 | 34 | 2.85 | 225 | 3.45 | 557 | 4.05 | 1,059 |
| 2.25 | 42 | 2.90 | 248 | 3.50 | 590 | 4.10 | 1,110 |
| 2.30 | 50 | 2.95 | 272 | 3.55 | 626 | 4.15 | 1,164 |
| 2.35 | 60 | 3.00 | 296 | 3.60 | 662 | 4.20 | 1,218 |
| 2.40 | 70 | 3.05 | 321 | 3.65 | 701 | 4.25 | 1,275 |
| 2.45 | 83 | 3.10 | 346 | 3.70 | 740 | 4.30 | 1,332 |
| 2.50 | 96 | 3.15 | 373 | 3.75 | 781 | 4.35 | 1,392 |
| 2.55 | 111 | 3.20 | 400 | 3.80 | 822 | 4.40 | 1,452 |
| 2.60 | 126 | | | | | | |

*Rating table for Dolores River at Dolores, Colorado.*

[This table is applicable only from June 17, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.20 | 8 | 3.10 | 234 | 3.95 | 802 | 4.80 | 1,550 |
| 2.25 | 10 | 3.15 | 264 | 4.00 | 840 | 4.85 | 1,601 |
| 2.30 | 12 | 3.20 | 294 | 4.05 | 880 | 4.90 | 1,652 |
| 2.35 | 15 | 3.25 | 324 | 4.10 | 920 | 4.95 | 1,703 |
| 2.40 | 18 | 3.30 | 354 | 4.15 | 962 | 5.00 | 1,754 |
| 2.45 | 23 | 3.35 | 385 | 4.20 | 1,004 | 5.05 | 1,807 |
| 2.50 | 28 | 3.40 | 416 | 4.25 | 1,047 | 5.10 | 1,860 |
| 2.55 | 36 | 3.45 | 448 | 4.30 | 1,090 | 5.15 | 1,913 |
| 2.60 | 44 | 3.50 | 480 | 4.35 | 1,133 | 5.20 | 1,966 |
| 2.65 | 54 | 3.55 | 513 | 4.40 | 1,176 | 5.25 | 2,021 |
| 2.70 | 64 | 3.60 | 546 | 4.45 | 1,222 | 5.30 | 2,076 |
| 2.75 | 80 | 3.65 | 582 | 4.50 | 1,268 | 5.35 | 2,131 |
| 2.80 | 96 | 3.70 | 618 | 4.55 | 1,314 | 5.40 | 2,186 |
| 2.85 | 114 | 3.75 | 654 | 4.60 | 1,360 | 5.45 | 2,241 |
| 2.90 | 132 | 3.80 | 690 | 4.65 | 1,408 | 5.50 | 2,296 |
| 2.95 | 156 | 3.85 | 727 | 4.70 | 1,456 | 5.55 | 2,351 |
| 3.00 | 180 | 3.90 | 764 | 4.75 | 1,503 | 5.60 | 2,406 |
| 3.05 | 207 | | | | | | |

*Estimated monthly discharge of Dolores River at Dolores, Colorado.*

[Drainage area, 562 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| March | 557 | 96 | 244 | 15,003 | 0.51 | 0.44 |
| April | 1,578 | 144 | 747 | 44,450 | 1.48 | 1.33 |
| May | 1,452 | 373 | 952 | 58,905 | 1.97 | 1.71 |
| June | 781 | 44 | 263 | 15,650 | 0.53 | 0.47 |
| July | 480 | 44 | 130 | 7,994 | 0.26 | 0.23 |
| August | 180 | 8 | 38 | 2,337 | 0.08 | 0.07 |
| September | 1,176 | 28 | 195 | 11,604 | 0.38 | 0.34 |
| October | 180 | 96 | 113 | 6,948 | 0.23 | 0.20 |
| November | 618 | 36 | 179 | 10,651 | 0.36 | 0.32 |

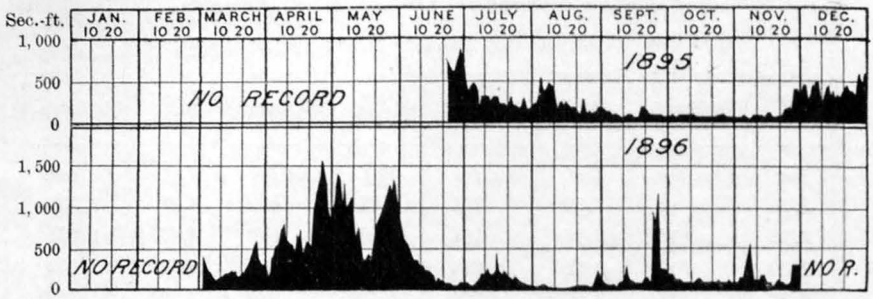



FIG. 39.—Discharge of Dolores River at Dolores, Colorado, 1895–96.

## FALL CREEK STATION ON SAN MIGUEL RIVER.

This station was described in Bulletin No. 140, page 193, under the title of Seymour Station. It was established in June, 1895. The gage is about 300 yards southwest of Fall Creek, a station on the Rio Grande Southern Railroad. Discharge measurements are made from the wagon-road bridge. The gage is vertical, 4 inches by 4 inches, and is spiked to the west side of the north abutment. One bench mark is a bolt-head in the north end of the west truss, 1 foot from the gage. It is 1.15 feet above the 10-foot mark. The second bench mark is a spike driven into a tree 200 feet northwest. This is 1.35 feet below the 10-foot mark. As the channel at this point is nearly straight and the banks are rarely overflowed, the section is a desirable one for measurements. Fall Creek empties into the San Miguel about 200 feet below the gage. The observer is Mrs. Dora Bradley; post-office address, Sawpit, Colorado. The record of daily gage heights for 1896, from April 12 to November 30, is given in Water-Supply and Irrigation Paper No. 11, page 68.

*List of discharge measurements made on San Miguel River at Fall Creek, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 24 | F. Cogswell | 55 | 4.00 | 104 | 4.90 | 512 |
| 2 | Aug. 27 | do | 14 | 3.20 | 66 | 3.08 | 205 |
| 3 | Oct. 8 | do | 14 | 2.65 | 36 | 2.24 | 81 |
| | 1896. | | | | | | |
| 4 | May 12 | F. Cogswell | 14 | 3.75 | 97 | 3.70 | 360 |
| 5 | June 16 | do | 14 | 3.45 | 78 | 3.72 | 290 |
| 6 | July 20 | do | 14 | 3.15 | 62 | 2.82 | 175 |
| 7 | Aug. 23 | do | 14 | 2.60 | 36 | 1.72 | 62 |
| 8 | Sept. 22 | do | 14 | 2.75 | 41 | 2.07 | 85 |
| 9 | Oct. 20 | do | 14 | 2.60 | 35 | 1.80 | 63 |

*Rating table for San Miguel River at Fall Creek, Colorado.*

[This table is applicable from January 1, 1896, to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.20 | 18 | 2.95 | 124 | 3.65 | 332 | 4.35 | 894 |
| 2.25 | 22 | 3.00 | 135 | 3.70 | 344 | 4.40 | 974 |
| 2.30 | 26 | 3.05 | 147 | 3.75 | 360 | 4.45 | 1,069 |
| 2.35 | 31 | 3.10 | 160 | 3.80 | 376 | 4.50 | 1,164 |
| 2.40 | 37 | 3.15 | 181 | 3.85 | 397 | 4.55 | 1,274 |
| 2.45 | 43 | 3.20 | 202 | 3.90 | 418 | 4.60 | 1,384 |
| 2.50 | 49 | 3.25 | 225 | 3.95 | 449 | 4.65 | 1,519 |
| 2.55 | 55 | 3.30 | 248 | 4.00 | 480 | 4.70 | 1,644 |
| 2.60 | 62 | 3.35 | 263 | 4.05 | 531 | 4.75 | 1,784 |
| 2.65 | 69 | 3.40 | 278 | 4.10 | 582 | 4.80 | 1,924 |
| 2.70 | 77 | 3.45 | 289 | 4.15 | 633 | 4.85 | 2,079 |
| 2.75 | 85 | 3.50 | 300 | 4.20 | 684 | 4.90 | 2,234 |
| 2.80 | 93 | 3.55 | 310 | 4.25 | 749 | 4.95 | 2,404 |
| 2.85 | 103 | 3.60 | 320 | 4.30 | 814 | 5.00 | 2,574 |
| 2.90 | 113 | | | | | | |

*Estimated monthly discharge of San Miguel River at Fall Creek, Colorado.*

[Drainage area, 327 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 12 to 30 | 531 | 147 | 281 | 10,583 | 0.60 | 0.86 |
| May | 2,404 | 310 | 770 | 47,345 | 2.72 | 2.36 |
| June | 684 | 135 | 349 | 20,767 | 1.19 | 1.07 |
| July | 320 | 93 | 157 | 9,653 | 0.55 | 0.48 |
| August | 113 | 49 | 65 | 3,997 | 0.22 | 0.20 |
| September | 1,069 | 62 | 176 | 10,472 | 0.60 | 0.54 |
| October | 135 | 49 | 82 | 5,042 | 0.29 | 0.25 |
| November | 147 | 22 | 57 | 3,392 | 0.19 | 0.17 |

## FORT CRAWFORD STATION ON UNCOMPAHGRE RIVER.

This station is described in Bulletin No. 140, page 188. It is located about one-half mile east of the depot, at a wagon bridge, and is about 8 miles above Montrose, being above the head of the Uncompahgre Ditch. It was established June 25, 1895. The gage consists of an

inclined 4 by 4 inch timber, bolted to the bridge, bent on the right-hand side of the stream, marked to vertical tenths of a foot, the space between marks being 0.16 of a foot. The bench mark consists of a spike driven in the base of a cottonwood post, and is 9.18 feet above zero. Both banks are low and liable to overflow at high water, and the bed of the stream is composed of sand and gravel. Stream measurements are made from the upper side of the bridge, except at very low stage of the water, when they are made by wading.

During the high water in the spring of 1896, the channel above the bridge was straightened out, and the bed of the river filled in near the gage, making a notable change in the cross section of the river, the relation of gage height to discharge during 1896 being materially different from that of 1895. The observer is Mrs. F. Humphrey; post-office, Uncompahgre, Colorado. The record of daily gage heights for 1896, from May 1 to November 30, is given in Water-Supply and Irrigation Paper No. 11, page 69.

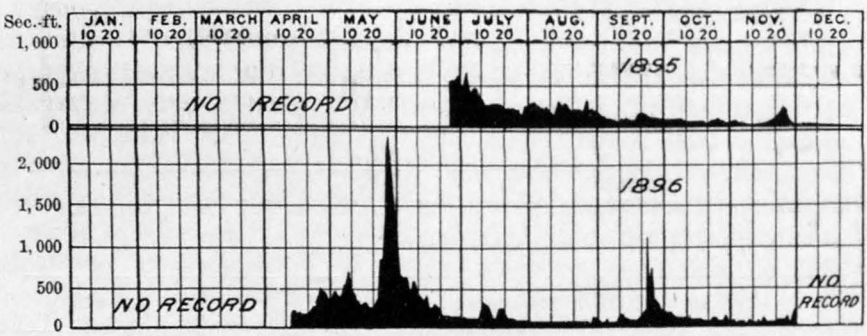



FIG. 40.—Discharge of San Miguel River at Fall Creek, Colorado, 1895-96.

*List of discharge measurements made on Uncompahgre River at Fort Crawford, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 25 | F. Cogswell | 55 | 4.60 | 123 | 6.80 | 834 |
| 2 | Aug. 26 | do | 14 | 3.25 | 64 | 3.38 | 218 |
| 3 | Oct. 7 | do | 14 | 2.60 | 43 | 2.05 | 89 |
| 4 | Nov. 18 | do | 14 | 2.55 | 41 | 2.23 | 92 |
| | 1896. | | | | | | |
| 5 | May 11 | F. Cogswell | 14 | 4.30 | 120 | 4.75 | 568 |
| 6 | June 15 | do | 14 | 4.10 | 117 | 4.78 | 560 |
| 7 | July 18 | do | 14 | 3.50 | 74 | 2.76 | 204 |
| 8 | Aug. 21 | do | 14 | 2.90 | 18 | 1.72 | 31 |
| 9 | Sept. 21 | do | 14 | 3.25 | 57 | 2.14 | 122 |
| 10 | Oct. 18 | do | 14 | 3.10 | 55 | 1.73 | 95 |

*Rating table for Uncompahgre River at Fort Crawford, Colorado.*

[This table is applicable from January 1, 1896, to December 31, 1896.]

| Gage heights. | Discharge. | Gage heights. | Discharge. | Gage heights. | Discharge. | Gage heights. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.70 | 10 | 3.45 | 190 | 4.15 | 530 | 4.85 | 1,570 |
| 2.75 | 11 | 3.50 | 207 | 4.20 | 568 | 4.90 | 1,680 |
| 2.80 | 13 | 3.55 | 224 | 4.25 | 615 | 4.95 | 1,800 |
| 2.85 | 24 | 3.60 | 242 | 4.30 | 662 | 5.00 | 1,920 |
| 2.90 | 37 | 3.65 | 262 | 4.35 | 721 | 5.05 | 2,055 |
| 2.95 | 49 | 3.70 | 282 | 4.40 | 780 | 5.10 | 2,190 |
| 3.00 | 62 | 3.75 | 303 | 4.45 | 850 | 5.15 | 2,340 |
| 3.05 | 75 | 3.80 | 324 | 4.50 | 920 | 5.20 | 2,490 |
| 3.10 | 88 | 3.85 | 348 | 4.55 | 1,000 | 5.25 | 2,655 |
| 3.15 | 101 | 3.90 | 372 | 4.60 | 1,080 | 5.30 | 2,820 |
| 3.20 | 115 | 3.95 | 399 | 4.65 | 1,170 | 5.35 | 3,000 |
| 3.25 | 129 | 4.00 | 426 | 4.70 | 1,260 | 5.40 | 3,180 |
| 3.30 | 143 | 4.05 | 459 | 4.75 | 1,360 | 5.45 | 3,375 |
| 3.35 | 158 | 4.10 | 492 | 4.80 | 1,460 | 5.50 | 3,570 |
| 3.40 | 174 | | | | | | |

*Estimated monthly discharge of Uncompahgre River at Fort Crawford, Colorado.*

[Drainage area, 497 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| May | 3,375 | 207 | 1,010 | 62,103 | 2.34 | 2.03 |
| June | 1,920 | 190 | 519 | 30,883 | 1.16 | 1.04 |
| July | 207 | 62 | 126 | 7,748 | 0.29 | 0.25 |
| August | 115 | 10 | 38 | 2,337 | 0.09 | 0.08 |
| September | 426 | 62 | 148 | 8,806 | 0.33 | 0.30 |
| October | 174 | 62 | 106 | 6,518 | 0.24 | 0.21 |
| November | 115 | 62 | 86 | 5,117 | 0.19 | 0.17 |

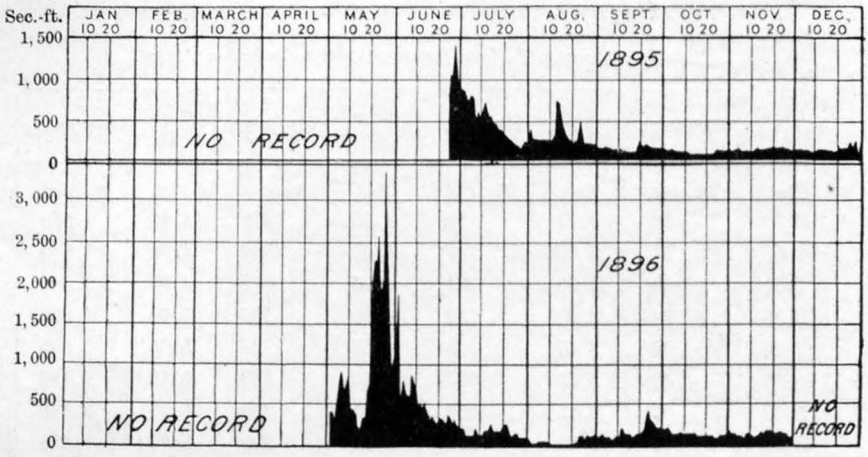



FIG. 41.—Discharge of Uncompahgre River at Fort Crawford, Colorado, 1895–96.

## GREEN RIVER.[1]

Green River rises in the Wind River range of mountains, in the western central portion of Wyoming, its main source being in the lofty peaks of the Continental Divide, where is conserved in the greatest quantity the winter's snow, the slow melting of which keeps the flow of this stream at a greater volume for a longer period each year than most of the other large streams of the State. Its western tributaries, also, having their rise in a high and mountainous country, materially contribute to this feature.

Although this stream is in volume and drainage the third largest stream in the State, yet there is less irrigation development, fewer ditches, and less utilization of its waters than along any other important stream in the State. This is not due to any absence of irrigable land along its course, but to the fact that practically all the irrigable land tributary to this stream in any considerable tracts lies at such an elevation above the ordinary water level as to render the construction of ditches of the length required to bring these lands under irrigation too expensive for individual effort.

There are, however, tributary to Green River sufficiently large areas of valuable land, which will ultimately be brought under irrigation, to render the maintenance of this station and the resulting ascertainment of the volume and discharge of the stream of great importance. There is now on file in the office of the State engineer of Wyoming an application for permit for a system of canals for the reclamation of some 20,000 acres of these bench lands; and others are certain to follow the successful prosecution of this one.

### GRANGER STATION ON BLACKS FORK.

This station is located near the Union Pacific Railroad bridge 3 miles west of Granger, Wyoming, the junction of the Union Pacific

[1] From description furnished by Prof. Elwood Mead, State engineer, cooperating with the Division of Hydrography.

and Oregon Short Line railways. The stream is so crooked and varies so greatly in width and grade that a desirable location for a station is hard to find. The point chosen is about 300 feet above the bridge. Here the banks are high enough to confine the channel during high water of ordinary years, and there is as long a stretch of straight channel as can be found anywhere within reasonable distance of an observer of gage heights.

In making the gaging a stout cotton cord was stretched from bank to bank, every 10 feet in distance on this cord being marked by a tag. The first measurement was made with floats, it being found impossible to use a meter because of the ice which was floating in the stream and the severe cold, which caused the meter to freeze whenever taken out of the water. Subsequent to this time all the measurements were made with a Gurley acoustic meter No. 104. When the stream was too high to permit of wading, the meter was used from an Acme folding boat attached to a cord stretched across the stream. The measurements at low stages were made by the observer standing in the water, holding the meter a sufficient distance from him to avoid any disturbance in the current. The measurement made July 7 had to be completed with floats, owing to an accident to the meter. An attempt to measure this stream June 1 failed, owing to the unusual high water of this year. Persons familiar with the stream for the past twenty years say that the stream was higher the present season than ever before in that period.

Owing to there being no way of protecting the rod at high water, it could not be placed at the point where gagings were made, the danger from floating timbers being too great. It was, therefore, fastened to the center pier of the railroad bridge, 300 feet below. This location has the further advantage of enabling the observer, Mr. Henry Lingelbach, to take daily readings without interfering with his work, he being section foreman on the railroad.

This bridge rests on three piers, one in the center of the channel and one at each shore. The bridge is elevated considerably above the banks on either side and the track approaches on a long, high fill on either side. The only increase in cross section at this point during high water is that due to depth alone, the side piers with the abutting earthen fill making the width for all depths uniform. Above and below the bridge extreme high water is accompanied by marked increase in width of channel. The banks being both low and sloping, the width at high water is three or four times that of mean discharge. As a result, there is a marked contraction in cross section at the bridge in high water, and this year it caused the water to back up and create eddies above the bridge. The backwater and eddies extended up to the gaging station at extreme high water and prevented any accurate determination of the discharge at that time. From tests made it was concluded that the mean velocity at high water did not exceed 5 cubic feet per second. Later in the season a profile was made of the channel at the

point where measured, and this cross section, multiplied by 5, was taken as the maximum discharge. This is, of course, only an approximation, but it is believed to be reasonably near the truth. It produces a reverse discharge curve, but this is the result to be expected from the contraction in the channel and consequent obstruction to the streams discharged.

The accompanying photograph shows the location of the gage rod. Its bench mark is a cross cut in the top stone on the north end of the pier, to which the rod is fastened, and is 4.63 feet above the 10-foot mark on the rod. The record of daily gage heights for 1896, from April 18 to December 26, is given in Water-Supply and Irrigation Paper No. 11.

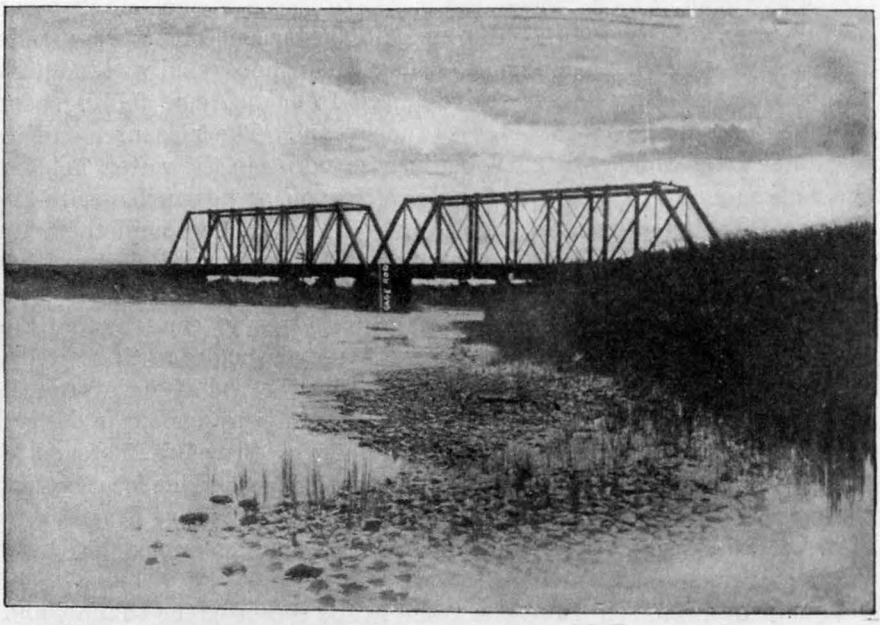


FIG. 42.—Gaging station on Blacks Fork near Granger, Wyoming.

*List of discharge measurements made on Blacks Fork River at Granger, Wyoming, 1896.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Apr. 18 | E. Mead..... | Float. | 3.00 | 162 | 2.56 | 339 |
| May 7 | W. M. Gilcrest..... | 104 | 5.10 | 337 | 3.32 | 1,140 |
| June 21 | .....do ..... | 104 | 4.90 | 309 | 3.24 | 1,069 |
| July 7 | .....do ..... | 104 | 2.60 | 92 | 3.12 | 302 |
| Aug. 2 | .....do ..... | 104 | 2.40 | 51 | 0.78 | 134 |
| Aug. 18 | .....do ..... | 104 | 2.80 | 94 | 2.33 | 260 |
| Sept. 30 | C. T. Johnston ..... | 104 | 1.80 | 33 | 3.30 | 108 |

*Rating table for Blacks Fork River near Granger, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.40 | 10 | 3.70 | 540 | 6.00 | 1,730 | 8.30 | 2,390 |
| 1.50 | 20 | 3.80 | 570 | 6.10 | 1,775 | 8.40 | 2,405 |
| 1.60 | 30 | 3.90 | 610 | 6.20 | 1,815 | 8.50 | 2,420 |
| 1.70 | 45 | 4.00 | 650 | 6.30 | 1,855 | 8.60 | 2,440 |
| 1 80 | 65 | 4.10 | 700 | 6.40 | 1,895 | 8.70 | 2,460 |
| 1.90 | 85 | 4.20 | 745 | 6.50 | 1,930 | 8.80 | 2,475 |
| 2.00 | 110 | 4.30 | 790 | 6.60 | 1,965 | 8.90 | 2,490 |
| 2.10 | 125 | 4.40 | 830 | 6.70 | 2,000 | 9.00 | 2,505 |
| 2.20 | 140 | 4.50 | 880 | 6.80 | 2,030 | 9.10 | 2,520 |
| 2.30 | 160 | 4.60 | 930 | 6.90 | 2,060 | 9.20 | 2,535 |
| 2.40 | 175 | 4.70 | 980 | 7.00 | 2,095 | 9.30 | 2,548 |
| 2.50 | 195 | 4.80 | 1,040 | 7.10 | 2,125 | 9.40 | 2,560 |
| 2.60 | 215 | 4.90 | 1,095 | 7.20 | 2,155 | 9.50 | 2,575 |
| 2.70 | 240 | 5.00 | 1,155 | 7.30 | 2,175 | 9.60 | 2,590 |
| 2.80 | 260 | 5.10 | 1,220 | 7.40 | 2,200 | 9.70 | 2,605 |
| 2.90 | 285 | 5.20 | 1,300 | 7.50 | 2,225 | 9.80 | 2,615 |
| 3.00 | 315 | 5.30 | 1,360 | 7.60 | 2,250 | 9.90 | 2,625 |
| 3.10 | 340 | 5.40 | 1,430 | 7.70 | 2,270 | 10.00 | 2,640 |
| 3.20 | 365 | 5.50 | 1,500 | 7.80 | 2,290 | 10.10 | 2,650 |
| 3.30 | 390 | 5.60 | 1,550 | 7.90 | 2,310 | 10.20 | 2,665 |
| 3.40 | 425 | 5.70 | 1,600 | 8.00 | 2,335 | 10.30 | 2,675 |
| 3.50 | 460 | 5.80 | 1,650 | 8.10 | 2,350 | 10.40 | 2,685 |
| 3.60 | 500 | 5.90 | 1,690 | 8.20 | 2,370 | 10.50 | 2,695 |

*Estimated monthly discharge of Blacks Fork River at Granger, Wyoming.*

[Drainage area, 1,747 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 19 to 30 | 460 | 215 | 377 | 8,976 | 0.10 | 0.22 |
| May | 2,405 | 365 | 996 | 61,242 | 0.66 | 0.57 |
| June | 2,675 | 425 | 1,562 | 92,945 | 0.99 | 0.89 |
| July | 390 | 175 | 275 | 16,909 | 0.18 | 0.16 |
| August | 1,360 | 20 | 301 | 18,507 | 0.21 | 0.17 |
| September | 610 | 20 | 100 | 5,950 | 0.07 | 0.06 |
| October | 110 | 45 | 56 | 3,443 | 0.03 | 0.03 |
| November | 285 | 85 | 168 | 9,997 | 0.10 | 0.09 |
| December | 285 | 285 | 285 | 17,523 | 0.18 | 0.16 |

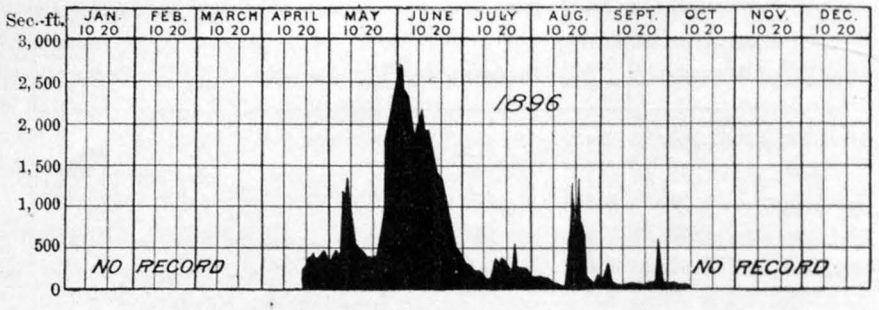



FIG. 43.—Discharge of Blacks Fork near Granger, Wyoming, 1896.

## GREENRIVER STATION ON GREEN RIVER.

This station, described in Bulletin No. 140, page 200, is located at Greenriver City, the permanent rod being set near the east end of the railway bridge at the pump house belonging to the railroad company. The rod is fixed at the same point at which the State engineer formerly had one located. The engineman in charge of the pumping station, Mr. William Slater, was employed to act as observer, and being always on duty from 7 o'clock a. m. to 7 p. m., it is possible to have readings of the rod each day at the same hours, morning and evening. An island dividing the stream into two channels at this point, and the channels being also obstructed by remnants of old piers of a former bridge, it was not possible to utilize the present bridge as a place from which to make meter measurements. During the season of 1895 a ferryboat, located about 1 mile below the gage rod, was advantageously utilized as a place from which to make the stream measurements. The bottom of the channel at this point is composed of small cobblestones and gravel, and the channel has the advantage of preserving at all times a very uniform and stable cross section, and as long as the ferry was operated it afforded a certain means of obtaining a measurement at any stage of the water. It is to be regretted, however, that an accident to the ferryboat prevented the possibility of using it this year at the time of highest water. Resort was therefore had to the ferry cable. A swinging cage was constructed and an attempt made to get a gaging by this means, but upon trial it was found that the weight depressed the cable so much that the cage would be submerged before reaching a point 100 feet from shore. Attempts were then made to carry a line across with a small boat, but proved futile, owing to the tremendous current and the great amount of drift débris being carried. It therefore became necessary to resort to floats to obtain the measurements for June 19 and July 7. That on June 19 was made at the railroad bridge, and, owing to the above-mentioned character of the channel at that point, can not be regarded as being entirely satisfactory.

The gaging on July 7 was made at the ferry, the water having fallen sufficiently to enable the swinging cage to be used on the cable. The

floats used at this time were bottles, which were filled sufficiently to cause them to assume an upright position, leaving the neck only projecting above the water. The surface of the water being smooth and the day calm, this measurement may be regarded as quite satisfactory. All other measurements were made with the current meter.

If this station is to be maintained another year, the difficulties encountered this season will not be met with, as a new wagon bridge has just been completed, which spans the river a short distance above the ferry, where very nearly the same character of channel exists; and with a proper arrangement this can be utilized for all future measurements, as from it the river can be satisfactorily gaged at all times and at any stage of the water. In establishing the station at Greenriver City regard was had to its convenience of access, it being situated on

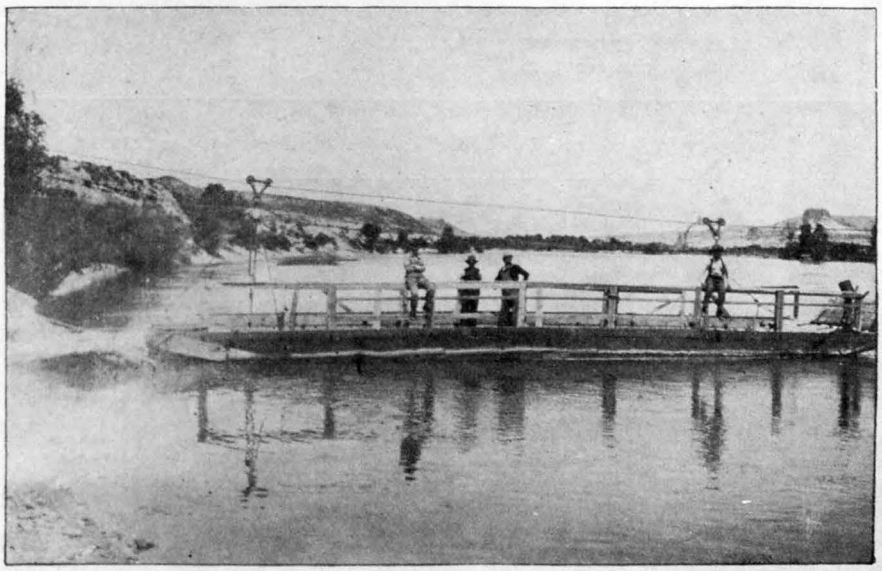


FIG. 44.—Ferry on Green River at Greenriver City, Wyoming.

the line of the Union Pacific Railway. The point is also important, as it is below all tributaries in Wyoming save one—Blacks Fork—and upon the latter stream a station is also maintained.

Green River after passing this point enters a broken bad-land country, with little or no irrigable land along its course in Wyoming. The discharge measurements obtained at this point therefore represent solely the surplus and waste water of the stream as it leaves this State. The bench mark consists of a cross on the third step from the bottom on the south end of east abutment, 5.48 feet above the 7-foot mark on the gage rod. The record of daily gage heights for 1896, from April 9 to October 15 and from December 1 to 27, is given in Water-Supply and Irrigation Paper No. 11, page 70.

*List of discharge measurements made on Green River at Greenriver City, Wyoming.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| June 20 | W. M. Gilcrest..... | Colo. | 3.30 | 1,129 | 3.43 | 3,866 |
| July 2 | .....do ..... | ..... | 4.25 | 1,762 | 3.97 | 7,011 |
| Oct. 22 | .....do ..... | ..... | 1.15 | 306 | 1.36 | 418 |
| 1896. | | | | | | |
| May 9 | W. M. Gilcrest..... | 104 | 2.27 | 794 | 2.52 | 2,095 |
| June 19 | .....do ..... | Floats. | 6.05 | 2,618 | 5.63 | 14,731 |
| July 7 | .....do ..... | Floats. | 3.60 | 1,455 | 3.30 | 4,805 |
| Aug. 8 | .....do ..... | Floats. | 2.55 | 942 | 2.49 | 2,450 |
| Aug. 17 | .....do ..... | 104 | 1.70 | 528 | 1.87 | 1,067 |
| Sept. 30 | C. T. Johnston..... | 104 | 1.30 | 375 | 2.41 | 920 |

*Rating table for Green River at Greenriver City, Wyoming, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 240 | 1.60 | 1,000 | 3.20 | 3,740 | 4.80 | 9,320 |
| 0.10 | 260 | 1.70 | 1,070 | 3.30 | 3,960 | 4.90 | 9,800 |
| 0.20 | 300 | 1.80 | 1,160 | 3.40 | 4,200 | 5.00 | 10,220 |
| 0.30 | 330 | 1.90 | 1,280 | 3.50 | 4,440 | 5.10 | 10,660 |
| 0.40 | 370 | 2.00 | 1,400 | 3.60 | 4,700 | 5.20 | 11,100 |
| 0.50 | 400 | 2.10 | 1,580 | 3.70 | 5,000 | 5.30 | 11,540 |
| 0.60 | 450 | 2.20 | 1,760 | 3.80 | 5,260 | 5.40 | 12,000 |
| 0.70 | 500 | 2.30 | 1,950 | 3.90 | 5,580 | 5.50 | 12,440 |
| 0.80 | 550 | 2.40 | 2,160 | 4.00 | 5,940 | 5.60 | 12,860 |
| 0.90 | 620 | 2.50 | 2,400 | 4.10 | 6,300 | 5.70 | 13,300 |
| 1.00 | 650 | 2.60 | 2,550 | 4.20 | 6,700 | 5.80 | 13,700 |
| 1.10 | 700 | 2.70 | 2,730 | 4.30 | 7,100 | 5.90 | 14,150 |
| 1.20 | 750 | 2.80 | 2,840 | 4.40 | 7,540 | 6.00 | 14,580 |
| 1.30 | 800 | 2.90 | 3,120 | 4.50 | 8,000 | 6.10 | 15,000 |
| 1.40 | 860 | 3.00 | 3,320 | 4.60 | 8,440 | 6.20 | 15,460 |
| 1.50 | 930 | 3.10 | 3,520 | 4.70 | 8,900 | | |

*Estimated monthly discharge of Green River at Greenriver City, Wyoming.*

[Drainage area, 7,450 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 9 to 30 | 1,049 | 930 | 1,020 | 44,506 | 0.12 | 0.14 |
| May | 6,980 | 1,220 | 2,136 | 131,337 | 0.33 | 0.29 |
| June | 15,460 | 7,540 | 11,769 | 700,303 | 1.76 | 1.58 |
| July | 6,380 | 2,430 | 4,198 | 258,127 | 0.64 | 0.56 |
| August | 2,505 | 979 | 1,470 | 90,387 | 0.23 | 0.20 |
| September | 1,035 | 750 | 869 | 51,709 | 0.13 | 0.12 |
| October 1 to 15 | 800 | 700 | 745 | 22,170 | 0.06 | 0.10 |
| November | ..... | ..... | *800 | 47,603 | 0.12 | 0.11 |
| December | 1,160 | 1,000 | 1,080 | 66,407 | 0.17 | 0.15 |

* Estimated.

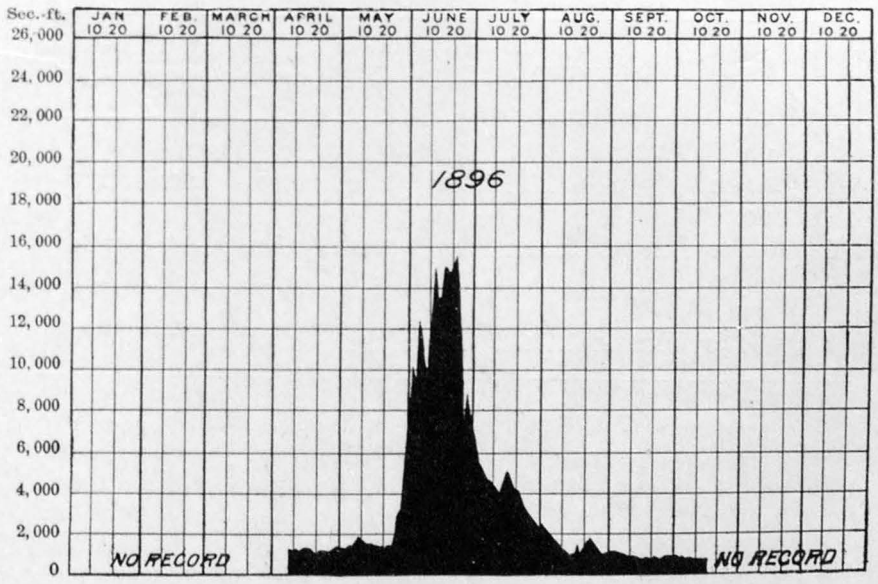



FIG. 45.—Discharge of Green River at Greenriver City, Wyoming, 1896

## BLAKE STATION ON GREEN RIVER.

This station is described in Bulletin 140, page 202. It is located at the crossing of the Rio Grande Western Railroad at Blake, Utah, in latitude 39°, longitude 110° 9′, in the San Rafael quadrangle. The station was established on October 21, 1894. Observations have been continued through 1896, and sufficient discharge measurements have

been made to warrant the construction of a rating table, applicable for 1894, 1895, and 1896.

When the station was visited in November, 1896, it was found that the inclined rod had been partially carried away during the high water. The observer was reading from a temporary rod, but so placed that the data of the two rods coincided. The elevation of the top of the pier is 22 feet above the zero of the inclined gage. On November 9 a wire gage was placed on the bridge. It is nailed to the guard rail on the lower side. The distance from the end of the rod to the outside edge of the pulley wheel is 1 foot; from the end of the weight to the wire index marker, 27.67 feet. The readings of the two gages were made to coincide. The observer is Mr. Frank Jacobs, engineman of the pumping station located at the end of the bridge. November 9, 1896, a measurement was made by Mr. Cyrus C. Babb, showing a gage height of 2.33 feet, area 1,416 square feet, mean velocity 1.37, and a discharge of 1,940 second-feet. The record of daily gage heights for 1896, from January 1 to November 28, is given in Water-Supply and Irrigation Paper No. 11, page 70.

*List of discharge measurements made on Green River at Blake, Utah.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet.) |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Oct. 21 | A. P. Davis..... | 22 | 2.48 | 1,660 | 1.83 | 3,035 |
| | 1895. | | | | | | |
| 2 | June 30 | .....do ..... | 55 | 5.80 | 3,397 | 4.43 | 15,065 |
| 3 | Sept. 29 | .....do ..... | 55 | 2.00 | 1,423 | 1.40 | 1,938 |
| | 1896. | | | | | | |
| 4 | Nov. 9 | C. C. Babb..... | 63 | 2.33 | 1,416 | 1.37 | 1,940 |

*Rating table for Green River at Blake, Utah, for 1894, 1895, and 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet* | *Sec. feet.* | *Feet* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.40 | 1,000 | 3.40 | 6,340 | 5.40 | 13,540 | 7.40 | 20,740 |
| 1.50 | 1,100 | 3.50 | 6,700 | 5.50 | 13,900 | 7.50 | 21,100 |
| 1.60 | 1,200 | 3.60 | 7,060 | 5.60 | 14,260 | 7.60 | 21,460 |
| 1.70 | 1,300 | 3.70 | 7,420 | 5.70 | 14,620 | 7.70 | 21,820 |
| 1.80 | 1,420 | 3.80 | 7,780 | 5.80 | 14,980 | 7.80 | 22,180 |
| 1.90 | 1,560 | 3.90 | 8,140 | 5.90 | 15,340 | 7.90 | 22,540 |
| 2.00 | 1,700 | 4.00 | 8,500 | 6.00 | 15,700 | 8.00 | 22,900 |
| 2.10 | 1,900 | 4.10 | 8,860 | 6.10 | 16,060 | 8.10 | 23,260 |
| 2.20 | 2,100 | 4.20 | 9,220 | 6.20 | 16,420 | 8.20 | 23,620 |
| 2.30 | 2,400 | 4.30 | 9,580 | 6.30 | 16,780 | 8.30 | 23,980 |
| 2.40 | 2,750 | 4.40 | 9,940 | 6.40 | 17,140 | 8.40 | 24,340 |
| 2.50 | 3,100 | 4.50 | 10,300 | 6.50 | 17,500 | 8.50 | 24,700 |
| 2.60 | 3,460 | 4.60 | 10,660 | 6.60 | 17,860 | 8.60 | 25,060 |
| 2.70 | 3,820 | 4.70 | 11,020 | 6.70 | 18,220 | 8.70 | 25,420 |
| 2.80 | 4,180 | 4.80 | 11,380 | 6.80 | 18,580 | 8.80 | 25,780 |
| 2.90 | 4,540 | 4.90 | 11,740 | 6.90 | 18,940 | 8.90 | 26,140 |
| 3.00 | 4,900 | 5.00 | 12,100 | 7.00 | 19,300 | 9.00 | 26,500 |
| 3.10 | 5,260 | 5.10 | 12,460 | 7.10 | 19,660 | | |
| 3.20 | 5,620 | 5.20 | 12,820 | 7.20 | 20,020 | | |
| 3.30 | 5,980 | 5.30 | 13,180 | 7.30 | 20,380 | | |

*Estimated monthly discharge of Green River at Blake, Utah.*

[Drainage area, 38,200 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 1,560 | 1,100 | 1,272 | 78,212 | 0.03 | 0.03 |
| February | 1,420 | 1,100 | 1,194 | 68,650 | 0.03 | 0.03 |
| March | 8,500 | 1,420 | 4,098 | 251,976 | 0.13 | 0.11 |
| April | 17,140 | 5,980 | 10,012 | 595,755 | 0.29 | 0.26 |
| May | 21,460 | 15,340 | 19,242 | 1,183,143 | 0.58 | 0.50 |
| June | 19,300 | 12,820 | 15,760 | 937,784 | 0.46 | 0.41 |
| July | 16,420 | 7,780 | 12,263 | 754,023 | 0.37 | 0.32 |
| August | 7,780 | 2,750 | 5,203 | 319,920 | 0.16 | 0.14 |
| September | 2,750 | 1,420 | 1,995 | 118,711 | 0.05 | 0.05 |
| October | 3,820 | 1,700 | 2,537 | 155,994 | 0.08 | 0.07 |
| November | 2,100 | 610 | 1,648 | 98,063 | 0.04 | 0.04 |
| December | 1,420 | 670 | 1,237 | 76,060 | 0.03 | 0.03 |
| Year | 21,460 | 610 | 6,372 | 4,638,291 | 2.25 | 0.17 |
| 1896. | | | | | | |
| January | 1,560 | 1,100 | 1,290 | 79,319 | 0.03 | 0.03 |
| February | 1,560 | 1,100 | 1,339 | 67,019 | 0.04 | 0.04 |
| March | 7,420 | 1,420 | 3,455 | 212,440 | 0.10 | 0.09 |
| April | 16,060 | 4,540 | 7,648 | 455,087 | 0.22 | 0.20 |
| May | 24,340 | 11,020 | 15,932 | 1,009,620 | 0.48 | 0.42 |
| June | 28,950 | 16,420 | 23,539 | 1,404,666 | 0.69 | 0.62 |
| July | 15,700 | 9,220 | 11,264 | 692,596 | 0.35 | 0.30 |
| August | 9,940 | 3,100 | 6,050 | 372,000 | 0.18 | 0.16 |
| September | 14,260 | 2,750 | 5,464 | 325,130 | 0.16 | 0.14 |
| October | 5,620 | 2,750 | 3,705 | 227,811 | 0.12 | 0.10 |
| November | 3,820 | 1,900 | 2,756 | 164,104 | 0.08 | 0.07 |
| December | 1,900 | 1,420 | 1,619 | 99,548 | 0.04 | 0.04 |
| Per annum | 28,950 | 1,100 | 7,005 | 5,109,340 | 2.49 | 0.18 |

## SAN JUAN RIVER.

This stream drains a very mountainous portion of southern Colorado, its principal tributaries flowing southerly across the Colorado line into northern New Mexico. It enters the Colorado River above Marble Canyon, near Navajo Mountain, in southern Utah. A more detailed description of its course and tributaries may be found in Bulletin 140, page 195.

ARBOLES STATION ON SAN JUAN RIVER.

This station is described in Bulletin No. 140, page 195. It is located at a foot bridge about 1,000 feet below the Denver and Rio Grande Railroad depot at Arboles, Colorado, and was established on June 19, 1895. It is above the mouth of the Piedra River. The gage consists

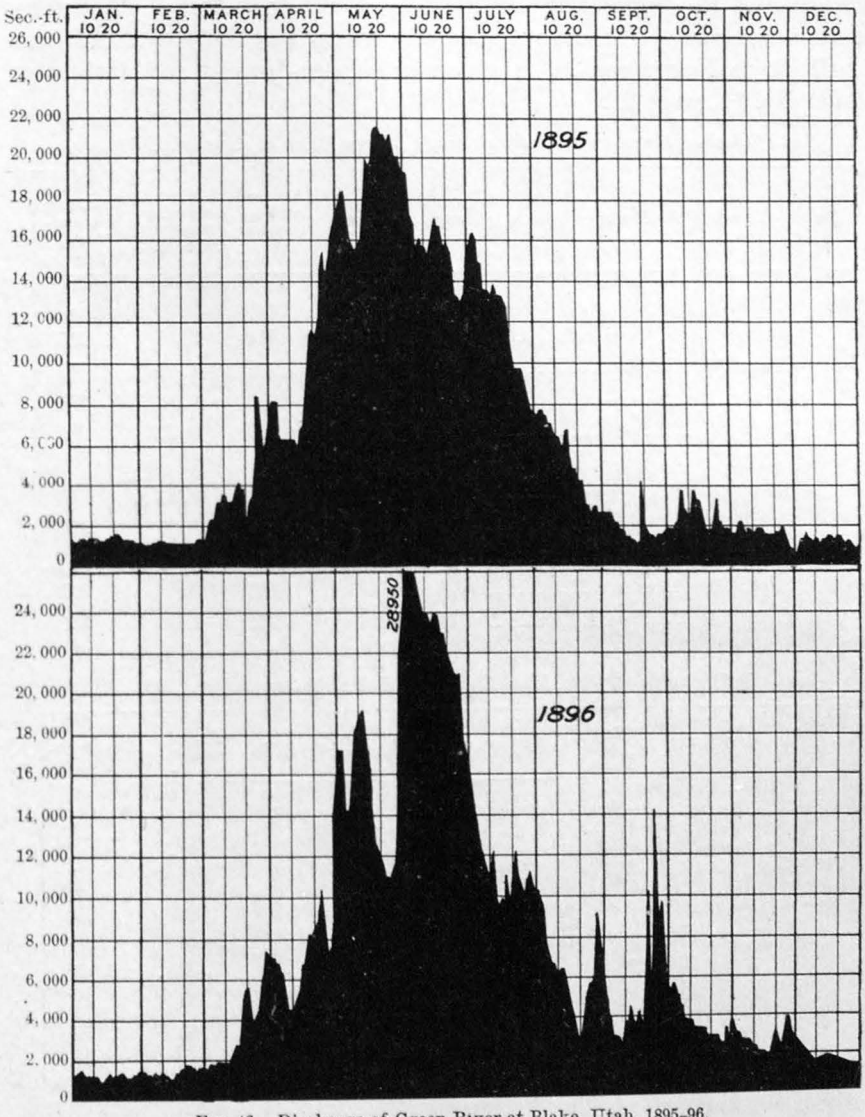



FIG. 46.—Discharge of Green River at Blake, Utah, 1895-96.

of a vertical 2 by 6 inch plank, fastened to the crib pier in the middle of the river, and graduated to tenths of a foot. This gage being liable to be washed out during the spring floods, on October 11, 1895, a new one was bolted to the rocky bank on the right-hand side of the river. It consists of two inclined 4 by 4 inch timbers with a 1 by 4 inch scale marked to vertical tenths of a foot, the space between marks being

0.131 of a foot. The left bank is low and liable to overflow; the right high and rocky; the current sluggish, and the bed sandy and shifting. Discharge measurements are made during high water at the foot bridge, and at low stage of the water about 1,300 feet below the gage, where the bed of the stream is composed of small stones and is less liable to change and the current is swift. The observer is Mr. T. F. Burke, section foreman. The record of daily gage heights for 1896, from April 12 to November 30, is given in Water-Supply and Irrigation Paper No. 11, page 71.

*List of discharge measurements made on San Juan River at Arboles, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 21 | F. Cogswell | 55 | 7.30 | 444 | 3.50 | 1,556 |
| 2 | Aug. 30 | do | 14 | 6.20 | 273 | 1.42 | 387 |
| 3 | Oct. 11 | do | 14 | 5.80 | 251 | 0.86 | 215 |
| 4 | Nov. 25 | do | 14 | 5.90 | 260 | 0.97 | 252 |
| | 1896. | | | | | | |
| 5 | May 16 | F. Cogswell | 14 | 6.65 | 330 | 2.33 | 768 |
| 6 | June 21 | do | 14 | 5.90 | 288 | 0.87 | 250 |
| 7 | July 25 | do | 14 | 6.00 | 111 | 2.41 | 268 |
| 8 | Sept. 26 | do | 14 | 6.15 | 133 | 2.42 | 322 |
| 9 | Oct. 24 | do | 14 | 6.20 | 224 | 1.56 | 349 |

*Rating table for San Juan River at Arboles, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.80 | 11 | 5.60 | 177 | 6.35 | 444 | 7.10 | 1,298 |
| 4.85 | 21 | 5.65 | 187 | 6.40 | 484 | 7.15 | 1,372 |
| 4.90 | 31 | 5.70 | 198 | 6.45 | 534 | 7.20 | 1,446 |
| 4.95 | 41 | 5.75 | 209 | 6.50 | 584 | 7.25 | 1,531 |
| 5.00 | 52 | 5.80 | 220 | 6.55 | 636 | 7.30 | 1,616 |
| 5.05 | 62 | 5.85 | 232 | 6.60 | 689 | 7.35 | 1,707 |
| 5.10 | 73 | 5.90 | 244 | 6.65 | 744 | 7.40 | 1,798 |
| 5.15 | 83 | 5.95 | 257 | 6.70 | 799 | 7.45 | 1,905 |
| 5.20 | 94 | 6.00 | 270 | 6.75 | 856 | 7.50 | 2,012 |
| 5.25 | 104 | 6.05 | 287 | 6.80 | 914 | 7.55 | 2,131 |
| 5.30 | 115 | 6.10 | 304 | 6.85 | 973 | 7.60 | 2,250 |
| 5.35 | 125 | 6.15 | 325 | 6.90 | 1,032 | 7.65 | 2,371 |
| 5.40 | 136 | 6.20 | 346 | 6.95 | 1,095 | 7.70 | 2,492 |
| 5.45 | 146 | 6.25 | 375 | 7.00 | 1,158 | 7.75 | 2,615 |
| 5.50 | 157 | 6.30 | 404 | 7.05 | 1,228 | 7.80 | 2,738 |
| 5.55 | 167 | | | | | | |

*Estimated monthly discharge of San Juan River at Arboles, Colorado.*

[Drainage area, 1,394 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 12 to 30 | 2,250 | 689 | 1,123 | 42,313 | 0.57 | 0.81 |
| May | 2,595 | 689 | 1,635 | 100,532 | 1.35 | 1.17 |
| June | 1,298 | 187 | 444 | 26,420 | 0.36 | 0.32 |
| July | 444 | 198 | 256 | 15,741 | 0.21 | 0.18 |
| August | 584 | 136 | 189 | 11,621 | 0.16 | 0.14 |
| September | 1,032 | 177 | 309 | 18,387 | 0.24 | 0.22 |
| October | 484 | 209 | 250 | 15,372 | 0.21 | 0.18 |
| November | 244 | 157 | 210 | 12,496 | 0.17 | 0.15 |

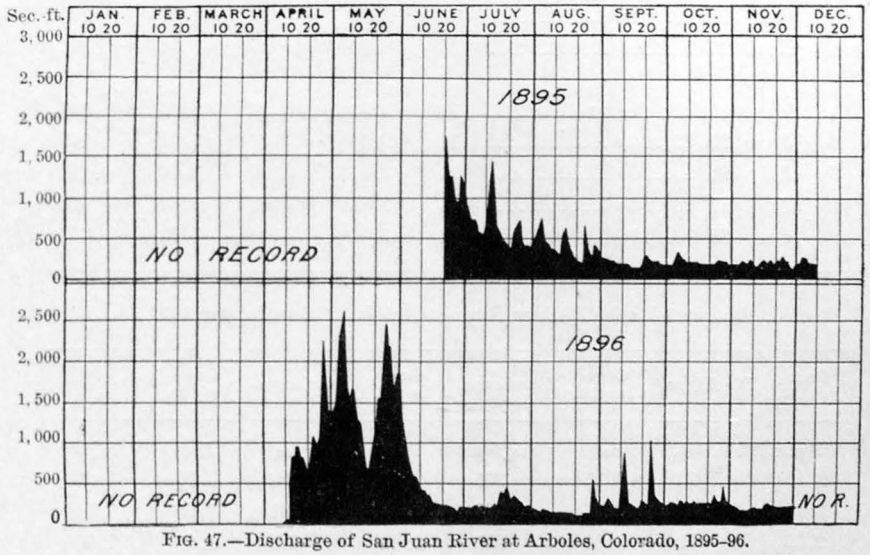



FIG. 47.—Discharge of San Juan River at Arboles, Colorado, 1895–96.

## ARBOLES STATION ON PIEDRAS RIVER.

This station is described in Bulletin No. 140, page 197. It is located at the railroad bridge across the Piedras River, about one-half mile from the Denver and Rio Grande Railroad depot at Arboles, Colorado, and was established on June 19, 1895. The Piedras empties into the San Juan a short distance below this point. The gage consists of a vertical 2 by 6 inch plank fastened to a crib just below the bridge near the left-hand side of the river, and is graduated to tenths of a foot. This gage being liable to be washed out during high water in the spring, a new gage has been bolted to the stone abutment of the railroad bridge on the right-hand side of the stream. It consists of a vertical 4 by 4 inch timber, with a 2 by 6 inch scale, graduated to tenths of a foot.

The 10-foot mark on the gage is 4.88 feet below a cross cut in the top of the abutment in the southeast corner of bridge 402 A. The banks are both high, the current is swift, the bed is composed of small stones, and the cross section does not change materially. Discharge measurements are made from the upper side of the railroad bridge. The observer is Mr. T. F. Burke. The record of daily gage heights for 1896, from April 12 to November 30, is given in Water-Supply and Irrigation Paper No. 11, page 71.

*List of discharge measurements made on Piedras River at Arboles, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 21 | F. Cogswell..... | 55 | 3.90 | 178 | 3.40 | 606 |
| 2 | Aug. 30 | .....do ..... | 14 | 3.20 | 121 | 1.94 | 235 |
| 3 | Oct. 11 | .....do ..... | 14 | 2.90 | 95 | 1.47 | 140 |
| 4 | Nov. 25 | .....do ..... | 14 | 2.80 | 87 | 1.31 | 115 |
| | 1896. | | | | | | |
| 5 | May 18 | F. Cogswell..... | 14 | 3.90 | 182 | 2.99 | 544 |
| 6 | June 20 | .....do ..... | 14 | 2.90 | 90 | 1.21 | 109 |
| 7 | July 24 | .....do ..... | 14 | 3.05 | 107 | 1.77 | 189 |
| 8 | Sept. 27 | .....do ..... | 14 | 3.70 | 161 | 2.51 | 405 |
| 9 | Oct. 25 | .....do ..... | 14 | 3.00 | 104 | 1.72 | 179 |

*Rating table for Piedras River at Arboles, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.40 | 23 | 3.10 | 205 | 3.80 | 468 | 4.50 | 1,236 |
| 2.45 | 33 | 3.15 | 220 | 3.85 | 501 | 4.55 | 1,315 |
| 2.50 | 43 | 3.20 | 235 | 3.90 | 534 | 4.60 | 1,394 |
| 2.55 | 54 | 3.25 | 250 | 3.95 | 580 | 4.65 | 1,480 |
| 2.60 | 66 | 3.30 | 266 | 4.00 | 626 | 4.70 | 1,566 |
| 2.65 | 79 | 3.35 | 282 | 4.05 | 677 | 4.75 | 1,660 |
| 2.70 | 92 | 3.40 | 299 | 4.10 | 728 | 4.80 | 1,754 |
| 2.75 | 105 | 3.45 | 317 | 4.15 | 784 | 4.85 | 1,855 |
| 2.80 | 119 | 3.50 | 335 | 4.20 | 840 | 4.90 | 1,956 |
| 2.85 | 133 | 3.55 | 354 | 4.25 | 901 | 4.95 | 2,066 |
| 2.90 | 147 | 3.60 | 373 | 4.30 | 962 | 5.00 | 2,176 |
| 2.95 | 161 | 3.65 | 394 | 4.35 | 1,028 | | |
| 3.00 | 176 | 3.70 | 416 | 4.40 | 1,094 | | |
| 3.05 | 190 | 3.75 | 442 | 4.45 | 1,165 | | |

*Estimated monthly discharge of Piedras River at Arboles, Colorado.*

[Drainage area, 650 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 12 to 30 | 1,660 | 354 | 804 | 30,305 | 0.87 | 1.24 |
| May | 2,066 | 416 | 1,048 | 64,438 | 1.87 | 1.52 |
| June | 677 | 79 | 229 | 13,627 | 0.39 | 0.35 |
| July | 190 | 66 | 111 | 6,825 | 0.20 | 0.17 |
| August | 266 | 23 | 59 | 3,628 | 0.10 | 0.09 |
| September | 3,000 | 66 | 347 | 20,648 | 0.59 | 0.53 |
| October | 235 | 119 | 175 | 10,760 | 0.30 | 0.27 |
| November | 176 | 92 | 121 | 7,200 | 0.21 | 0.19 |

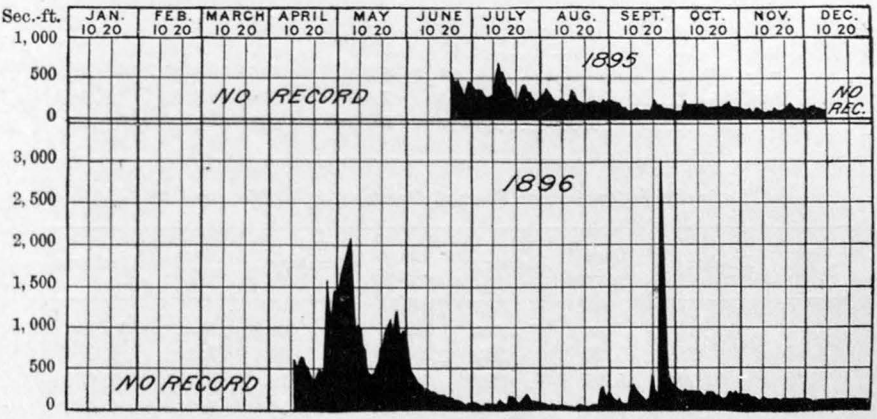



FIG. 48.—Discharge of Piedras River at Arboles, Colorado, 1895-96.

## DURANGO STATION ON ANIMAS RIVER.

This station is described in Bulletin No. 140, page 198. It is located about 200 yards west of the railroad station at Durango, Colorado, at the wagon bridge crossing Animas River, 200 feet above the Rio Grande Southern Railroad bridge, in the Durango quadrangle. The observer is George Robertson, a miller at Durango. The gage is spiked to the west side of the south end of the middle pier of the wagon bridge. The 15-foot mark on the gage is 2.24 feet below the head of a bolt at the east abutment of the railroad bridge. The banks are high and rocky and the section is excellent for obtaining accurate measurements of discharge. Lightner Creek enters Animas River from the right about 100 feet below the wagon bridge and between it and the railroad bridge.

There has been no material change in the cross section of the stream since August 12, 1895, at which time a dam was formed just below the gage from the sand and gravel brought down by the flood resulting from a cloudburst up Lightner Creek. This dam reduced the velocity in the west half of the river and caused the water to back up on the gage about 0.30 of a foot. The record of daily gage heights for 1896, from April 12 to December 30, is given in Water-Supply and Irrigation Paper No. 11, page 72.

*List of discharge measurements made on Animas River at Durango, Colorado.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 18 | F. Cogswell..... | 55 | 6.50 | 535 | 3.55 | 1,893 |
| 2 | Aug. 29 | .....do ..... | 14 | 5.80 | 415 | 1.30 | 543 |
| 3 | Oct. 10 | .....do ..... | 14 | 5.40 | 326 | 1.00 | 328 |
| 4 | Nov. 24 | .....do ..... | 14 | 5.20 | 292 | 0.89 | 260 |
| | 1896. | | | | | | |
| 5 | May 15 | F. Cogswell..... | 14 | 6.35 | 520 | 2.04 | 1,063 |
| 6 | June 19 | .....do ..... | 14 | 5.80 | 407 | 1.44 | 590 |
| 7 | July 23 | .....do ..... | 14 | 5.50 | 155 | 2.32 | 360 |
| 8 | Sept. 25 | .....do ..... | 14 | 7.40 | 756 | 3.39 | 2,566 |
| 9 | Oct. 23 | .....do ..... | 14 | 5.50 | 333 | 1.24 | 414 |

*Rating table for Animas River at Durango, Colorado, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.20 | 18 | 5.20 | 252 | 6.15 | 869 | 7.10 | 1,984 |
| 4.25 | 27 | 5.25 | 272 | 6.20 | 912 | 7.15 | 2,082 |
| 4.30 | 36 | 5.30 | 292 | 6.25 | 956 | 7.20 | 2,180 |
| 4.35 | 45 | 5.35 | 313 | 6.30 | 1,000 | 7.25 | 2,280 |
| 4.40 | 54 | 5.40 | 334 | 6.35 | 1,047 | 7.30 | 2,380 |
| 4.45 | 64 | 5.45 | 359 | 6.40 | 1,094 | 7.35 | 2,484 |
| 4.50 | 74 | 5.50 | 384 | 6.45 | 1,146 | 7.40 | 2,588 |
| 4.55 | 84 | 5.55 | 413 | 6.50 | 1,198 | 7.45 | 2,700 |
| 4.60 | 94 | 5.60 | 442 | 6.55 | 1,251 | 7.50 | 2,812 |
| 4.65 | 105 | 5.65 | 475 | 6.60 | 1,304 | 7.55 | 2,925 |
| 4.70 | 116 | 5.70 | 508 | 6.65 | 1,360 | 7.60 | 3,038 |
| 4.75 | 127 | 5.75 | 546 | 6.70 | 1,416 | 7.65 | 3,156 |
| 4.80 | 138 | 5.80 | 584 | 6.75 | 1,478 | 7.70 | 3,274 |
| 4.85 | 150 | 5.85 | 623 | 6.80 | 1,540 | 7.75 | 3,397 |
| 4.90 | 162 | 5.90 | 662 | 6.85 | 1,610 | 7.80 | 3,520 |
| 4.95 | 175 | 5.95 | 701 | 6.90 | 1,680 | 7.85 | 3,648 |
| 5.00 | 188 | 6.00 | 740 | 6.95 | 1,750 | 7.90 | 3,776 |
| 5.05 | 203 | 6.05 | 783 | 7.00 | 1,820 | 7.95 | 3,909 |
| 5.10 | 218 | 6.10 | 826 | 7.05 | 1,902 | 8.00 | 4,042 |
| 5.15 | 235 | | | | | | |

*Estimated monthly discharge of Animas River at Durango, Colorado.*

[Drainage area, 812 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| June 20 to 30 | 836 | 574 | 646 | 14,091 | 0.56 | 0.80 |
| July | 574 | 278 | 388 | 23,857 | 0.55 | 0.48 |
| August | 990 | 208 | 510 | 31,359 | 0.72 | 0.63 |
| September | 512 | 278 | 363 | 21,600 | 0.50 | 0.45 |
| October | 379 | 259 | 307 | 18,870 | 0.44 | 0.38 |
| November | 296 | 224 | 246 | 14,638 | 0.33 | 0.30 |
| December | 316 | 208 | 251 | 15,433 | 0.36 | 0.31 |
| 1896. | | | | | | |
| April 12 to 30 | 3,776 | 869 | 1,634 | 61,579 | 1.42 | 2.00 |
| May | 4,042 | 956 | 2,326 | 143,021 | 3.32 | 2.88 |
| June | 1,902 | 334 | 875 | 52,066 | 1.19 | 1.07 |
| July | 508 | 272 | 349 | 21,459 | 0.49 | 0.43 |
| August | 292 | 138 | 199 | 12,236 | 0.28 | 0.24 |
| September | 7,800 | 218 | 1,004 | 59,742 | 1.38 | 1.24 |
| October | 826 | 334 | 475 | 29,206 | 0.55 | 0.48 |
| November | 334 | 203 | 274 | 16,304 | 0.38 | 0.34 |
| December | 252 | 188 | 216 | 13,280 | 0.31 | 0.27 |

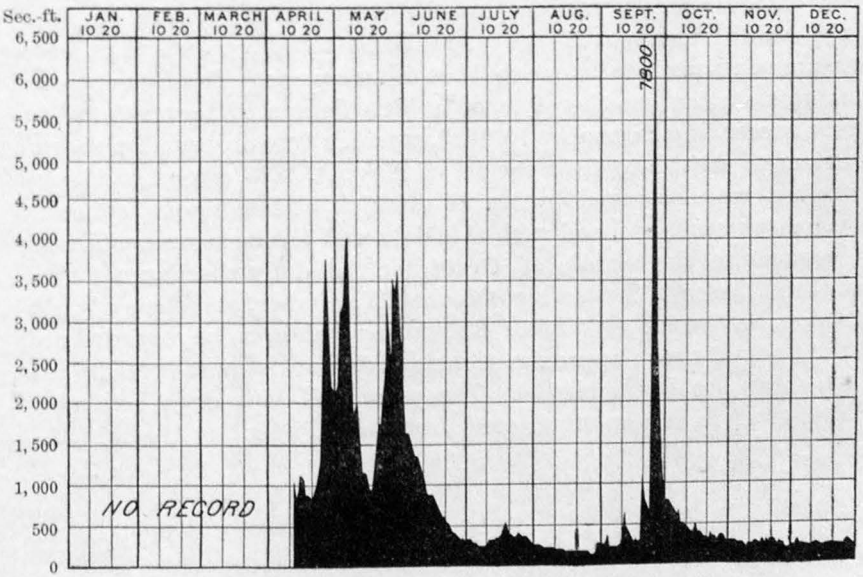



FIG. 49.—Discharge of Animas River at Durango, Colorado, 1895–96.

## GILA RIVER.

This stream enters the Colorado River just above the town of Yuma, being the lowest and last tributary of that river. It has been described in the Twelfth Annual Report of the United States Geological Survey, Part II, Irrigation, pages 292 to 316. The demand for information, both on the Gila River proper and its principal tributary, Salt River, is very great, on account of the competition for the waters to use in irrigation in the respective valleys, but owing to the great expense few measurements have been made previous to 1896 other than those given in Bulletin 140, pages 206 and 207, and in the Twelfth Annual Report above mentioned.

### BUTTES STATION ON GILA RIVER.

In the fall of 1895 measurements of Gila River were begun by the establishment of a station at the buttes 16 miles above Florence, Arizona, at the same point that observations were carried on during the years 1889 and 1890 by the Irrigation Survey. A temporary gage was first driven into the river bed, from which observations were begun. The stream was measured, from a car suspended from a cable stretched across the river, about a quarter of a mile up the windings of the stream above the point where the river passes through the narrow gorge between the buttes. On February 20, 1896, in order to make it more accessible to the residence of the observer, the cable was removed to the point where the river emerges from the lower end of the gorge, and a permanent gage was bolted to the solid rock on the right bank of the river. Measurements were continued throughout the year by Mr. W. J. Brash, daily readings of the gage being taken and current meter measurements made from one to three times a week. The data obtained from this station are therefore of a high degree of accuracy for the period succeeding December 10, 1895, at which date observations began. Previous to that date, from the 1st of August, 1895, gage heights and soundings were observed by Mr. W. Richins, and occasional estimates of velocity were made, and with this data and the measurements made subsequent to the middle of December the daily discharge for the months of August, September, October, November, and the early part of December have been made. But these results can be regarded only in the light of rough approximations and do not compare in value with those following December 10. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 72.

*List of discharge measurements made on Gila River at Buttes, Arizona.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Dec. 28 | A. P. Davis | 61 | 2.35 | | 3.70 | 585 |
| Dec. 31 | do | 61 | 2.23 | | 3.55 | 519 |
| 1896. | | | | | | |
| Jan. 12 | C. C. Babb | 61 | 2.03 | 130 | 3.30 | 436 |
| Jan. 25 | do | 61 | 1.79 | 122 | 2.21 | 270 |
| Jan. 26 | A. P. Davis | 18 | 1.78 | 94 | 2.83 | 268 |
| Jan. 26 | C. C. Babb | 61 | 1.78 | 94 | 2.92 | 275 |
| Feb. 8 | H. G. Heisler | 61 | 1.73 | 118 | 2.69 | 317 |
| Feb. 9 | J. F. Appleby | 61 | 1.70 | 110 | 2.23 | 247 |
| Feb. 12 | H. G. Heisler | 61 | 1.73 | 106 | 2.37 | 251 |
| Feb. 18 | W. J. Brash | 61 | 1.74 | 106 | 2.46 | 260 |
| Feb. 22 | do | 61 | 1.75 | 111 | 2.29 | 253 |
| Feb. 25 | do | 61 | 1.72 | | 2.09 | 208 |
| Feb. 28 | do | 61 | 1.72 | | 2.28 | 214 |
| Mar. 4 | do | 61 | 1.80 | | 2.00 | 196 |
| Mar. 8 | do | 61 | 1.79 | | 2.26 | 218 |
| Mar. 10 | do | 61 | 1.80 | | 2.00 | 214 |
| Mar. 13 | do | 61 | 1.88 | 108 | 2.38 | 258 |
| Mar. 17 | do | 108 | 1.91 | 115 | 1.61 | 184 |
| Mar. 21 | do | 61 | 1.81 | 96 | 1.94 | 187 |
| Mar. 26 | do | 61 | 1.71 | 76 | 1.79 | 137 |
| Mar. 28 | do | 61 | 1.70 | 76 | 1.95 | 149 |
| Mar. 31 | do | 61 | 1.70 | | 1.82 | 137 |
| Apr. 3 | do | 61 | 1.87 | | 2.13 | 222 |
| Apr. 7 | do | 61 | 1.89 | 105 | 2.13 | 225 |
| Apr. 10 | do | 61 | 1.80 | 93 | 1.87 | 174 |
| Apr. 14 | do | 61 | 1.67 | 78 | 1.70 | 133 |
| Apr. 17 | do | 61 | 1.62 | 69 | 1.86 | 129 |
| Apr. 21 | do | 61 | 1.60 | 61 | 1.73 | 105 |
| Apr. 25 | do | 61 | 1.53 | 54 | 1.41 | 76 |
| Apr. 28 | do | 61 | 1.51 | 49 | 1.51 | 74 |
| May 2 | do | 61 | 1.48 | 45 | 1.43 | 64 |
| May 5 | do | 61 | 1.44 | 38 | 1.40 | 53 |
| May 8 | do | 61 | 1.40 | 37 | 1.30 | 48 |
| May 12 | do | 61 | 1.35 | 29 | 1.36 | 40 |
| May 15 | do | 61 | 1.30 | 27 | 1.31 | 36 |
| May 19 | do | 61 | 1.25 | 22 | 1.14 | 25 |
| May 22 | do | 61 | 1.21 | 19 | 1.01 | 19 |
| May 27 | do | 61 | 1.16 | 14 | 0.87 | 12 |
| June 1 | do | 61 | 1.11 | 13 | 0.70 | 9 |
| June 6 | do | 61 | 1.06 | 8 | 0.78 | 6 |

*List of discharge measurements made on Gila River at Buttes, Arizona*—Continued.

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| June 19 | W. J. Brash | 61 | 0.91 | 2 | 0.61 | 1 |
| June 27 | do | 61 | 1.32 | 26 | 1.32 | 35 |
| July 3 | do | 61 | 0.91 | 3 | 1.04 | 3 |
| July 8 | do | 61 | 1.36 | 30 | 1.39 | 42 |
| July 13 | do | 61 | 1.24 | 21 | 1.20 | 25 |
| July 16 | do | 61 | 4.25 | 444 | 5.60 | 2,485 |
| July 20 | do | 61 | 3.00 | 281 | 5.02 | 1,408 |
| July 21 | do | 61 | 5.30 | 664 | 7.11 | 4,720 |
| July 29 | do | 61 | 2.15 | 170 | 3.36 | 572 |
| Aug. 5 | do | 61 | 3.20 | 240 | 6.07 | 1,453 |
| Aug. 8 | do | 61 | 3.25 | 186 | 3.21 | 596 |
| Aug. 11 | do | 61 | 1.90 | 135 | 2.65 | 356 |
| Aug. 15 | do | 61 | 1.70 | 101 | 2.65 | 269 |
| Aug. 18 | do | 61 | 1.83 | 111 | 2.43 | 268 |
| Aug. 21 | do | 61 | 2.00 | 130 | 2.95 | 383 |
| Aug. 25 | do | 61 | 2.41 | 210 | 3.78 | 793 |
| Aug. 29 | do | 61 | 2.05 | 143 | 3.25 | 463 |
| Aug. 30 | do | 61 | 3.70 | 339 | 6.24 | 2,114 |
| Sept. 1 | do | 61 | 2.50 | 157 | 4.70 | 735 |
| Sept. 5 | do | 61 | 2.40 | 171 | 3.85 | 658 |
| Sept. 8 | do | 61 | 2.70 | 185 | 4.23 | 783 |
| Sept. 10 | do | 61 | 4.10 | 442 | 6.53 | 2,885 |
| Sept. 14 | do | 61 | 2.95 | 217 | 4.88 | 1,060 |
| Sept. 18 | do | 61 | 2.23 | 145 | 3.77 | 547 |
| Sept. 22 | do | 61 | 2.80 | 218 | 4.74 | 1,034 |
| Sept. 25 | do | 61 | 2.40 | 156 | 4.09 | 637 |
| Sept. 30 | do | 61 | 2.05 | 131 | 3.08 | 402 |
| Oct. 2 | do | 61 | 6.37 | 812 | 7.65 | 6,215 |
| Oct. 4 | do | 61 | 5.20 | 534 | 7.83 | 4,180 |
| Oct. 7 | do | 61 | 3.75 | 357 | 5.94 | 2,121 |
| Oct. 9 | do | 61 | 3.90 | 358 | 6.36 | 2,277 |
| Oct. 13 | do | 61 | 4.90 | 505 | 7.47 | 3,772 |
| Oct. 14 | do | 61 | 8.60 | 1,269 | 7.55 | 9,589 |
| Oct. 15 | do | 61 | 7.80 | 1,116 | 8.91 | 9,941 |
| Oct. 21 | do | 61 | 3.55 | 308 | 5.50 | 1,693 |
| Oct. 23 | do | 61 | 6.60 | 841 | 8.60 | 7,231 |
| Oct. 24 | do | 61 | 5.45 | ..... | 7.51 | 4,834 |
| Oct. 27 | do | 61 | 5.55 | 660 | 7.73 | 5,100 |
| Oct. 29 | do | 61 | 5.00 | 556 | 7.18 | 3,996 |
| Oct. 31 | do | 61 | 4.10 | 427 | 6.45 | 2,753 |
| Nov. 4 | do | 61 | 3.30 | 270 | 5.49 | 1,483 |

*List of discharge measurements made on Gila River at Buttes, Arizona*—Continued.

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Nov. 7 | W. J. Brash..... | 61 | 2.95 | 229 | 5.23 | 1,197 |
| Nov. 11 | .....do ..... | 61 | 2.70 | 202 | 4.80 | 971 |
| Nov. 14 | .....do ..... | 61 | 2.60 | 184 | 4.54 | 837 |
| Nov. 18 | .....do ..... | 61 | 2.50 | 170 | 4.13 | 701 |
| Nov. 23 | .....do ..... | 61 | 2.40 | 154 | 4.05 | 623 |
| Nov. 27 | .....do ..... | 61 | 2.53 | 174 | 4.30 | 747 |
| Dec. 1 | .....do ..... | 61 | 2.40 | 144 | 4.34 | 625 |
| Dec. 5 | .....do ..... | 61 | 2.31 | 155 | 3.86 | 599 |
| Dec. 8 | .....do ..... | 61 | 2.30 | 132 | 3.90 | 513 |
| Dec. 11 | .....do ..... | 61 | 2.28 | 131 | 3.82 | 499 |
| Dec. 17 | .....do ..... | 61 | 2.30 | 133 | 3.68 | 490 |
| Dec. 22 | .....do ..... | 61 | 2.24 | 125 | 3.73 | 466 |
| Dec. 28 | .....do ..... | 61 | 2.23 | 127 | 3.58 | 455 |

*Rating table for Gila River at Buttes, Arizona.*

[This table is applicable only to December 31, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.90 | 1 | 2.90 | 1,150 | 5.10 | 4,355 | 7.30 | 8,205 |
| 0.95 | 2 | 3.00 | 1,270 | 5.20 | 4,530 | 7.40 | 8,380 |
| 1.00 | 3 | 3.10 | 1,400 | 5.30 | 4,705 | 7.50 | 8,555 |
| 1.05 | 5 | 3.20 | 1,530 | 5.40 | 4,880 | 7.60 | 8,730 |
| 1.10 | 10 | 3.30 | 1,650 | 5.50 | 5,055 | 7.70 | 8,905 |
| 1.20 | 20 | 3.40 | 1,760 | 5.60 | 5,230 | 7.80 | 9,080 |
| 1.30 | 30 | 3.50 | 1,870 | 5.70 | 5,405 | 7.90 | 9,255 |
| 1.40 | 40 | 3.60 | 2,000 | 5.80 | 5,580 | 8.00 | 9,430 |
| 1.50 | 75 | 3.70 | 2,125 | 5.90 | 5,755 | 8.10 | 9,605 |
| 1.60 | 120 | 3.80 | 2,275 | 6.00 | 5,930 | 8.20 | 9,780 |
| 1.70 | 175 | 3.90 | 2,425 | 6.10 | 6,105 | 8.30 | 9,955 |
| 1.80 | 250 | 4.00 | 2,500 | 6.20 | 6,280 | 8.40 | 10,130 |
| 1.90 | 340 | 4.10 | 2,700 | 6.30 | 6,455 | 8.50 | 10,305 |
| 2.00 | 420 | 4.20 | 2,850 | 6.40 | 6,630 | 8.60 | 10,480 |
| 2.10 | 490 | 4.30 | 3,000 | 6.50 | 6,805 | 8.70 | 10,655 |
| 2.20 | 560 | 4.40 | 3,150 | 6.60 | 6,980 | 8.80 | 10,830 |
| 2.30 | 640 | 4.50 | 3,300 | 6.70 | 7,155 | 8.90 | 11,005 |
| 2.40 | 710 | 4.60 | 3,500 | 6.80 | 7,330 | 9.00 | 11,180 |
| 2.50 | 800 | 4.70 | 3,650 | 6.90 | 7,505 | 9.10 | 11,355 |
| 2.60 | 880 | 4.80 | 3,885 | 7.00 | 7,680 | 9.20 | 11,530 |
| 2.70 | 950 | 4.90 | 4,000 | 7.10 | 7,855 | 9.30 | 11,705 |
| 2.80 | 1,030 | 5.00 | 4,180 | 7.20 | 8,030 | 9.40 | 11,880 |

*Estimated monthly discharge of Gila River at Buttes, Arizona.*

[Drainage area, 13,750 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1889. | | | | | | |
| September | 210 | 90 | 128 | 7,616 | 0.010 | 0.009 |
| October | 210 | 110 | 157 | 9,655 | 0.013 | 0.011 |
| November | 250 | 156 | 212 | 12,614 | 0.017 | 0.015 |
| December | 890 | 124 | 275 | 16,909 | 0.023 | 0.020 |
| 1890. | | | | | | |
| January | 2,100 | 310 | 680 | 41,812 | 0.056 | 0.049 |
| February | 1,514 | 405 | 578 | 32,100 | 0.043 | 0.042 |
| March | 710 | 300 | 387 | 23,795 | 0.032 | 0.028 |
| April | 333 | 158 | 238 | 14,161 | 0.019 | 0.017 |
| May | 150 | 35 | 87 | 5,350 | 0.007 | 0.006 |
| June | 35 | 27 | 28 | 1,666 | 0.002 | 0.002 |
| July | 3,112 | 11 | 130 | 7,995 | 0.010 | 0.009 |
| August | 6,330 | 1,115 | 3,137 | 192,888 | 0.263 | 0.228 |
| Total for year | ..... | ..... | ..... | 366,561 | ..... | ..... |
| 1895. | | | | | | |
| August | 3,910 | 536 | 1,583 | 97,336 | 0.133 | 0.115 |
| September | 2,880 | 300 | 812 | 48,317 | 0.065 | 0.059 |
| October | 12,000 | 400 | 1,577 | 96,966 | 0.133 | 0.115 |
| November | 7,500 | 300 | 1,103 | 65,633 | 0.089 | 0.080 |
| December | 1,150 | 518 | 751 | 46,177 | 0.056 | 0.055 |
| 1896. | | | | | | |
| January | 560 | 250 | 396 | 24,349 | 0.032 | 0.028 |
| February | 340 | 175 | 209 | 12,027 | 0.016 | 0.015 |
| March | 356 | 153 | 242 | 14,880 | 0.021 | 0.018 |
| April | 340 | 68 | 180 | 10,711 | 0.014 | 0.013 |
| May | 68 | 12 | 32 | 1,968 | 0.002 | 0.002 |
| June | 32 | 1 | 5 | 298 | 0.0003 | 0.0003 |
| July | 11,708 | 1 | 1,441 | 88,604 | 0.121 | 0.105 |
| August | 3,150 | 175 | 810 | 49,805 | 0.068 | 0.059 |
| September | 2,850 | 455 | 980 | 58,314 | 0.079 | 0.071 |
| October | 11,793 | 1,030 | 4,145 | 254,868 | 0.347 | 0.301 |
| November | 2,275 | 696 | 1,037 | 61,706 | 0.083 | 0.075 |
| December | 710 | 576 | 629 | 38,676 | 0.053 | 0.046 |
| Per annum | 11,793 | 1 | 842 | 616,206 | 0.839 | 0.062 |

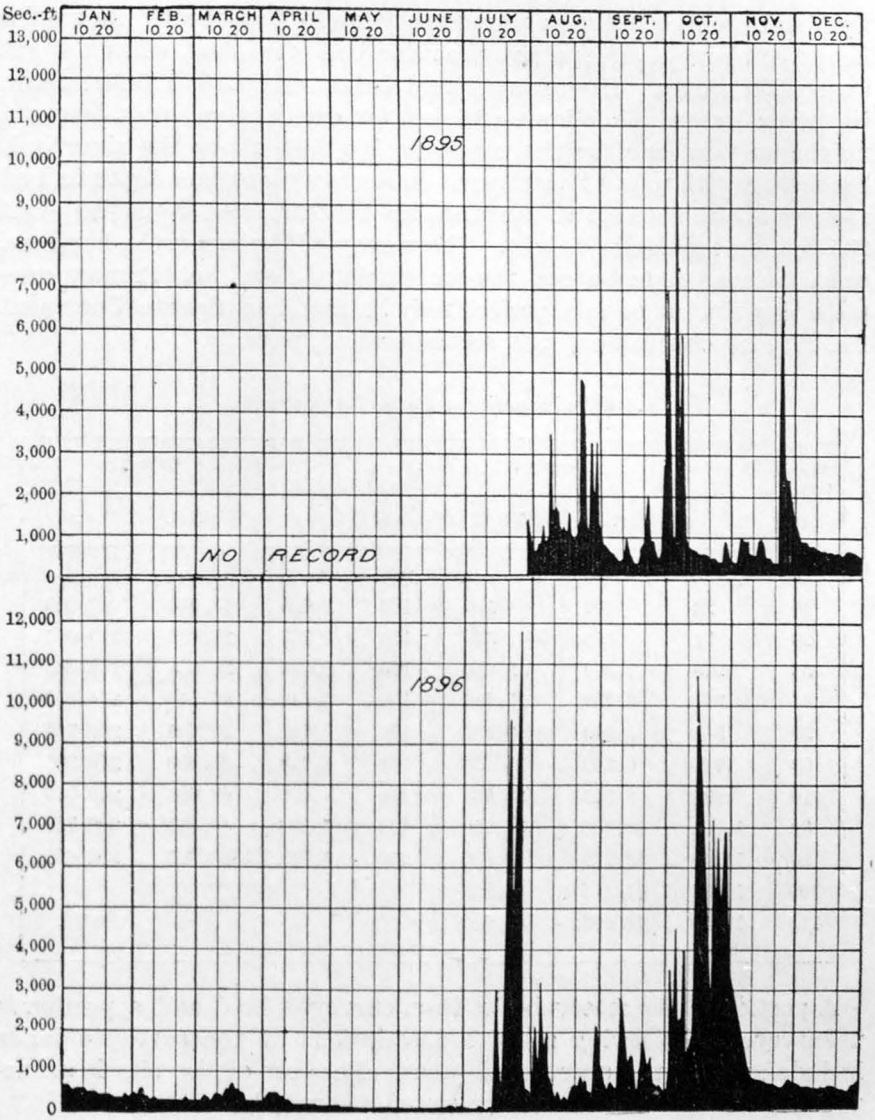



FIG. 50.—Discharge of Gila River at Buttes, Arizona, 1895–96.

## BUTTES RESERVOIR ON GILA RIVER.

A reservoir site was surveyed and segregated by Mr. Arthur P. Davis in January, 1896, in connection with an irrigation investigation for the benefit of the Indians on the Gila River Reservation. The site selected for the dam is at the point where the Gila River enters the narrow gorge between two buttes, about 14 miles east of Florence, Arizona. At this point the river is flowing nearly north. The west abutment of the dam is nearly vertical for 150 feet. The bottom width of the canyon is about 350 feet. The eastern abutment rises abruptly

for about 100 feet and then slopes gently away from the stream until a height of about 150 feet above the river bed is reached, when a slight depression occurs. The contemplated height of dam is 170 feet above the river bed, which, allowing 10 feet for depth of spillway, leaves a maximum flow line for the reservoir 160 feet above the river bed. Soundings with rods at this point indicate a maximum depth to bed rock of about 65 feet; so that the dam contemplated would be about 235 feet in maximum height. The survey of the reservoir, however, was continued 40 feet above the contemplated flow line. A more complete description of this project may be found in Senate Document No. 27, Fifty-fourth Congress, second session, page 25.

*Area and capacity of Buttes Reservoir site.*

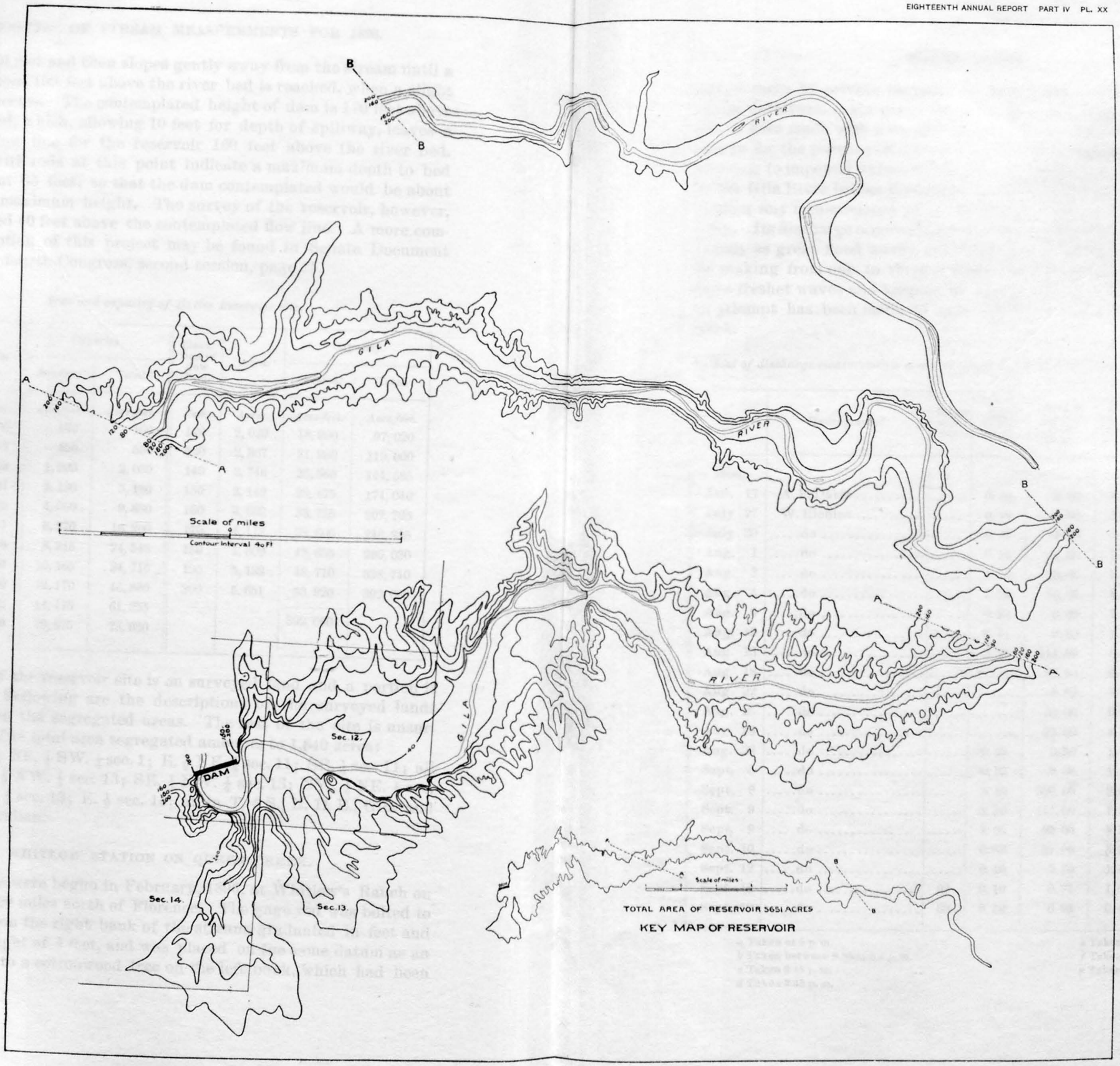
| Elevation of flow line. | Area. | Capacity. | | Elevation of flow line. | Area. | Capacity. | |
|---|---|---|---|---|---|---|---|
| | | Section. | Total. | | | Section. | Total. |
| *Feet.* | *Acres.* | *Acre-feet.* | *Acre-feet.* | *Feet.* | *Acres.* | *Acre-feet.* | *Acre-feet.* |
| 10 | 20 | 100 | 100 | 120 | 2,029 | 18,990 | 97,020 |
| 20 | 71 | 450 | 550 | 130 | 2,367 | 21,980 | 119,000 |
| 30 | 229 | 1,500 | 2,050 | 140 | 2,746 | 25,565 | 144,565 |
| 40 | 397 | 3,130 | 5,180 | 150 | 3,149 | 29,475 | 174,040 |
| 50 | 533 | 4,650 | 9,830 | 160 | 3,602 | 33,755 | 207,795 |
| 60 | 741 | 6,370 | 16,200 | 170 | 4,118 | 38,600 | 246,395 |
| 70 | 928 | 8,345 | 24,545 | 180 | 4,609 | 43,635 | 290,030 |
| 80 | 1,105 | 10,165 | 34,710 | 190 | 5,133 | 48,710 | 338,740 |
| 90 | 1,329 | 12,170 | 46,880 | 200 | 5,651 | 53,920 | 392,660 |
| 100 | 1,566 | 14,475 | 61,355 | | | 392,660 | |
| 110 | 1,769 | 16,675 | 78,030 | | | | |

A portion of the reservoir site is on surveyed land and a portion is unsurveyed. Following are the descriptions of the surveyed lands included within the segregated areas. The rest of the site is unsurveyed land. The total area segregated amounts to 1,640 acres:

SE. ¼ sec. 1; SE. ¼ SW. ¼ sec. 1; E. ½ NE. ¼ sec. 11; SE. ¼ sec. 11; all of sec. 12; N. ½ NW. ¼ sec. 13; SE. ¼ NW. ¼ sec. 13; NW. ¼ NE. ¼ sec. 13; W. ½ SW. ¼ sec. 13; E. ½ sec. 14; all in T. 4 S., R. 11 E., Gila and Salt River meridian.

## WHITLOW STATION ON QUEEN CREEK.

Observations were begun in February, 1896, at Whitlow's Ranch on Queen Creek, 20 miles north of Florence. The gage rod was bolted to the solid rock on the right bank of the stream, graduated in feet and tenths to a height of 4 feet, and was placed on the same datum as an old rod nailed to a cottonwood tree on the left bank, which had been




BUTTES RESERVOIR SITE ON GILA RIVER, ARIZONA.

placed there by private parties. In July, 1896, a cable was stretched across the stream in the gorge above the gage rod, from which measurements were made with a current meter. These observations were carried on for the purpose of determining the water supply for a proposed reservoir to impound waters at this point for supplying the Pima Indians on the Gila River Indian Reservation. The flashy nature of this stream renders any measurement of its discharge a matter of extreme difficulty. Its discharge occurs almost entirely in violent freshets, recurring usually as great flood waves, subsiding almost as rapidly as they rise. By making from one to three current meter measurements of each of these freshet waves and keeping an hourly record of the gage height, an attempt has been made to approximate the total discharge of the creek.

*List of discharge measurements made on Queen Creek at Whitlow's ranch, Arizona.*

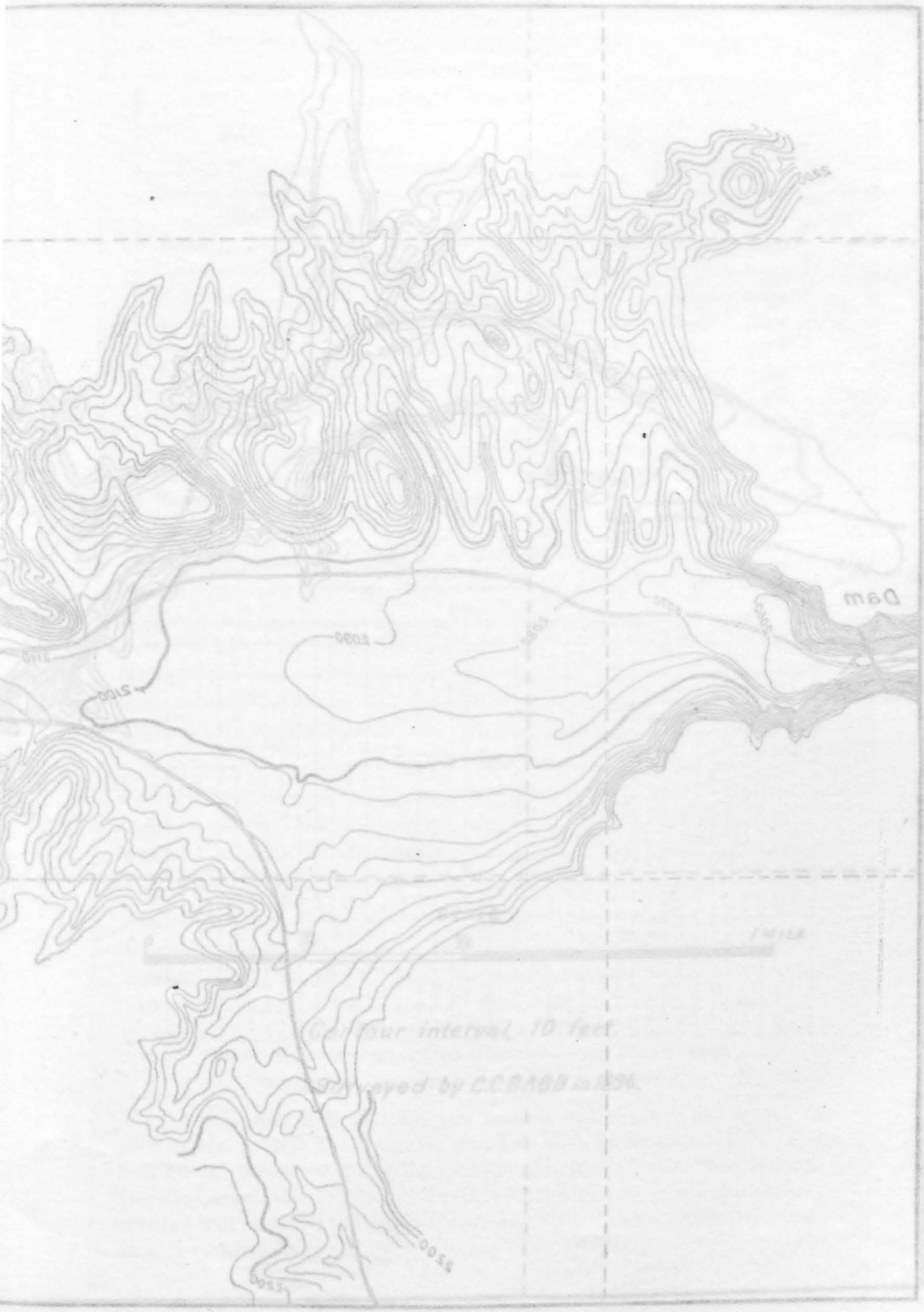
| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Jan. 17 | A. P. Davis | ..... | 0.80 | 2.00 | 0.90 | 2.00 |
| July 27 | W. Richins | ..... | 0.19 | 1.00 | 0.83 | 1.00 |
| July 30 | .....do | ..... | 0.19 | 1.00 | 0.61 | 0.86 |
| Aug. 1 | .....do | ..... | 0.19 | 1.00 | 0.45 | 0.63 |
| Aug. 3 | .....do | ..... | 1.70 | 39.00 | 6.64 | 258.00 |
| Aug. 4 | .....do | ..... | 2.00 | 90.00 | 6.77 | 610.00 |
| Aug. 6 | .....do | ..... | 0.22 | 0.80 | 1.20 | 0.96 |
| Aug. 15 | .....do | ..... | 0.31 | 0.80 | 1.20 | 0.96 |
| Aug. 18 | .....do | ..... | 2.90 | 214.00 | 6.69 | *a* 1,433.00 |
| Aug. 18 | .....do | ..... | ..... | 85.00 | 6.15 | *b* 523.00 |
| Aug. 22 | .....do | ..... | ..... | 0.80 | 1.08 | 0.86 |
| Aug. 25 | .....do | ..... | ..... | 60.00 | 0.80 | *c* 477.00 |
| Aug. 25 | .....do | ..... | ..... | 22.00 | 4.96 | *d* 108.00 |
| Aug. 29 | .....do | ..... | 0.23 | 0.90 | 1.00 | 0.90 |
| Sept. 5 | .....do | ..... | 0.22 | 0.58 | 1.09 | 0.63 |
| Sept. 9 | .....do | ..... | 3.10 | 390.00 | 8.80 | *e* 3,428.00 |
| Sept. 9 | .....do | ..... | 2.90 | 111.00 | 7.32 | *f* 810.00 |
| Sept. 9 | .....do | ..... | 1.00 | 29.00 | 5.55 | *g* 161.00 |
| Sept. 10 | .....do | ..... | 0.80 | 21.00 | 5.30 | 111.00 |
| Sept. 12 | .....do | ..... | 0.10 | 0.70 | 1.00 | 0.70 |
| Sept. 18 | .....do | 69 | 0.10 | 0.77 | 1.00 | 0.77 |
| Sept. 19 | .....do | 69 | 0.10 | 0.98 | 0.45 | 0.452 |

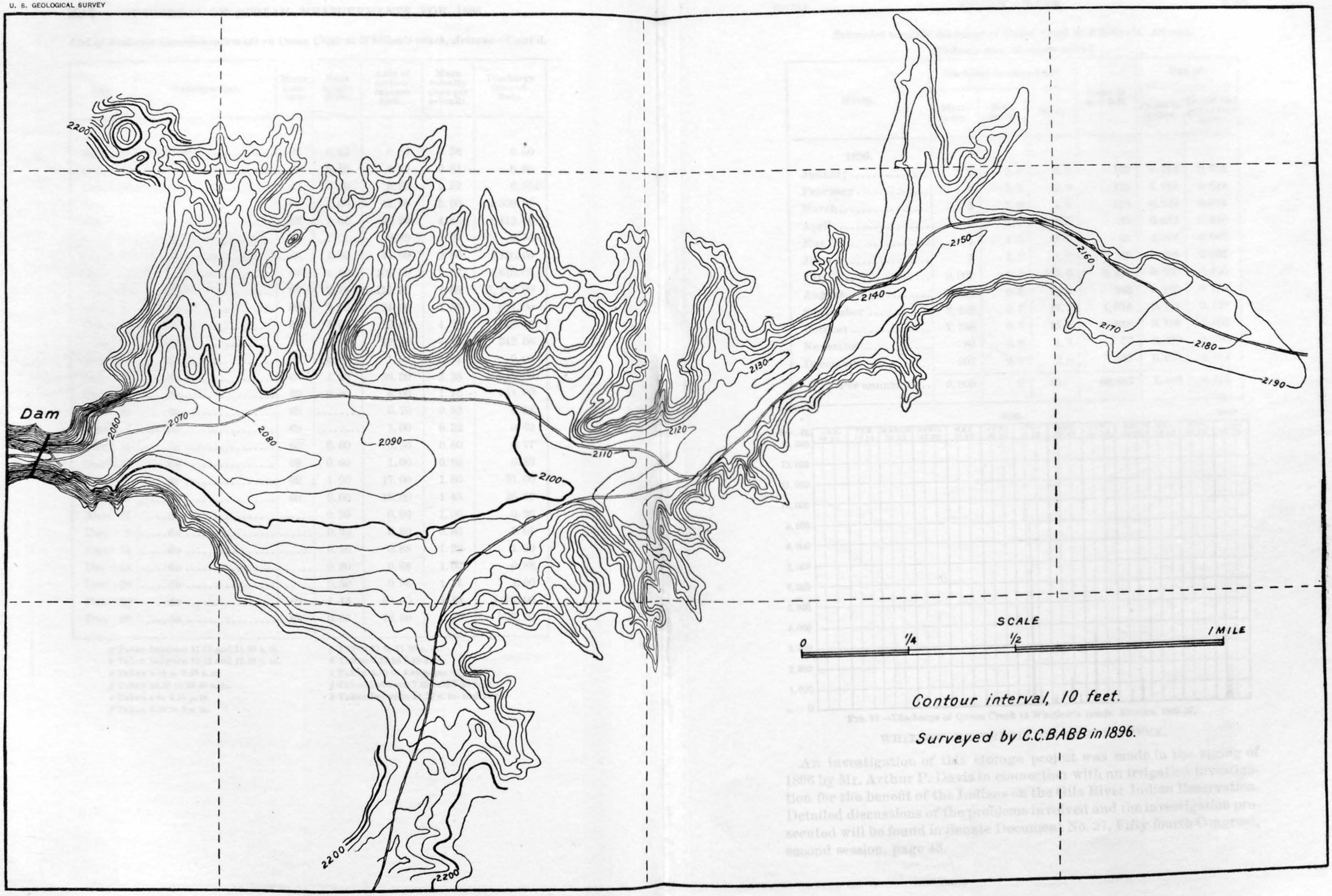
*a* Taken at 5 p. m.
*b* Taken between 5.30 and 6 p. m.
*c* Taken 2.45 p. m.
*d* Taken 3.45 p. m.
*e* Taken 1.30 p. m.
*f* Taken 4.30 p. m.
*g* Taken 6.15 p. m.

*List of discharge measurements made on Queen Creek at Whitlow's ranch, Arizona*—Cont'd.

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Sept. 25 | W. Richins | 69 | 0.10 | 0.86 | 0.58 | 0.50 |
| Oct. 3 | do | 69 | 0.10 | 0.80 | 0.81 | 0.65 |
| Oct. 10 | do | 69 | 0.10 | 0.80 | 0.82 | 0.554 |
| Oct. 12 | do | 69 | 1.60 | 62.00 | 5.00 | *a* 309.00 |
| Oct. 12 | do | 69 | 1.00 | 25.00 | 4.40 | *b* 112.00 |
| Oct. 17 | do | 69 | ..... | 0.89 | 0.74 | 0.66 |
| Oct. 22 | do | 69 | 1.10 | 41.00 | 2.90 | *c* 120.00 |
| Oct. 22 | do | 69 | 1.80 | 105.00 | 5.87 | *d* 616.00 |
| Oct. 22 | do | 69 | 2.15 | 151.00 | 7.85 | *e* 1,188.00 |
| Oct. 23 | do | 69 | 0.95 | 24.00 | 1.55 | *f* 37.00 |
| Oct. 23 | do | 69 | 1.00 | 23.00 | 1.78 | *g* 40.00 |
| Oct. 23 | do | 69 | 1.65 | 72.00 | 4.75 | 342.08 |
| Oct. 24 | do | 69 | 0.45 | 1.00 | 0.91 | 0.96 |
| Oct. 28 | do | 69 | 1.20 | 36.00 | 2.38 | *h* 86.00 |
| Oct. 29 | do | 69 | 0.90 | 6.00 | 1.75 | *i* 11.00 |
| Oct. 30 | do | 69 | ..... | 0.70 | 0.83 | 0.58 |
| Nov. 7 | do | 69 | ..... | 1.00 | 0.52 | 0.62 |
| Nov. 14 | do | 69 | 0.60 | 0.96 | 0.80 | 0.77 |
| Nov. 21 | do | 69 | 0.60 | 1.00 | 0.80 | 0.83 |
| Nov. 25 | do | 69 | 1.00 | 17.00 | 1.80 | 31.00 |
| Nov. 26 | do | 69 | 0.60 | 18.00 | 1.45 | 26.00 |
| Nov. 27 | do | ..... | 0.30 | 0.96 | 1.00 | 0.96 |
| Dec. 5 | do | ..... | 0.30 | 0.80 | 0.80 | 0.64 |
| Dec. 12 | do | ..... | 0.30 | 0.88 | 1.32 | 1.00 |
| Dec. 18 | do | ..... | 0.30 | 0.88 | 1.00 | 0.88 |
| Dec. 26 | do | ..... | 0.30 | 0.96 | 1.14 | 1.00 |
| Dec. 29 | do | 69 | 1.15 | 59.00 | 3.49 | *j* 207.00 |
| Dec. 29 | do | 69 | 0.65 | 12.00 | 1.39 | *k* 17.00 |

*a* Taken between 11.10 and 11.50 a. m.
*b* Taken between 12.15 and 12.30 p. m.
*c* Taken 9.15 to 9.45 a. m.
*d* Taken 10.15 to 10.40 a. m.
*e* Taken 4 to 4.30 p. m.
*f* Taken 5.40 to 6 a. m.
*g* Taken 11 to 11.25 a. m.
*h* Taken 6.15 to 6.40 a. m.
*i* Taken 4.30 to 4.45 p. m.
*j* Taken between 7.05 and 7.30 a. m.
*k* Taken between 11.20 a. m. and 12 m.


Dam
5100
5300




WHITLOW RESERVOIR SITE ON QUEEN CREEK, ARIZONA.

Contour interval, 10 feet.

Surveyed by C.C.BABB in 1896.

*Estimated monthly discharge of Queen Creek at Whitlow's, Arizona.*

[Drainage area, 143 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 2 | 2.0 | 2.0 | 123 | 0.016 | 0.014 |
| February | 2 | 2.0 | 2.0 | 115 | 0.015 | 0.014 |
| March | 2 | 2.0 | 2.0 | 123 | 0.016 | 0.014 |
| April | 2 | 1.0 | 1.5 | 89 | 0.011 | 0.010 |
| May | 1 | 1.0 | 1.0 | 61 | 0.008 | 0.007 |
| June | 1 | 1.0 | 1.0 | 60 | 0.008 | 0.007 |
| July | 9,000 | 0.0 | 121.6 | 7,477 | 0.980 | 0.850 |
| August | 1,433 | 0.6 | 13.1 | 805 | 0.106 | 0.092 |
| September | 3,428 | 0.5 | 17.1 | 1,016 | 0.134 | 0.120 |
| October | 1,188 | 0.5 | 13.3 | 818 | 0.108 | 0.093 |
| November | 80 | 0.6 | 1.3 | 77 | 0.010 | 0.009 |
| December | 207 | 0.6 | 2.0 | 123 | 0.016 | 0.014 |
| Per annum | 9,000 | 0 | 15 | 10,887 | 1.428 | 0.104 |

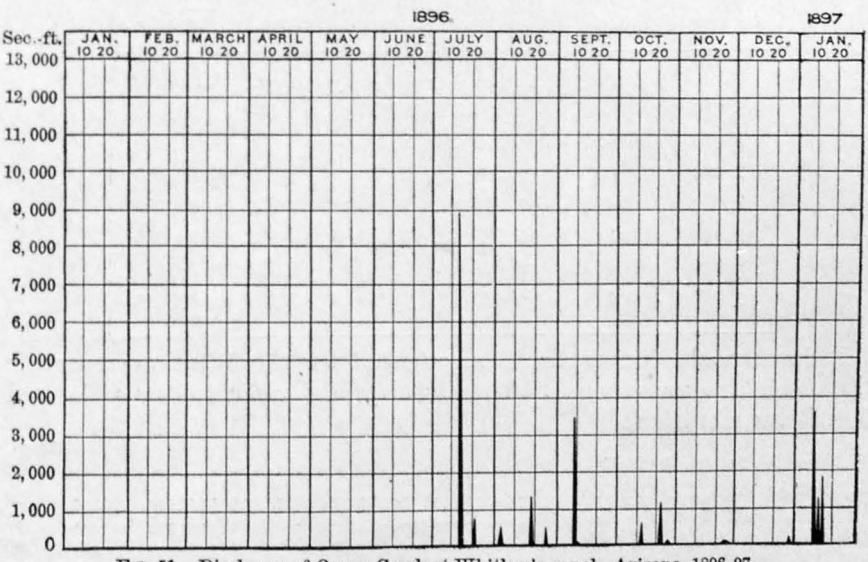



FIG. 51.—Discharge of Queen Creek at Whitlow's ranch, Arizona, 1896–97.

## WHITLOW RESERVOIR ON QUEEN CREEK.

An investigation of this storage project was made in the spring of 1896 by Mr. Arthur P. Davis in connection with an irrigation investigation for the benefit of the Indians on the Gila River Indian Reservation. Detailed discussions of the problems involved and the investigation prosecuted will be found in Senate Document No. 27, Fifty-fourth Congress, second session, page 43.

Queen Creek rises in the mountains to the east of Silver King mining camp, and flowing in a generally southwestern direction, leaves the mountain region a short distance below Whitlow's ranch, and ordinarily loses itself in the desert north of the Gila River Reservation. In times of extremely high and protracted floods the waters of this creek reach the Gila River below the range known as the Sacaton Hills. At Whitlow's ranch the creek passes between two buttes, forming a narrow rocky gorge advantageously conditioned for a dam site, and above this point the valley spreads out in a broad valley suitable for storage. A plane-table survey of the basin shows a drainage area of 142.5 square miles, of which 61 per cent is above an elevation of 3,000 feet and 39 per cent below that elevation. The survey of the reservoir was made in 10-foot contours to an elevation 140 feet above the bed of the creek at the dam site. About this elevation a natural spillway occurs, but it would never be advisable to build a dam to this height, as there is not sufficient water to fill the reservoir it would form, except in years of abnormal rainfall and run-off. The height of dam estimated is 115 feet above the bed of the creek. Soundings with rods along three sections of the dam site indicate a maximum depth to bed rock of about 32 feet. One small frame house and one abandoned adobe cabin are on the reservoir site, there being no other improvements.

*Area and capacity of Queen Creek reservoir.*

| Contour. | Area. | Capacity. | Contour. | Area. | Capacity. |
|---|---|---|---|---|---|
| | *Acres.* | *Acre-feet.* | | *Acres.* | *Acre-feet.* |
| 2,060 | 8 | 40 | 2,130 | 445 | 12,605 |
| 2,070 | 22 | 190 | 2,140 | 538 | 17,520 |
| 2,080 | 52 | 560 | 2,150 | 630 | 23,360 |
| 2,090 | 112 | 1,380 | 2,160 | 757 | 30,795 |
| 2,100 | 209 | 2,985 | 2,170 | 894 | 39,050 |
| 2,110 | 279 | 5,425 | 2,180 | 1,019 | 48,615 |
| 2,120 | 356 | 8,600 | 2,190 | 1,191 | 59,665 |

Following is a list of lands segregated for the Whitlow reservoir site. All are unsurveyed. The descriptions refer to the Gila and Salt River meridian:

| | Acres. |
|---|---|
| SE. ¼ sec. 36, T. 1 S., R. 10 E. | 160 |
| E. ½ NE. ¼ sec. 36, T. 1 S., R. 10 E. | 80 |
| SE. ¼ SE. ¼ sec. 25, T. 1 S., R. 10 E. | 40 |
| All of sec. 31, T. 1 S., R. 11 E. | 640 |
| SW. ¼ sec. 32, T. 1 S., R. 11 E. | 160 |
| W. ½ NW. ¼ sec. 32, T. 1 S., R. 11 E. | 80 |
| SE. ¼ NW. ¼ sec. 32, T. 1 S., R. 11 E. | 40 |
| NE. ¼ sec. 32, T. 1 S., R. 11 E. | 160 |
| NW. ¼ SE. ¼ sec. 32, T. 1 S., R. 11 E. | 40 |
| W. ½ NW. ¼ sec. 33, T. 1 S., R. 11 E. | 80 |
| SE. ¼ NW. ¼ sec. 33, T. 1 S., R. 11 E. | 40 |
| SW. ¼ SW. ¼ sec. 30, T. 1 S., R. 11 E. | 40 |
| S. ½ SE. ¼ sec. 29, T. 1 S., R. 11 E. | 80 |
| NW. ¼ NW. ¼ sec. 5, T. 2 S., R. 11 E. | 40 |

RESERVOIR DAM SITE ON SALT RIVER, FROM ENTRANCE OF CANYON.

| | Acres. |
|---|---|
| E. ¼ NW. ¼ sec. 6, T. 2 S., R. 11 E | 80 |
| NW. ¼ NW. ¼ sec. 6, T. 2 S., R. 11 E | 40 |
| W. ½ NE. ¼ sec. 6, T. 2 S., R. 11 E | 80 |
| NE. ¼ NE. ¼ sec. 6, T. 2 S., R. 11 E | 40 |
| Total | 1,920 |

## SALT AND VERDE RIVERS.

The measurements made by the Hudson Reservoir and Canal Company, described in Bulletin 140, page 205, were continued during a portion of 1896, and have been kindly furnished to this office by that company. A measurement made on the Salt River one-fourth of a mile above Verde, June 12, 1896, by Mr. Cyrus C. Babb, showed a gage height of 0.68 foot and a discharge of 220 second-feet. A measurement made by Mr. Babb on the same date on the Verde River 1 mile above its mouth showed a gage height of 4.24 feet and a discharge of 117 second-feet.

*Estimated monthly discharge of Verde River at mouth.*

[Drainage area, 6,000 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 33,000 | 527 | 4,037 | 248,225 | 0.77 | 0.67 |
| February | 5,800 | 583 | 1,688 | 93,747 | 0.29 | 0.28 |
| March | 8,400 | 1,887 | 3,720 | 228,734 | 0.71 | 0 62 |
| April | 2,800 | 280 | 750 | 44,628 | 0.14 | 0.13 |
| May | 429 | 127 | 258 | 15,864 | 0.04 | 0.04 |
| June | 180 | 129 | 153 | 9,104 | 0.03 | 0.03 |
| July | 275 | 116 | 145 | 8,916 | 0.02 | 0.02 |
| August | 1,426 | 185 | 359 | 22,074 | 0.07 | 0.06 |
| September | 348 | 141 | 176 | 10,473 | 0.03 | 0.03 |
| October | 3,912 | 197 | 475 | 29,207 | 0.09 | 0.08 |
| November | 1,800 | 241 | 463 | 27,550 | 0.09 | 0.08 |
| December | 881 | 345 | 391 | 24,042 | 0.08 | 0.07 |
| Per annum | 33,000 | 116 | 1,051 | 762,564 | 2.36 | 0.18 |
| 1896. | | | | | | |
| January | 354 | 314 | 324 | 19,923 | 0.06 | 0.05 |
| February | 352 | 278 | 154 | 8,852 | 0.03 | 0.03 |
| March | 338 | 258 | 276 | 16,971 | 0.06 | 0.05 |
| April | 237 | 206 | 220 | 13,090 | 0.04 | 0.04 |
| May | 206 | 138 | 172 | 10,576 | 0.03 | 0.03 |
| June | 137 | 101 | 117 | 6,962 | 0.02 | 0.02 |
| July | 3,380 | 98 | 864 | 53,127 | 0.16 | 0.14 |

*Estimated monthly discharge of Salt River above mouth of Verde.*

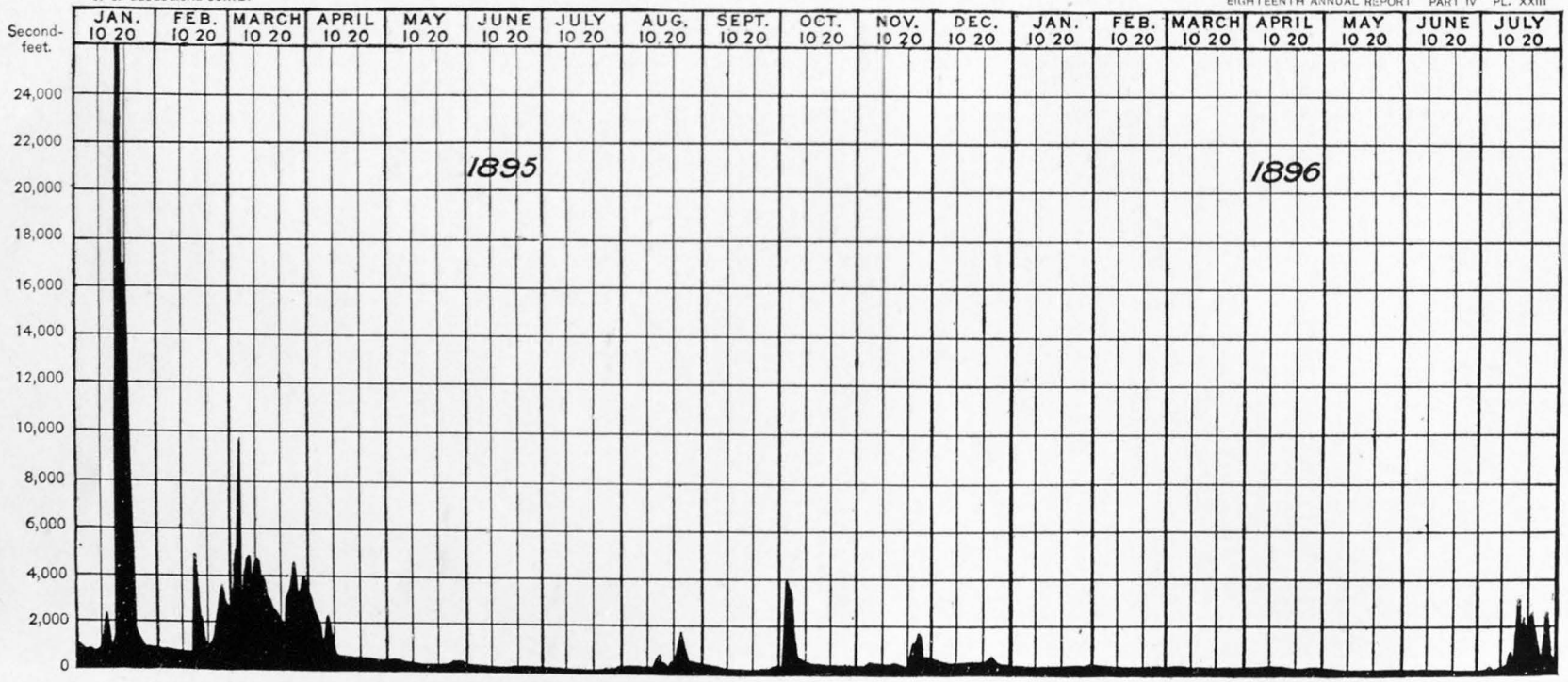
[Drainage area, 6,260 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 49,796 | 791 | 5,733 | 352,508 | 1.06 | 0.92 |
| February | 3,892 | 914 | 1,445 | 80,251 | 0.24 | 0.23 |
| March | 3,340 | 1,319 | 1,829 | 112,461 | 0.33 | 0.29 |
| April | 2,939 | 1,044 | 1,860 | 110,678 | 0.33 | 0.30 |
| May | 990 | 505 | 708 | 43,533 | 0.13 | 0.11 |
| June | 500 | 203 | 325 | 19,339 | 0.06 | 0.05 |
| July | 896 | 145 | 204 | 12,543 | 0.03 | 0.03 |
| August | 1,516 | 226 | 584 | 35,909 | 0.10 | 0.09 |
| September | 684 | 201 | 329 | 19,577 | 0.06 | 0.05 |
| October | 13,205 | 390 | 1,624 | 99,856 | 0.30 | 0.26 |
| November | 9,620 | 380 | 1,376 | 81,878 | 0.25 | 0.22 |
| December | 2,055 | 513 | 888 | 54,601 | 0.16 | 0.14 |
| Per annum | 49,796 | 145 | 1,409 | 1,023,134 | 3.05 | 0.22 |
| 1896. | | | | | | |
| January | 613 | 400 | 470 | 28,900 | 0.08 | 0.07 |
| February | 612 | 414 | 476 | 27,380 | 0.09 | 0.08 |
| March | 3,020 | 457 | 1,185 | 72,863 | 0.22 | 0.19 |
| April | 1,660 | 605 | 959 | 57,061 | 0.17 | 0.15 |
| May | 621 | 335 | 446 | 27,424 | 0.08 | 0.07 |
| June | 332 | 158 | 224 | 13,328 | 0.04 | 0.04 |
| July | 4,377 | 151 | 639 | 39,292 | 0.12 | 0.10 |

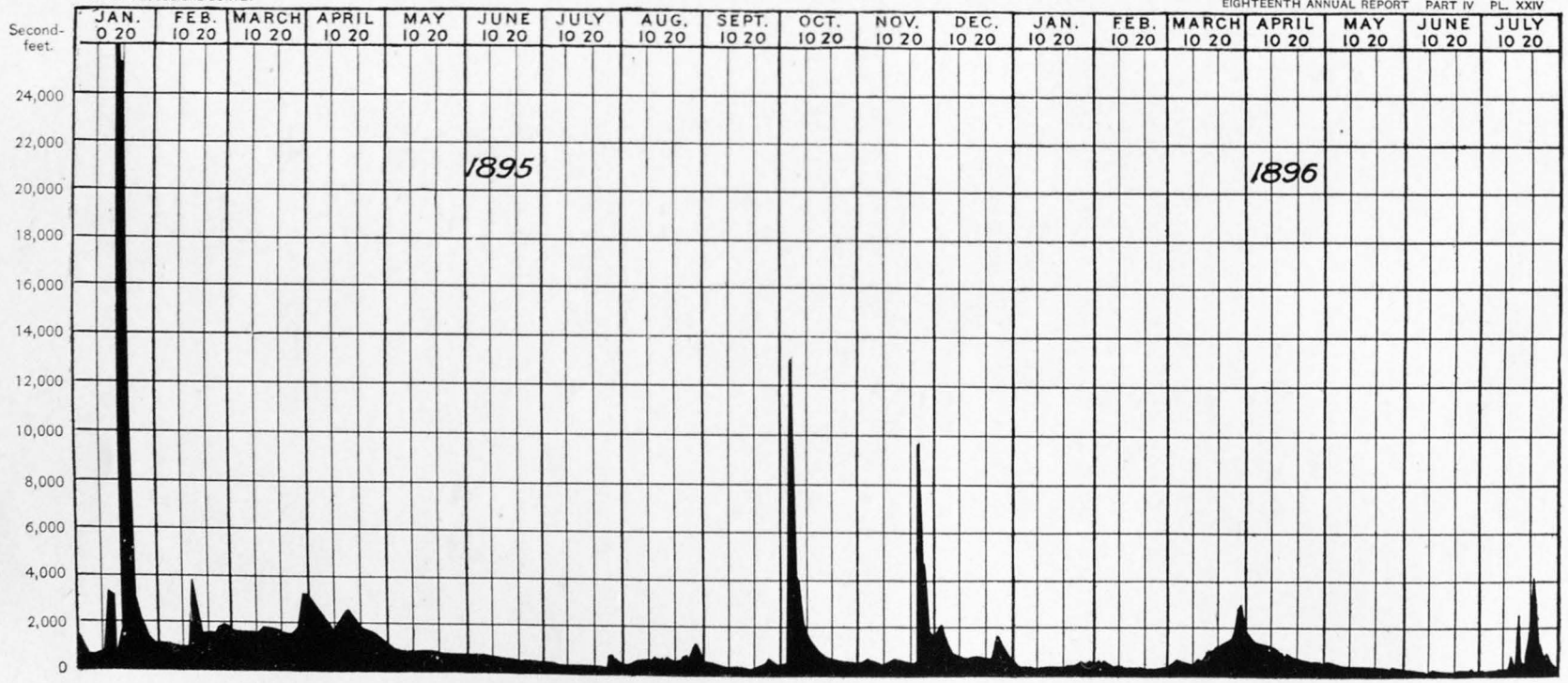
## LOWER COLORADO RIVER.

### YUMA STATION ON COLORADO RIVER.

This station is described in Bulletin No. 131, page 51. Records of river height from 1891 to December 31, 1895, have been published in Bulletins No. 131 and No. 140. The gage at this point, reading from 10 to 22 feet, is nailed to the lower side of the first pier on the south bank of the river; the portion reading from 22 feet to 40 feet is nailed to a large post on the north side, east of the bridge. The figures of gage height, plus 100, indicate the elevation above sea level according to the South Pacific elevation. The channel of the river shifts so rapidly, scouring or filling with every change of river height, that it is not possible with the funds available to obtain a reliable record of discharge. One measurement, however, was made on May 20, 1896, when the gage




DISCHARGE OF RIO VERDE ABOVE SALT RIVER, 1895–96.




DISCHARGE OF SALT RIVER ABOVE JUNCTION WITH RIO VERDE, 1895-96.

stood at 22 feet and 2 inches. The river was at this time about at the maximum of its spring flood, according to the record of the bridge watchman. An effort was made to sound by lowering the weight from the downstream side of the bridge and guying it with a line to the upstream edge. It was found, however, that a point was quickly reached below which the guy line and the current would take up all of the rod, and the sounding line would become slack, as if the lead had reached the bottom. Only surface velocities were taken, it being impossible to get the meter to the bottom of the river. The mean velocity was assumed as 95 per cent of the surface velocity, which gave 7.7 feet, the total discharge being about 58,000 cubic feet per second. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 73.

*List of discharge measurements made on Colorado River at Yuma, Arizona.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| | 1876. | | | | | |
| *a* | Mar. 20 | ..... | ..... | ..... | ..... | *a* 7,659 |
| | 1895. | | | | | |
| 1 | Jan. 17 | A. P. Davis ..... | 24 | 19.66 | 3.80 | 9,737 |
| 2 | Apr. 18 | J. B. Lippincott ..... | 24 | 20.25 | 5.23 | 21,095 |
| 3 | July 10 | .....do ..... | 24 | 21.20 | 5.46 | 45,533 |
| | 1896. | | | | | |
| 4 | May 20 | J. B. Lippincott ..... | ..... | 22.20 | 7.70 | 58,000 |

*a* Twelfth Annual Report United States Geological Survey, Part II, p. 292.

## INTERIOR BASIN IN NEVADA.

This subdivision of the Great Interior Basin includes the entire western portion of the basin draining into the various sinks in Nevada and northeastern California, the principal of which are Pyramid Lake and Carson Sink. The principal rivers are Truckee, Carson, Walker, and Humboldt. Measurements in this region have been under the supervision of Mr. L. H. Taylor.

### HUMBOLDT RIVER.

#### ELKO STATION ON HUMBOLDT RIVER.

This station was established by Mr. L. H. Taylor on June 17, 1895, at a point 1 mile southwest of the town of Elko. At that time the gage was placed in the right bank of the river, about 100 feet above the county highway bridge, but this gage was carried away early in April, 1896. On April 11, 1896, an inclined gage, fastened to iron

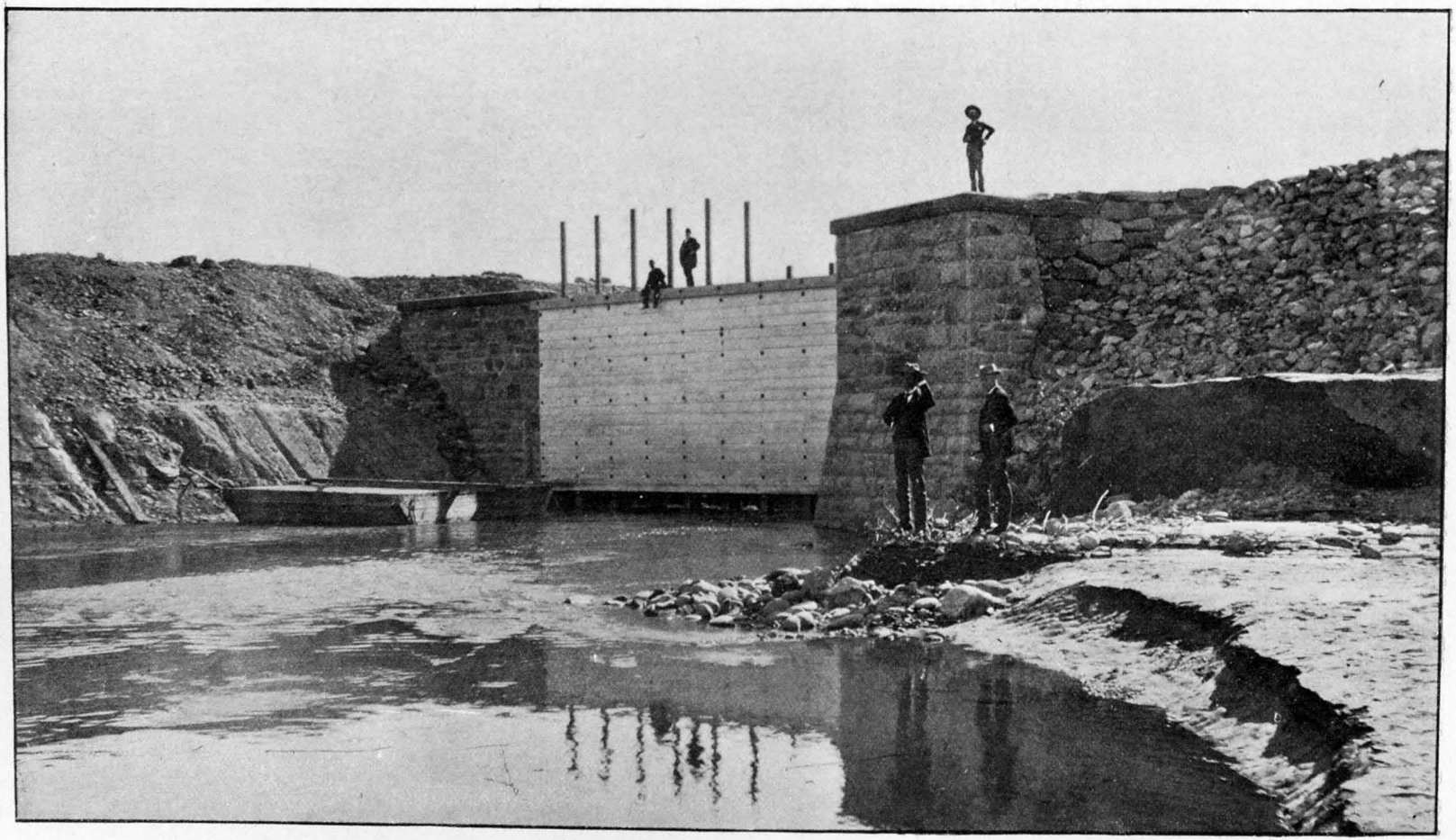
bolts driven into the solid rock, was placed on the left bank immediately below the bridge. Measurements are made from the bridge. The bench mark is on the southwest corner of the cofferdam surrounding a stone pier of the bridge, 80 feet north of the gage, and is at an elevation of 7.5 feet above zero on the gage, which latter is 1.5 feet below the zero of the original gage. The channel is straight, both above and below this point; the right bank is quite low, but the left is high and rocky. The bed of the stream is of gravel and sand, shifting slightly. The observations of river heights have been made daily throughout the year, excepting during the month of March, when they were discontinued from lack of funds to pay the observer, and the first ten days of April, when the gage was not in place, and excepting also the months of November and December, during which time they have been made from one to four times per week, and intermediate heights interpolated. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 73.

*List of discharge measurements made on Humboldt River, at Elko, Nevada.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 17 | L. H. Taylor..... | 100 | 1.50 | ..... | 2.50 | 186 |
| 2 | July 13 | .....do ..... | 100 | 0.80 | ..... | 1.14 | 48 |
| 3 | Sept. 5 | .....do ..... | 100 | 0.30 | ..... | 0.25 | 4 |
| 4 | Dec. 14 | .....do ..... | 100 | 0.55 | ..... | 0.62 | 19 |
| | 1896. | | | | | | |
| 5 | Feb. 19 | L. H. Taylor..... | 100 | 0.72 | 40 | 1.30 | *a* 52 |
| 6 | April 11 | .....do ..... | 100 | 3.45 | 146 | 2.06 | *b* 302 |
| 7 | June 7 | .....do ..... | 100 | 7.60 | 677 | 2.68 | 181 |
| 8 | June 24 | .....do ..... | 100 | 7.05 | 603 | 2.58 | 1,556 |
| 9 | July 10 | .....do ..... | 100 | 4.15 | 196 | 2.78 | 545 |
| 10 | July 21 | .....do ..... | 29 | 3.20 | 136 | 1.36 | 185 |
| 11 | Aug. 1 | .....do ..... | 29 | 2.60 | 104 | 1.00 | 103 |
| 12 | Aug. 28 | .....do ..... | 100 | 2.05 | 68 | 0.26 | 17 |
| 13 | Sept. 30 | .....do ..... | 100 | 1.90 | 46 | 0.20 | 9 |

*a* At old gage.

*b* New gage. On this gage 1.50′ corresponds to 0′ on old. Location at bridge, 100 feet below old gage.



HEAD GATES OF MESA CONSOLIDATED CANAL ON SALT RIVER.

*Rating table for Humboldt River at Elko, Nevada.*

[Constructed by L. H. Taylor, from discharge measurements Nos. 5 to 13.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet* | *Feet.* | *Sec. feet.* |
| 1.90 | 10 | 3.40 | 285 | 4.90 | 810 | 6.40 | 1,372 |
| 2.00 | 20 | 3.50 | 314 | 5.00 | 847 | 6.50 | 1,410 |
| 2.10 | 30 | 3.60 | 344 | 5.10 | 884 | 6.60 | 1,448 |
| 2.20 | 41 | 3.70 | 376 | 5.20 | 921 | 6.70 | 1,486 |
| 2.30 | 53 | 3.80 | 409 | 5.30 | 958 | 6.80 | 1,524 |
| 2.40 | 67 | 3.90 | 443 | 5.40 | 995 | 6.90 | 1,562 |
| 2.50 | 83 | 4.00 | 478 | 5.50 | 1,032 | 7.00 | 1,600 |
| 2.60 | 101 | 4.10 | 514 | 5.60 | 1,069 | 7.10 | 1,638 |
| 2.70 | 120 | 4.20 | 551 | 5.70 | 1,106 | 7.20 | 1,676 |
| 2.80 | 140 | 4.30 | 588 | 5.80 | 1,144 | 7.30 | 1,714 |
| 2.90 | 161 | 4.40 | 625 | 5.90 | 1,182 | 7.40 | 1,752 |
| 3.00 | 183 | 4.50 | 662 | 6.00 | 1,220 | 7.50 | 1,790 |
| 3.10 | 206 | 4.60 | 699 | 6.10 | 1,258 | 7.60 | 1,829 |
| 3.20 | 231 | 4.70 | 736 | 6.20 | 1,296 | 7.70 | 1,868 |
| 3.30 | 257 | 4.80 | 773 | 6.30 | 1,334 | | |

*Estimated monthly discharge of Humboldt River at Elko, Nevada.*

[Drainage area, 2,840 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 60 | 20 | 36 | 2,214 | 0.015 | 0.013 |
| February | 78 | 41 | 55 | 3,164 | 0.021 | 0.019 |
| March | 314 | 53 | 125 | 7,686 | 0.051 | 0.044 |
| April | 478 | 299 | 386 | 22,969 | 0.152 | 0.136 |
| May | 680 | 314 | 416 | 25,579 | 0.169 | 0.146 |
| June | 1,848 | 958 | 1,665 | 99,074 | 0.631 | 0.586 |
| July | 1,032 | 101 | 413 | 25,395 | 0.167 | 0.145 |
| August | 101 | 20 | 48 | 2,951 | 0.019 | 0.017 |
| September | 20 | 10 | 13 | 774 | 0.005 | 0.005 |
| October | 36 | 15 | 27 | 1,660 | 0.011 | 0.009 |
| November | 67 | 20 | 50 | 2,975 | 0.020 | 0.018 |
| December | 87 | 53 | 74 | 4,550 | 0.030 | 0.026 |
| Per annum | 1,848 | 10 | 276 | 198,991 | 1.291 | 0.097 |

## BATTLE MOUNTAIN STATION ON HUMBOLDT RIVER.

This station was established by Mr. L. H. Taylor on June 21, 1896, at which time the river was at the maximum flood stage for the season. It is located at the county highway bridge three-fourths of a mile northeast of the town of Battle Mountain. C. R. Taylor is the observer, and observations are made daily in the afternoon. The gage is vertical and is spiked to the timber wing wall immediately above the bridge, on the left bank. The bench mark is on a spike in the tie beam at the east side of the bridge near the south end, at an elevation of 10 feet above zero on the gage. The channel is curved at this point, and the banks are low and liable to overflow at high water. There are also several sloughs or side channels, so at extreme high water it is not possible to obtain an accurate measurement of the flow of the stream. However, since this is the point where the Humboldt River has its greatest flow, an attempt has been made to measure it. The bed of the stream is of sand and gravel, and shifts considerably. Six discharge measurements have been made, and a rating table constructed from them. The record of daily gage heights for 1896, from June 28 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 74.

*List of discharge measurements made on Humboldt River at Battle Mountain, Nevada.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| June 21 | L. H. Taylor..... | 100 | 8.40 | ..... | ..... | 3,000.00 |
| July 13 | .....do ..... | 29 | 5.00 | 285. | 2.61 | 742.00 |
| July 20 | .....do ..... | 29 | 3.80 | 187. | 2.76 | 515.00 |
| Aug. 14 | .....do ..... | 100 | 1.27 | 24.60 | 1.78 | 43.77 |
| Sept. 14 | .....do ..... | 100 | 0.80 | 9. | 1.54 | 13.81 |
| Dec. 31 | .....do ..... | 100 | 2.20 | 55. | 2.70 | 147.00 |

*Rating table for Humboldt River at Battle Mountain, Nevada.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.70 | 9 | 1.40 | 55 | 2.10 | 137 | 2.80 | 251 |
| 0.80 | 14 | 1.50 | 65 | 2.20 | 151 | 2.90 | 270 |
| 0.90 | 19 | 1.60 | 75 | 2.30 | 166 | 3.00 | 290 |
| 1.00 | 25 | 1.70 | 86 | 2.40 | 182 | 3.10 | 310 |
| 1.10 | 31 | 1.80 | 98 | 2.50 | 198 | 3.20 | 331 |
| 1.20 | 38 | 1.90 | 110 | 2.60 | 215 | 3.30 | 352 |
| 1.30 | 46 | 2.00 | 123 | 2.70 | 233 | 3.40 | 374 |

*Rating table for Humboldt River at Battle Mountain, Nevada*—Continued.

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.50 | 397 | 4.80 | 744 | 6.10 | 1,249 | 7.40 | 2,064 |
| 3.60 | 420 | 4.90 | 775 | 6.20 | 1,299 | 7.50 | 2,144 |
| 3.70 | 444 | 5.00 | 807 | 6.30 | 1,351 | 7.60 | 2,227 |
| 3.80 | 469 | 5.10 | 840 | 6.40 | 1,405 | 7.70 | 2,313 |
| 3.90 | 494 | 5.20 | 874 | 6.50 | 1,461 | 7.80 | 2,401 |
| 4.00 | 520 | 5.30 | 909 | 6.60 | 1,519 | 7.90 | 2,492 |
| 4.10 | 546 | 5.40 | 946 | 6.70 | 1,579 | 8.00 | 2,586 |
| 4.20 | 573 | 5.50 | 985 | 6.80 | 1,641 | 8.10 | 2,684 |
| 4.30 | 600 | 5.60 | 1,025 | 6.90 | 1,705 | 8.20 | 2,786 |
| 4.40 | 628 | 5.70 | 1,067 | 7.00 | 1,771 | 8.30 | 2,892 |
| 4.50 | 656 | 5.80 | 1,110 | 7.10 | 1,840 | 8.40 | 3,001 |
| 4.60 | 685 | 5.90 | 1,155 | 7.20 | 1,912 | 8.50 | 3,113 |
| 4.70 | 714 | 6.00 | 1,201 | 7.30 | 1,987 | | |

*Estimated monthly discharge of Humboldt River at Battle Mountain, Nevada.*

[Drainage area, 7,800 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| May | 1,519 | 321 | 743 | 45,686 | 0.109 | 0.095 |
| June | 3,001 | 1,579 | 2,664 | 158,519 | 0.349 | 0.342 |
| July | 2,586 | 166 | 971 | 59,705 | 0.143 | 0.125 |
| August | 137 | 14 | 48 | 2,951 | 0.007 | 0.006 |
| September | 31 | 11 | 16 | 952 | 0.002 | 0.002 |
| October | 55 | 14 | 26 | 1,599 | 0.004 | 0.003 |
| November | 104 | 55 | 82 | 4,879 | 0.012 | 0.011 |
| December | 151 | 98 | 121 | 7,440 | 0.018 | 0.016 |

## GOLCONDA STATION ON HUMBOLDT RIVER.

This station, described in Bulletins No. 131, page 52, and No. 140 page 217, was established on October 24, 1894, by Mr. L. H. Taylor, and has been maintained continuously since that time. The station is 1¼ miles northerly from the town of Golconda. The observer is Mr. L. Dutertre, a farmer and merchant. The observations have been taken each day at about 5 p. m. The gage is vertical and is spiked to posts driven into the left bank of the river. There are two bench marks, one on a 2 by 4 inch post driven flush with the ground surface 20 feet from

the gage, and the other on a large spike driven into a post which is firmly set about 15 feet from the gage. The first is at an elevation of 10.55 feet and the second 13.70 feet above zero on the gage. Measurements are made from a cable and suspended car. The channel is nearly straight for about 400 feet. The banks are moderately high, but liable to overflow at extreme flood stages, perhaps once in four or five years. The bed of the stream is of gravel and sand, shifting somewhat. Fifteen measurements have been made in 1896, and a rating table constructed which is here given. Anderson's ditch is diverted a short distance above the station, and has also been measured a number of times. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 74.

*List of discharge measurements made on Humboldt River at Golconda, Nevada.*

[Where two sets of figures occur the upper figures represent Anderson's Ditch.]

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Oct. 24 | L. H. Taylor..... | 100 | 1.30 | ..... | 1.29 | 57 |
| 2 | Dec. 4 | .....do ..... | 100 | 2.00 | ..... | 1.34 | 114 |
| | 1895. | | | | | | |
| 3 | Mar 22 | L. H. Taylor..... | 100 | 3.82 | ..... | 2.12 | 463 |
| 4 | June 21 | .....do ..... | 100 | 2.55 | ..... | 1.35 | 2?4 |
| 5 | July 12 | .....do ..... | 100 | 1.62 | ..... | 1.15 | 96 |
| 6 | Aug. 12 | .....do ..... | 100 | 0.05 | ..... | 0.91 | 11 |
| 7 | Sept. 8 | .....do ..... | 100 | —0.30 | ..... | 1.20 | 1 |
| | 1896. | | | | | | |
| 8 | Jan. 26 | L. H. Taylor..... | 100 | 1.00 | 60 | 0.92 | 55 |
| 9 | Feb. 10 | .....do ..... | 100 | 1.52 | 69 | 1.35 | 93 |
| 10 | Mar. 19 | .....do ..... | 100 | 1.20<br>0.20 | 11<br>18 | 0.48<br>0.89 | 5<br>17 |
| 11 | Apr. 15 | .....do ..... | 100 | 2.20<br>1.45 | 25<br>71 | 0.74<br>1.27 | 19<br>90 |
| 12 | May 18 | .....do ..... | 100 | 2.50<br>3.30 | 34<br>191 | .....<br>1.59 | 21<br>304 |
| 13 | June 6 | .....do ..... | 100 | 3.10<br>4.80 | 48<br>295 | .....<br>1.73 | 33<br>509 |
| 14 | June 15 | .....do ..... | 100 | .....<br>5.93 | 48<br>388 | .....<br>2.40 | 33<br>930 |
| 15 | June 25 | .....do ..... | 100 | .....<br>7.05 | 48<br>474 | .....<br>2.89 | 33<br>1,370 |
| 16 | July 14 | .....do ..... | 29 | 3.10<br>5.05 | 48<br>303 | .....<br>2.05 | 33<br>620 |
| 17 | July 25 | .....do ..... | 29 | 2.00<br>3.50 | 26<br>206 | .....<br>1.51 | 16<br>310 |
| 18 | Aug. 7 | .....do ..... | 29 | 1.20<br>2.20 | 11<br>117 | .....<br>1.12 | 5<br>131 |

*List of discharge measurements made on Humboldt River at Golconda, Nevada*—Continued.

[Where two sets of figures occur the upper figures represent Anderson's Ditch.]

| No. | Date. | Hydrographer. | Meter. number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 19 | Aug. 22 | .....do ..... | 100 | 1.05 | 54 | 1.07 | 58 |
| 20 | Sept. 26 | .....do ..... | 100 | 0.15 | 20 | 0.79 | 16 |
| 21 | Oct. 19 | .....do ..... | 100 | 0.70 | 40 | 0.91 | 36 |
| 22 | Dec. 27 | .....do ..... | 100 | 2.00 | 89 | 1.38 | 123 |

*Rating table for Humboldt River at Golconda, Nevada, constructed by L. H. Taylor, from discharge measurements Nos. 8 to 22.*

[Where two sets of figures occur the upper figures represent discharge of Anderson's Ditch.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.00 | 13 | 1.80 | 13 | 3.30 | 36 | 5.20 | 637 |
| 0.10 | 15 | | 110 | | 282 | 5.30 | 664 |
| 0.20 | 17 | 1.90 | 14 | 3.40 | 37 | 5.40 | 692 |
| 0.30 | 20 | | 119 | | 296 | 5.50 | 722 |
| 0.40 | 1 | 2.00 | 15 | 3.50 | 39 | 5.60 | 754 |
| | 23 | | 128 | | 311 | 5.70 | 788 |
| 0.50 | 27 | 2.10 | 17 | 3.60 | 41 | 5.80 | 824 |
| 0.60 | 2 | | 137 | | 326 | 5.90 | 862 |
| | 31 | 2.20 | 18 | 3.70 | 42 | 6.00 | 902 |
| 0.70 | 36 | | 147 | | 341 | 6.10 | 944 |
| 0.80 | 3 | 2.30 | 20 | 3.80 | 44 | 6.20 | 988 |
| | 41 | | 157 | | 357 | 6.30 | 1,033 |
| 0.90 | 46 | 2.40 | 21 | 3.90 | 46 | 6.40 | 1,080 |
| 1.00 | 4 | | 168 | | 373 | 6.50 | 1,128 |
| | 52 | 2.50 | 22 | 4.00 | 48 | 6.60 | 1,178 |
| 1.10 | 5 | | 179 | | 390 | 6.70 | 1,229 |
| | 58 | 2.60 | 24 | 4.10 | 49 | 6.80 | 1,281 |
| 1.20 | 6 | | 191 | | 407 | 6.90 | 1,334 |
| | 64 | 2.70 | 26 | 4.20 | 51 | 7.00 | 1,388 |
| 1.30 | 7 | | 203 | | 425 | 7.10 | 1,443 |
| | 71 | 2.80 | 27 | 4.30 | 443 | 7.20 | 1,499 |
| 1.40 | 8 | | 215 | 4.40 | 462 | 7.30 | 1,556 |
| | 78 | 2.90 | 29 | 4.50 | 481 | 7.40 | 1,614 |
| 1.50 | 9 | | 228 | 4.60 | 501 | 7.50 | 1,674 |
| | 86 | 3.00 | 31 | 4.70 | 522 | 7.60 | 1,735 |
| 1.60 | 10 | | 241 | 4.80 | 543 | | |
| | 94 | 3.10 | 32 | 4.90 | 565 | | |
| 1.70 | 11 | | 254 | 5.00 | 588 | | |
| | 102 | 3.20 | 34 | 5.10 | 612 | | |
| | | | 268 | | | | |

*Estimated monthly discharge of Humboldt River at Golconda, Nevada.*

[Drainage area, 10,780 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 102 | 14 | 42 | 2,582 | 0.005 | 0.004 |
| February | 110 | 31 | 78 | 4,487 | 0.008 | 0.007 |
| March | 38 | 17 | 28 | 1,722 | 0.003 | 0.003 |
| April | 191 | 20 | 128 | 7,617 | 0.013 | 0.012 |
| May | 373 | 197 | 303 | 18,631 | 0.028 | 0.028 |
| June | 1,614 | 390 | 1,009 | 60,040 | 0.104 | 0.094 |
| July | 1,614 | 241 | 752 | 46,239 | 0.080 | 0.070 |
| August | 241 | 36 | 108 | 6,641 | 0.012 | 0.010 |
| September | 36 | 17 | 22 | 1,309 | 0.002 | 0.002 |
| October | 46 | 20 | 33 | 2,029 | 0.004 | 0.003 |
| November | 102 | 49 | 80 | 4,760 | 0.008 | 0.007 |
| December | 147 | 94 | 125 | 7,686 | 0.013 | 0.012 |
| Per annum | 1,614 | 14 | 226 | 163,743 | 0.280 | 0.021 |

## OREANA STATION ON HUMBOLDT RIVER.

This station was established by Mr. L. H. Taylor on January 27, 1896, at the old Oreana highway bridge, about 12 miles northeast of Lovelocks, and above all the canals diverting water for irrigation in the vicinity of that town. The observer to the end of July was Mary Luiz, succeeded by Mr. Joe Rodgers, a section foreman on the Central Pacific Railroad. The gage is vertical, and is spiked to a pile in the bridge abutment at the right bank of the river. The bench mark is on the abutment of the bridge 12 feet north of the gage, at an elevation of 11.70 feet above zero on the gage. Measurements are made from the bridge. The river banks are high and not liable to overflow. The channel is nearly straight for about 250 feet both above and below the station. The bed of the stream is sandy and shifting. Observations of the river height have been made daily up to the end of October, and since that date from one to three times per week. Eleven measurements of discharge have been made, and a rating table constructed. The record of daily gage heights for 1896, from January 27 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 75.

*List of discharge measurements made on Humboldt River at Oreana, Nevada.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| 1 | Jan. 27 | L. H. Taylor..... | 100 | 2.70 | 45 | 1.08+ | 49 |
| 2 | Apr. 9 | .....do ..... | 100 | 2.04 | 18 | 0.84+ | 15 |
| 3 | May 31 | .....do ..... | 100 | 3.95 | 105 | 2.13+ | 224 |
| 4 | June 26 | .....do ..... | 100 | 6.50 | 346 | 2.96 | 1,024 |
| 5 | July 5 | .....do ..... | 100 | 7.40 | 408 | 3.25— | 1,327 |
| 6 | July 15 | .....do ..... | 100 | 6.80 | 339 | 3.07— | 1,043 |
| 7 | July 24 | .....do ..... | 29 | 5.60 | 292 | 2.15 | 627 |
| 8 | Aug. 8 | .....do ..... | 29 | 4.15 | 152 | 1.57 | 238 |
| 9 | Aug. 27 | .....do ..... | 29 | 3.00 | 78 | 1.23 | 96 |
| 10 | Sept. 25 | .....do ..... | 29 | 2.60 | 63 | 1.09 | 69 |
| 11 | Oct. 20 | .....do ..... | 100 | 1.90 | 38 | 0.89 | 34 |

*Rating table for Humboldt River at Oreana, Nevada.*

[Constructed by L. H. Taylor from discharge measurements Nos. 1 to 11.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.90 | 20 | 3.40 | 132 | 4.90 | 428 | 6.40 | 909 |
| 2.00 | 23 | 3.50 | 145 | 5.00 | 454 | 6.50 | 950 |
| 2.10 | 27 | 3.60 | 159 | 5.10 | 480 | 6.60 | 992 |
| 2.20 | 31 | 3.70 | 174 | 5.20 | 507 | 6.70 | 1,035 |
| 2.30 | 36 | 3.80 | 190 | 5.30 | 535 | 6.80 | 1,079 |
| 2.40 | 42 | 3.90 | 207 | 5.40 | 564 | 6.90 | 1,125 |
| 2.50 | 48 | 4.00 | 225 | 5.50 | 594 | 7.00 | 1,172 |
| 2.60 | 55 | 4.10 | 244 | 5.60 | 625 | 7.10 | 1,220 |
| 2.70 | 62 | 4.20 | 264 | 5.70 | 657 | 7.20 | 1,269 |
| 2.80 | 69 | 4.30 | 285 | 5.80 | 690 | 7.30 | 1,320 |
| 2.90 | 77 | 4.40 | 307 | 5.90 | 724 | 7.40 | 1,372 |
| 3.00 | 86 | 4.50 | 330 | 6.00 | 759 | 7.50 | 1,425 |
| 3.10 | 96 | 4.60 | 354 | 6.10 | 795 | 7.60 | 1,480 |
| 3.20 | 107 | 4.70 | 378 | 6.20 | 832 | 7.70 | 1,536 |
| 3.30 | 119 | 4.80 | 403 | 6.30 | 870 | | |

*Estimated monthly discharge of Humboldt River at Oreana, Nevada.*

[Drainage area, 13,800 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| February | 73 | 63 | 72 | 4,141 | 0.005 | 0.005 |
| March | 69 | 42 | 54 | 3,320 | 0.005 | 0.004 |
| April | 42 | 24 | 28 | 1,666 | 0.002 | 0.002 |
| May | 428 | 25 | 110 | 6,764 | 0.009 | 0.008 |
| June | 1,125 | 119 | 503 | 29,931 | 0.041 | 0.036 |
| July | 1,508 | 428 | 1,001 | 61,549 | 0.084 | 0.073 |
| August | 403 | 86 | 196 | 12,052 | 0.016 | 0.014 |
| September | 107 | 48 | 70 | 4,165 | 0.006 | 0.005 |
| October | 55 | 20 | 32 | 1,968 | 0.003 | 0.002 |
| December | 107 | 62 | 79 | 4,858 | 0.007 | 0.006 |

## BATTLE MOUNTAIN STATION ON ROCK CREEK.

This station was established by Mr. L. H. Taylor on February 12, 1896, at a point about 22 miles northeast of Battle Mountain. This stream is the last considerable tributary entering the Humboldt River on its course to the sinks 150 miles below Battle Mountain. The gaging station is located about 20 miles above the confluence of the creek and river, at the head of a narrow, rocky gorge, through which the stream flows, and which affords an excellent site for a storage-reservoir dam, the purpose of the station being the determination of the quantity of water available for impounding at this point. The observer was Mr. John S. Taylor, a laborer. The observations were taken at 8 o'clock a. m. and 5 p. m. up to the end of July, when the stream reached its lowest stage, and they were discontinued for the season.

The gage is inclined, of timber, set in the right bank and fastened to posts driven in the earth and an iron pin set in the solid rock. The bench mark is on a shelf on the side of the rock bluff, 10 feet south of the gage, at an elevation of 9.12 feet above zero on the gage. Measurements are made from a cable and suspended car. The channel is slightly curved for 160 feet above the station, and almost straight for over 250 feet below. The right bank is high and not liable to overflow; the left for 100 feet above the station is a vertical rock bluff, 50 feet high, while below the gage it is earth, low, and liable to overflow at extreme high water. The bed of the stream is sandy and shifting.

Since July the flow of the stream was nearly uniform until about September 10, when it began to rise gradually, and by the middle of

November the discharge was about double the minimum for the month of July. Five discharge measurements have been made and a rating table constructed. The record of daily gage heights for 1896, from May 12 to August 1, is given in Water-Supply and Irrigation Paper No. 11, page 75.

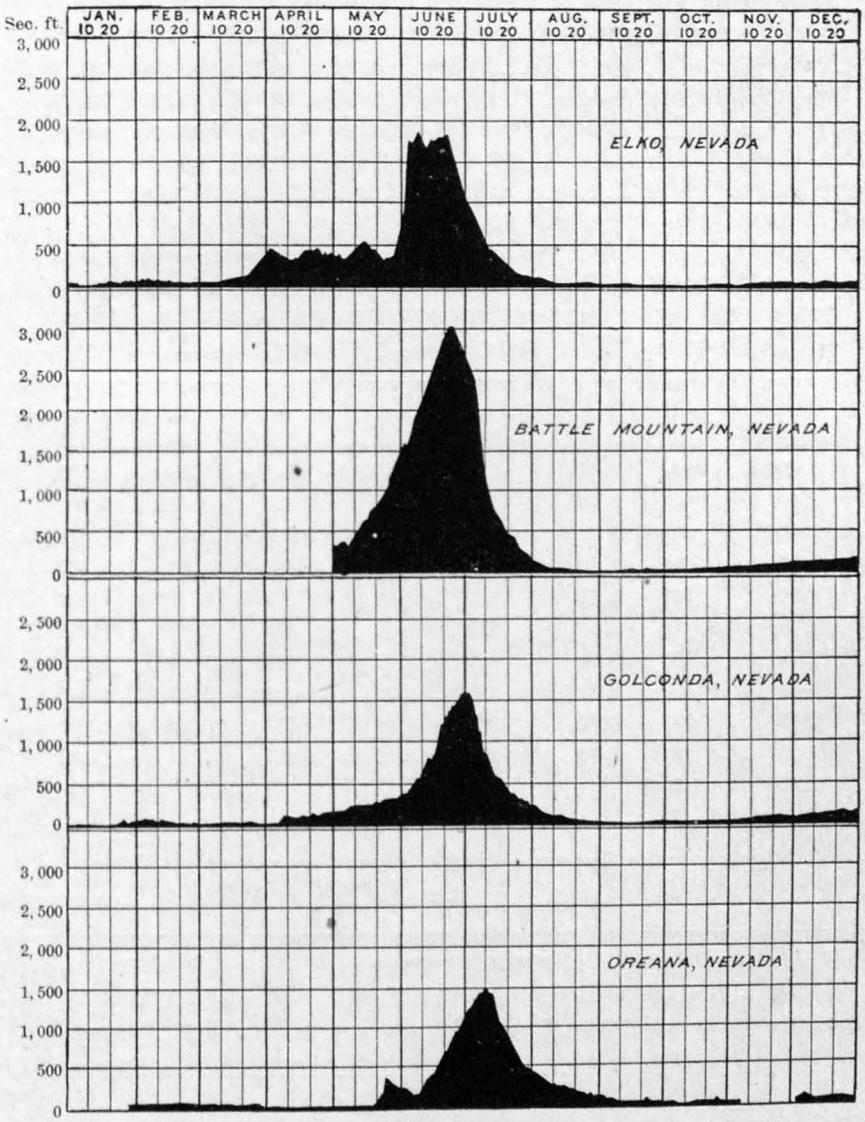



FIG. 52.—Discharge of Humboldt River at Elko, Battle Mountain, Golconda, and Oreana, Nevada, 1896.

*List of discharge measurements made on Rock Creek at Battle Mountain, Nevada.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Feb. 12 | L. H. Taylor..... | 100 | 1.90 | 12.00 | 1.07 | 13.00 |
| 2 | Apr. 26 | .....do ..... | 100 | 2.70 | 39.85 | 1.68 | 66.87 |
| 3 | June 2 | .....do ..... | 100 | 5.70 | 271.00 | 3.37 | 914.00 |
| 4 | June 13 | .....do ..... | 100 | 3.10 | 59.60 | 2.37 | 140.00 |
| 5 | Aug. 4 | .....do ..... | 100 | 1.80 | 11.00 | 1.08 | 11.06 |

*Rating table for Rock Creek at Battle Mountain, Nevada.*

[Constructed by L. H. Taylor from discharge measurements Nos. 1 to 5.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.80 | 11 | 3.00 | 117 | 4.10 | 370 | 5.20 | 724 |
| 1.90 | 14 | 3.10 | 134 | 4.20 | 399 | 5.30 | 762 |
| 2.00 | 18 | 3.20 | 152 | 4.30 | 429 | 5.40 | 801 |
| 2.10 | 23 | 3.30 | 172 | 4.40 | 459 | 5.50 | 841 |
| 2.20 | 29 | 3.40 | 193 | 4.50 | 490 | 5.60 | 882 |
| 2.30 | 36 | 3.50 | 214 | 4.60 | 521 | 5.70 | 924 |
| 2.40 | 44 | 3.60 | 237 | 4.70 | 553 | 5.80 | 967 |
| 2.50 | 53 | 3.70 | 262 | 4.80 | 585 | 5.90 | 1,011 |
| 2.60 | 63 | 3.80 | 288 | 4.90 | 618 | 6.00 | 1,056 |
| 2.70 | 75 | 3.90 | 315 | 5.00 | 652 | 6.10 | 1,102 |
| 2.80 | 88 | 4.00 | 342 | 5.10 | 687 | 6.20 | 1,149 |
| 2.90 | 102 | | | | | | |

*Estimated monthly discharge of Rock Creek near Battle Mountain, Nevada.*

[Drainage area, 750 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| March ..... | 724 | 9 | 142 | 8,731 | 0.219 | 0.19 |
| April..... ..... | 335 | 36 | 85 | 5,058 | 0.126 | 0.113 |
| May ..... | 1,102 | 75 | 500 | 30,744 | 0.744 | 0.666 |
| June..... | 1,011 | 81 | 276 | 16,423 | 0.41 | 0.367 |
| July ..... | 78 | 11 | 39 | 2,398 | 0.06 | 0.052 |

MASON'S RANCH STATION ON SOUTH FORK OF HUMBOLDT RIVER.

This station was established by Mr. L. H. Taylor on August 29, 1896, at a point on the South Fork of Humboldt River, about 10 miles southwest of the town of Elko, and about 6 miles above its junction with the main stream. Like the Rock Creek station, its purpose is the determination of the volume of water available for storage, there being a good site for a reservoir a short distance above the station. The observer is Mr. Martin Mason, a farmer. The gage is inclined and is spiked to posts driven firmly into the right bank.

There is one bench mark on a 2 by 4 inch post 2½ feet long driven flush with the ground 10 feet north of the gage, and having an elevation of 7.5 feet above zero on the gage. Measurements are made from a cable and suspended car at a point 1 mile above the gage, the latter being placed, for the convenience of the observer, near his farm. At the point of measurement the banks are high and the channel is straight for over 600 feet. The bed of the stream is of rock and gravel and is quite stable. Only two measurements of discharge have been made, so that it is not yet practicable to construct a rating table. The record of daily gage heights for 1896, from August 30 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 76.

*List of discharge measurements made on South Fork of Humboldt River at Mason's Ranch, Nevada.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | Aug. 29 | L. H. Taylor..... | 100 | 1.00 | 41 | 0.26 | 11 |
| 2 | Sept. 29 | .....do ..... | 100 | 0.95 | 33 | 0.24 | 8 |

## INTERIOR BASIN IN UTAH AND IDAHO.

This region includes that portion of the Great Interior Basin which is tributary to the Great Salt Lake. A general description of the conditions of water supply in this basin is given in Bulletin 140, beginning on page 221. Work has been carried on during 1896 on substantially the same basis as in 1895, under the charge of Professor Fortier.

### BEAR RIVER.

This is the largest stream flowing into Great Salt Lake, and is described in Bulletin 140, page 225. Two stations have been continued on this river. Besides the regular stations, Professor Fortier made an extended investigation during the summer of 1896 of a number of tribu-

taries and ditches for the purpose of determining the seepage or return waters[1] from irrigation in this basin. Measurements for this purpose were made on Cub River, Blacksmith Fork, East Canyon Creek, and South Fork of Little Bear River. A station was also established on Logan River, in addition to the two on Bear River.

### SODA SPRINGS STATION ON BEAR RIVER.

This station was established May 25, 1896, by Mr. F. J. Mills, State engineer of Idaho. It is located at the wagon bridge about 1 mile southwest of the town of Soda Springs, Idaho. The cross section is inferior, owing to its being obstructed by four bridge piers. The rod is vertical and nailed to one of the piers. The drainage area at this point is 3,940 square miles. The record of daily gage heights for 1896, from May 25 to October 2, is given in Water-Supply and Irrigation Paper No. 11, page 76.

*List of discharge measurements made on Bear River at Soda Springs, Idaho.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Mar. 8 | F. J. Mills | | 5.0 | 244 | 1.49 | 364 |
| June 11 | L. B. Kendall | Floats. | 8.30 | 942 | 6.30 | 5,927 |

*Rating table for Bear River at Soda Springs, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.10 | 0 | 5.20 | 470 | 6.30 | 1,355 | 7.40 | 3,155 |
| 4.20 | 35 | 5.30 | 525 | 6.40 | 1,475 | 7.50 | 3,385 |
| 4.30 | 70 | 5.40 | 585 | 6.50 | 1,605 | 7.60 | 3,630 |
| 4.40 | 105 | 5.50 | 650 | 6.60 | 1,740 | 7.70 | 3,890 |
| 4.50 | 145 | 5.60 | 720 | 6.70 | 1,885 | 7.80 | 4,170 |
| 4.60 | 185 | 5.70 | 795 | 6.80 | 2,040 | 7.90 | 4,470 |
| 4.70 | 225 | 5.80 | 875 | 6.90 | 2,200 | 8.00 | 4,790 |
| 4.80 | 270 | 5.90 | 960 | 7.00 | 2,370 | 8.10 | 5,140 |
| 4.90 | 315 | 6.00 | 1,050 | 7.10 | 2,550 | 8.20 | 5,520 |
| 5.00 | 365 | 6.10 | 1,145 | 7.20 | 2,740 | 8.30 | 5,930 |
| 5.10 | 425 | 6.20 | 1,245 | 7.30 | 2,940 | 8.40 | 6,380 |

[1] Seepage waters of northern Utah, by Samuel Fortier: Water-Supply and Irrigation Paper No. 7.

*Estimated monthly discharge of Bear River at Soda Springs, Idaho.*

[Drainage area, 3,940 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| May 25 to 31 | 2,370 | 1,605 | 1,880 | 26,100 | 0.13 | 0.48 |
| June | 6,380 | 3,385 | 4,605 | 274,016 | 1.31 | 1.17 |
| July | 3,155 | 875 | 1,395 | 85,775 | 0.40 | 0.35 |
| August | 960 | 525 | 675 | 41,495 | 0.20 | 0.17 |
| September | 585 | 525 | 542 | 32,251 | 0.16 | 0.14 |

## BATTLE CREEK STATION ON BEAR RIVER.

This station has been described in Bulletin 131, page 53, and Bulletin 140, page 225. It is located 5 miles northwest of Preston, Idaho. The observer is Mr. John Murdock, a farmer, living about 1,000 feet from the gage. The station is equipped with a cable and car. The gage consists of a vertical board nailed to a pile. The bench mark is a nail in the southeast corner of the house of the observer, about 1.5 feet from the ground, and it is 10.95 feet above the zero of the gage. The relation of the gage to this bench mark was tested in the fall of 1894, and again in 1896, and its accuracy verified.

The importance of such measurements to the people of southern Idaho and northern Utah is apparent upon consideration of the existing conditions. The capacity of the west branch of Bear River Canal system in Boxelder County, Utah, is 1,000 cubic feet per second, and the flow of Bear River as it crosses the line from Idaho into Utah is frequently less than would be necessary to supply this one canal. Causes of disputes are thus arising over the waters of this stream between the irrigators of southern Idaho and those of Boxelder County, Utah. Careful measurements will constitute the only reliable basis upon which to settle such rights. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 76.

*List of discharge measurements made on Bear River at Battle Creek, Idaho.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 16 | Oct. 29 | A. P. Davis..... | 24 | 1.90 | 164 | 2.12 | 980 |
| 17 | Nov. 30 | S. Fortier ..... | 106 | 1.80 | 448 | 2.30 | 1,030 |
| | 1895. | | | | | | |
| 18 | Apr. 6 | J. L. Rhead ..... | 106 | 2.68 | 620 | 3.38 | 2,092 |
| 19 | Apr. 15 | .....do ..... | 103 | 3.00 | 666 | 3.57 | 2,380 |
| 20 | Apr. 29 | .....do ..... | ..... | 2.93 | 650 | 3.50 | 2,268 |
| 21 | Oct. 14 | .....do ..... | 103 | 1.40 | 369 | 1.87 | 689 |
| | 1896. | | | | | | |
| 22 | May 24 | J. L. Rhead ..... | 103 | 2.90 | 671 | 3.36 | 2,254 |
| 23 | June 23 | .....do ..... | 103 | 4.45 | 965 | 4.09 | 3,954 |
| 24 | July 25 | S. Fortier ..... | 10 | 2.06 | 477 | 2.30 | 1,099 |
| 25 | July 25 | J. L. Rhead ..... | 106 | 2.04 | 485 | 2.47 | 1,199 |
| 26 | Sept. 5 | .....do ..... | 106 | 1.64 | 403 | 2.17 | 873 |
| 27 | Sept. 28 | .....do ..... | 10 | 1.63 | 394 | 1.87 | 737 |
| 28 | Sept. 28 | .....do ..... | 103 | 1.63 | 394 | 2.08 | 821 |

*Rating table of Bear River at Battle Creek, Idaho, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.1 | 135 | 1.6 | 800 | 3.1 | 2,335 | 4.6 | 4,150 |
| 0.2 | 145 | 1.7 | 875 | 3.2 | 2,445 | 4.7 | 4,275 |
| 0.3 | 165 | 1.8 | 970 | 3.3 | 2,560 | 4.8 | 4,400 |
| 0.4 | 190 | 1.9 | 1,065 | 3.4 | 2,675 | 4.9 | 4,525 |
| 0.5 | 220 | 2.0 | 1,165 | 3.5 | 2,785 | 5.0 | 4,650 |
| 0.6 | 250 | 2.1 | 1,255 | 3.6 | 2,900 | 5.1 | 4,775 |
| 0.7 | 285 | 2.2 | 1,365 | 3.7 | 3,025 | 5.2 | 4,805 |
| 0.8 | 320 | 2.3 | 1,470 | 3.8 | 3,155 | 5.3 | 4,930 |
| 0.9 | 360 | 2.4 | 1,570 | 3.9 | 3,280 | 5.4 | 5,055 |
| 1.0 | 410 | 2.5 | 1,675 | 4.0 | 3,405 | 5.5 | 5,180 |
| 1.1 | 455 | 2.6 | 1,780 | 4.1 | 3,530 | 5.6 | 5,305 |
| 1.2 | 520 | 2.7 | 1,885 | 4.2 | 3,655 | 5.7 | 5,430 |
| 1.3 | 580 | 2.8 | 1,990 | 4.3 | 3,780 | 5.8 | 5,555 |
| 1.4 | 650 | 2.9 | 2,100 | 4.4 | 3,905 | 5.9 | 5,680 |
| 1.5 | 725 | 3.0 | 2,220 | 4.5 | 4,025 | 6.0 | 5,805 |

*Estimated monthly discharge of Bear River at Battle Creek, Idaho.*

[Drainage area, 4,500 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 650 | 580 | 645 | 39,659 | 0.16 | 0.14 |
| February | 650 | 580 | 621 | 35,719 | 0.15 | 0.14 |
| March | 1,470 | 650 | 802 | 49,312 | 0.21 | 0.18 |
| April | 1,990 | 1,470 | 1,836 | 109,249 | 0.47 | 0.42 |
| May | 3,530 | 1,885 | 2,231 | 137,179 | 0.58 | 0.50 |
| June | 5,205 | 3,025 | 4,333 | 266,426 | 1.07 | 0.96 |
| July | 2,900 | 1,255 | 1,650 | 101,454 | 0.43 | 0.37 |
| August | 1,255 | 800 | 917 | 56,384 | 0.23 | 0.20 |
| September | 800 | 800 | 800 | 47,603 | 0.20 | 0.18 |
| October | 875 | 800 | 812 | 49,927 | 0.21 | 0.18 |
| November | 1,780 | 875 | 1,096 | 65,216 | 0.28 | 0.24 |
| December | 1,780 | 970 | 1,024 | 62,963 | 0.26 | 0.23 |
| Per annum | 5,205 | 580 | 1,397 | 1,021,091 | 4.25 | 0.31 |

## MISCELLANEOUS MEASUREMENTS.

| Date. | Stream. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|
| 1896. | | | | | |
| June 19 | South Fork of Little Bear | 1.60 | 40.9 | 4.04 | 165.25 |
| July 11 | do | 0.50 | 23.8 | 2.98 | 70.89 |
| Aug. 6 | do | 0.30 | 18.4 | 2.32 | 42.63 |
| Sept. 15 | do | 0.15 | 14.1 | 2.095 | 29.52 |
| June 19 | East Canyon Creek *a* | | 29.5 | 1.90 | 56.0 |
| Aug. 6 | do | | 15.0 | 2.34 | 35.1 |
| Sept. 15 | do | | 10.0 | 2.25 | 22.5 |
| June 18 | Blacksmith Fork *b* | 1.20 | 86.9 | 3.40 | 302.37 |
| June 29 | do | 1.00 | 79.0 | 3.34 | 264.00 |
| July 10 | do | 0.93 | 75.2 | 3.072 | 230.40 |
| Aug. 5 | do | 0.86 | 73.5 | 2.960 | 218.77 |
| Sept. 15 | do | 0.84 | 65.0 | 2.757 | 181.23 |

*a* Measurements of East Canyon Creek were made a short distance above the head gate of Paradise Canal.

*b* Measurements of Blacksmith Fork were made about 1 mile below the mouth of Black Fork Canyon.

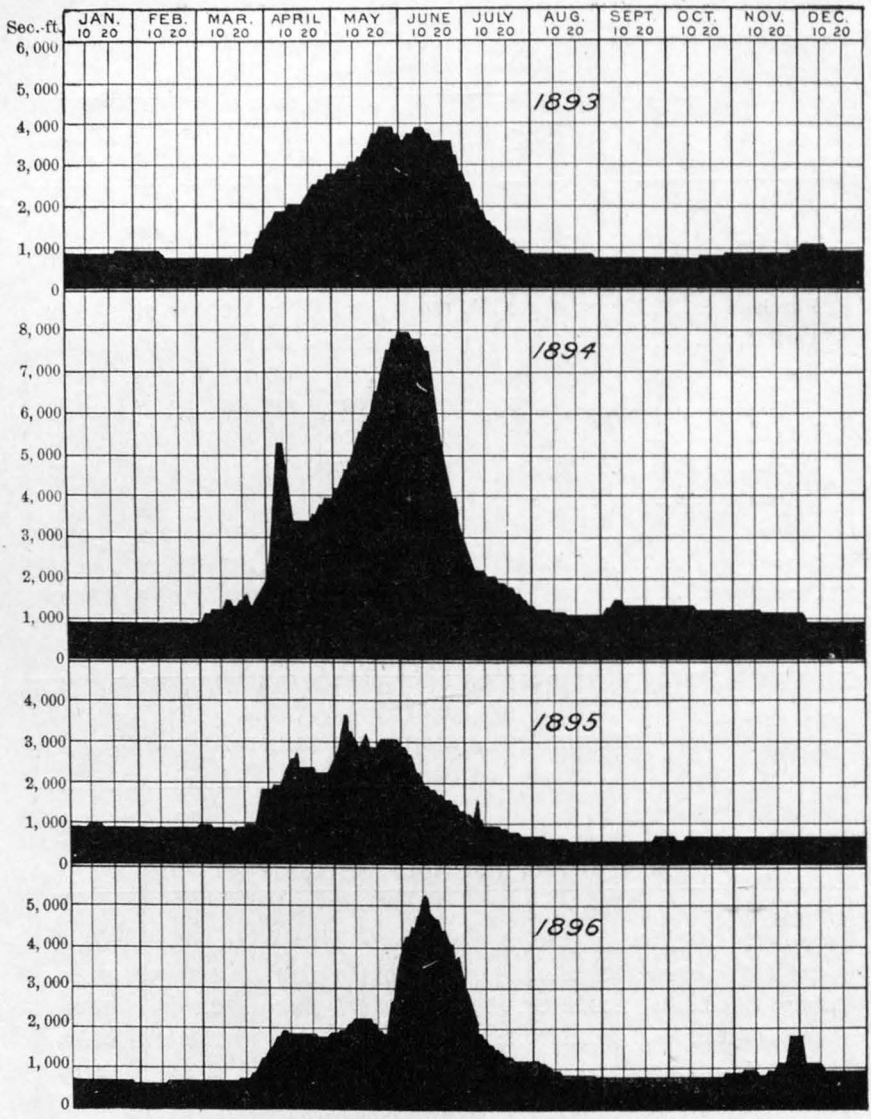



FIG. 53.—Discharge of Bear River at Battle Creek, Idaho, 1893–1896.

## LOGAN STATION ON LOGAN RIVER.

This station was established by Mr. Samuel Fortier on June 1, 1896. It is located in the river canyon about 2 miles east of the city of Logan, Utah. The gage is a vertical wooden post set firmly into the ground and graduated to tenths of a foot. The equipment consists of a cable, car, and tag wire. The observer is Mr. J. S. Pehrson, living about one-half mile from the gage. The bench mark is a stone 35 feet northeast of the end of the cable on the north side of the river. The eleva-

tion is 14.01 feet above datum. The point of the rock and the letters B. M. are marked with red paint. Ten measurements of discharge have been made at this station and used in the construction of a rating table.

The measurements of August 17, September 4, and September 26, 1896, in the following table were made on Logan River at the county road bridge about 6 miles due west of Logan City and near the mouth of Logan River. They show the relation between the flow of Logan River at the mouth of Logan Canyon diminished by the various irrigation canals and the surplus waters of the several streams in the southern portion of Cache Valley increased by the seepage waters from irrigated areas and from the adjacent hillsides. The observations on Logan River at the county bridge were maintained from June 1 to December 25, 1896, with a few omissions in June and December. The table showing results is given in Water-Supply and Irrigation Paper No. 11, page 77.

*List of discharge measurements made on Logan River at Logan, Utah.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| June 11 | S. Fortier | 103 | 4.65 | 192 | 8.57 | 1,646 |
| June 15 | do | 103 | 4.64 | 187 | 8.46 | 1,584 |
| June 15 | do | 103 | 4.64 | 187 | 8.27 | 1,549 |
| June 29 | do | 103 | 3.90 | 133 | 6.76 | 901 |
| June 29 | do | 103 | 3.90 | 133 | 6.46 | 861 |
| July 6 | T. H. Humphreys | 106 | 3.75 | 116 | 6.27 | 728 |
| July 16 | S. Fortier | 10 | 3.47 | 99 | 4.93 | 488 |
| Aug. 3 | do | 10 | 3.14 | 83 | 4.01 | 334 |
| Aug. 17 | do | 106 | 2.00 | 230 | 1.28 | *a* 294 |
| Aug. 18 | J. L. Rhead | 106 | 2.96 | 78 | 4.51 | 354 |
| Sept. 11 | do | 106 | 2.45 | 263 | 1.57 | *a* 412 |
| Sept. 26 | do | 103 | 3.00 | 290 | 1.80 | *a* 527 |
| Oct. 6 | T. H. Humphreys | 103 | 2.70 | 6 | 3.75 | 243 |

*a* At county bridge, 6 miles west of Logan.

*Rating table for Logan River at Logan, Utah, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.90 | 6 | 2.00 | 104 | 3.10 | 363 | 4.20 | 1,105 |
| 1.00 | 12 | 2.10 | 119 | 3.20 | 400 | 4.30 | 1,200 |
| 1.10 | 18 | 2.20 | 135 | 3.30 | 442 | 4.40 | 1,300 |
| 1.20 | 25 | 2.30 | 152 | 3.40 | 488 | 4.50 | 1,425 |
| 1.30 | 32 | 2.40 | 172 | 3.50 | 535 | 4.60 | 1,545 |
| 1.40 | 40 | 2.50 | 193 | 3.60 | 597 | 4.70 | 1,660 |
| 1.50 | 47 | 2.60 | 218 | 3.70 | 656 | 4.80 | 1,760 |
| 1.60 | 56 | 2.70 | 242 | 3.80 | 720 | 4.90 | 1,860 |
| 1.70 | 68 | 2.80 | 270 | 3.90 | 815 | 5.00 | 1,965 |
| 1.80 | 78 | 2.90 | 296 | 4.00 | 935 | | |
| 1.90 | 90 | 3.00 | 325 | 4.10 | 1,024 | | |

*Estimated monthly discharge of Logan River at Logan, Utah.*

[Drainage area, 218 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| June | 1,860 | 815 | 1,469 | 87,411 | 7.78 | 6.80 |
| July | 815 | 363 | 548 | 33,695 | 2.91 | 2.52 |
| August | 363 | 296 | 321 | 19,737 | 1.72 | 1.49 |
| September | 270 | 242 | 258 | 15,352 | 1.33 | 1.19 |
| October | 242 | 218 | 240 | 14,757 | 1.27 | 1.10 |
| November | 242 | 218 | 219 | 13,091 | 1.11 | 1.00 |
| December | 218 | 193 | 204 | 12,543 | 1.08 | 0.94 |

## MEASUREMENTS OF CUB RIVER.

Four measurements were made on this stream at a point near the foothills above all irrigation canals.

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 25 | J. L. Rhead | 103 | 1.5 | 94.7 | 3.95 | 373.93 |
| 2 | June 25 | do | 103 | 1.5 | 97.0 | 4.07 | 394.56 |
| 3 | July 27 | do | 106 | 0.35 | 40.7 | 1.48 | 60.34 |
| 4 | Sept. 7 | do | 106 | 0.21 | 34.6 | 1.21 | 42.00 |

## COLLINSTON STATION ON BEAR RIVER.

This station is described in Bulletin 131, page 55, and in Bulletin 140, page 227. It is located in the canyon below Cache Valley, Utah, about 4 miles from the railroad station of Collinston or 2 miles east of the town of Fielding. The observer is J. H. Garns, who is the ditch rider of the Bear River Canal, and lives at Fielding, Utah. The gage consists of a vertical iron rod, graduated to tenths of a foot. The bench mark is a nail in an oak post 20 feet west of the gage and 20 feet north of the cable. Its elevation is 7.35 feet above the zero of the gage. The chief source of error at this station is the large rocks which are scattered over the bed. There is also considerable underflow, owing to the porous character of a portion of the river channel. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 77.

*List of discharge measurements made on Bear River at Collinston, Utah.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 20 | Oct. 6 | S. Fortier | 106 | 2.01 | 690 | 2.61 | 1,800 |
| 21 | Dec. 22 | do | 103 | 2.10 | 730 | 2.57 | 1,875 |
| | 1895. | | | | | | |
| 22 | Apr. 8 | W. F. Culmer | 106 | 3.16 | 1,011 | 3.01 | 3,041 |
| 23 | Apr. 15 | do | 106 | 3.75 | 1,120 | 3.44 | 3,853 |
| 24 | Apr. 22 | W. W. McLaughlin | 106 | 3.58 | 1,055 | 3.27 | 3,453 |
| 25 | Apr. 29 | S. Fortier | 106 | 3.61 | 1,058 | 3.27 | 3,460 |
| 26 | Aug. 19 | J. L. Rhead | 106 | 1.17 | 364 | 2.15 | 819 |
| 27 | Sept. 23 | S. Fortier | 106 | 1.62 | 495 | 2.14 | 1,058 |
| 28 | Dec. 9 | do | 106 | 1.95 | 633 | 2.21 | 1,397 |
| | 1896. | | | | | | |
| 29 | Apr. 20 | J. L. Rhead | 103 | 3.25 | 984 | 2.92 | 2,868 |
| 30 | July 23 | S. Fortier | 106 | 2.24 | 687 | 2.50 | 1,724 |
| 31 | July 23 | do | 10 | 2.24 | 690 | 2.19 | 1,506 |
| 32 | Aug. 8 | do | 103 | 2.14 | 618 | 2.38 | 1,470 |
| 33 | Aug. 8 | do | 10 | 2.14 | 618 | 2.20 | 1,358 |
| 34 | Aug. 28 | J. L. Rhead | 103 | 1.88 | 551 | 2.45 | 1,339 |
| 35 | Aug. 28 | do | 10 | 1.88 | 574 | 2.17 | 1,246 |
| 36 | Sept. 25 | do | 103 | 1.91 | 586 | 2.30 | 1,349 |

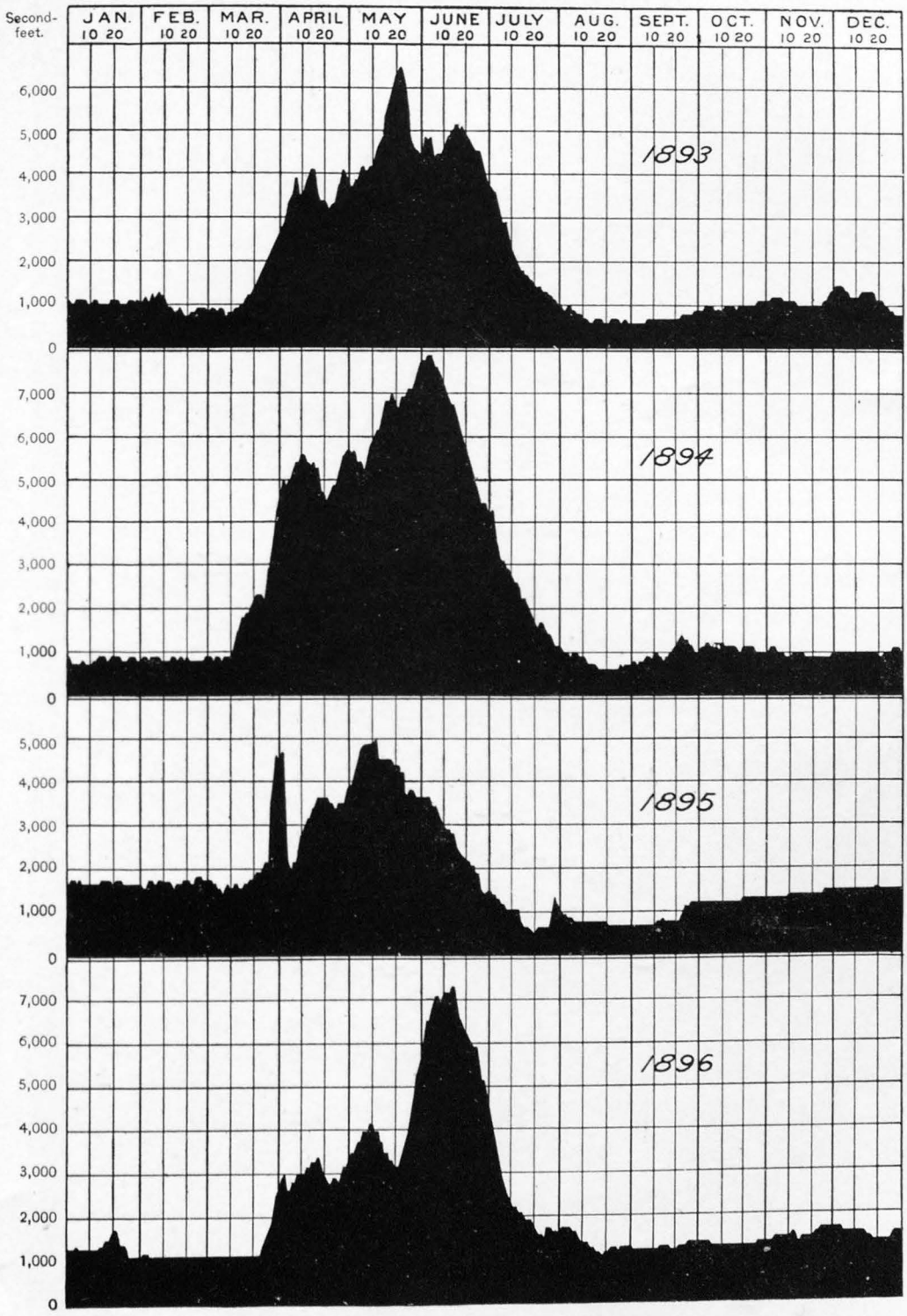
*Rating table of Bear River at Collinston, Utah, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.5 | 415 | 2.3 | 1,695 | 4.1 | 4,125 | 5.9 | 6,540 |
| 0.6 | 460 | 2.4 | 1,805 | 4.2 | 4,260 | 6.0 | 6,665 |
| 0.7 | 500 | 2.5 | 1,930 | 4.3 | 4,390 | 6.1 | 6,785 |
| 0.8 | 545 | 2.6 | 2,060 | 4.4 | 4,535 | 6.2 | 6,915 |
| 0.9 | 595 | 2.7 | 2,180 | 4.5 | 4,670 | 6.3 | 7,040 |
| 1.0 | 645 | 2.8 | 2,310 | 4.6 | 4,805 | 6.4 | 7,165 |
| 1.1 | 695 | 2.9 | 2,445 | 4.7 | 4,950 | 6.5 | 7,295 |
| 1.2 | 750 | 3.0 | 2,570 | 4.8 | 5,090 | 6.6 | 7,415 |
| 1.3 | 815 | 3.1 | 2,745 | 4.9 | 5,230 | 6.7 | 7,545 |
| 1.4 | 880 | 3.2 | 2,870 | 5.0 | 5,385 | 6.8 | 7,665 |
| 1.5 | 955 | 3.3 | 3,005 | 5.1 | 5,500 | 6.9 | 7,790 |
| 1.6 | 1,025 | 3.4 | 3,150 | 5.2 | 5,640 | 7.0 | 7,920 |
| 1.7 | 1,100 | 3.5 | 3,285 | 5.3 | 5,765 | 7.1 | 8,040 |
| 1.8 | 1,185 | 3.6 | 3,425 | 5.4 | 5,900 | 7.2 | 8,160 |
| 1.9 | 1,275 | 3.7 | 3,565 | 5.5 | 6,025 | 7.3 | 8,290 |
| 2.0 | 1,375 | 3.8 | 3,710 | 5.6 | 6,150 | 7.4 | 8,415 |
| 2.1 | 1,480 | 3.9 | 3,845 | 5.7 | 6,280 | 7.5 | 8,535 |
| 2.2 | 1,590 | 4.0 | 3,990 | 5.8 | 6,415 | 7.6 | 8,655 |

*Estimated monthly discharge of Bear River at Collinston, Utah.*

[Drainage area, 6,000 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 1,690 | 1,100 | 1,324 | 81,409 | 0.25 | 0.22 |
| February | 1,185 | 1,100 | 1,108 | 63,733 | 0.19 | 0.18 |
| March | 2,570 | 1,100 | 1,310 | 80,549 | 0.25 | 0.22 |
| April | 3,425 | 2,570 | 2,986 | 177,679 | 0.54 | 0.48 |
| May | 5,650 | 3,150 | 3,890 | 231,650 | 0.75 | 0.65 |
| June | 7,415 | 4,539 | 6,401 | 380,886 | 1.19 | 1.07 |
| July | 4,260 | 1,480 | 2,233 | 132,873 | 0.43 | 0.37 |
| August | 1,695 | 1,100 | 1,361 | 80,985 | 0.26 | 0.23 |
| September | 1,375 | 1,185 | 1,247 | 74,202 | 0.23 | 0.21 |
| October | 1,375 | 1,275 | 1,308 | 80,425 | 0.25 | 0.22 |
| November | 1,695 | 1,375 | 1,520 | 90,446 | 0.28 | 0.25 |
| December | 1,695 | 1,375 | 1,556 | 95,674 | 0.30 | 0.26 |
| Per annum | 7,415 | 1,100 | 2,187 | 1,570,511 | 4.92 | 0.36 |




DISCHARGE OF BEAR RIVER AT COLLINSTON, UTAH, 1893–1896.

## OGDEN, WEBER, AND PROVO RIVERS.

These rivers rise in the Wasatch Mountains and flow in a generally westerly course. The two former, uniting near the city of Ogden, flow into the Great Salt Lake. The Provo River farther south flows into Utah Lake, which in turn empties, by way of Jordan River, into the Great Salt Lake.

### EDEN STATION ON OGDEN RIVER.

This station is described in Bulletin 140, page 230, under the title of Ogden Station. It was established in June, 1895, and is located about 10 miles east of the city of Ogden, at the upper end of the canyon, near the house of the observer, Mr. James Ririe. The station is equipped with a cable and car. The gage is inclined, and divided into tenths of a foot. The bench mark is a nail on the top of a stake between the guy post and an upright on the north side of the river. Its elevation is 8.51 feet above the zero of the gage. Its position was verified April 20, 1896. A second bench mark is on a rock at the edge of the road, 300 feet northwest of the gage. Its elevation is 18.5 feet above the zero. A rating table was made applicable for gage heights up to 6 feet, but not beyond. This station is now temporarily abandoned on account of backwater caused by a dam built by the Electric Pioneer Power Company, of Ogden. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 78.

*List of discharge measurements made on Ogden River at Eden, Utah.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | June 13 | J. L. Rhead..... | 103 | 2.02 | 105 | 1.43 | 150 |
| 2 | Sept. 13 | S. Fortier ..... | 106 | 1.45 | 52 | 1,09 | 57 |
| 3 | Oct. 14 | .....do ..... | 106 | 1.53 | 61 | 1.20 | 73 |
| 4 | Nov. 11 | .....do ..... | 106 | 1.55 | 56 | 1.26 | 71 |
| | 1896. | | | | | | |
| 5 | Apr. 20 | S. Fortier ..... | 106 | 4.36 | 251 | 2.46 | 618 |
| 6 | July 8 | .....do ..... | 10 | 1.98 | 84 | 1.66 | 140 |
| 7 | Aug. 19 | .....do ..... | 10 | 1.57 | 62 | 1.25 | 78 |
| 8 | Aug. 21 | J. L. Rhead..... | 103 | 1.61 | 63 | 1.59 | 101 |
| 9 | Sept. 8 | S. Fortier ..... | 10 | 1.63 | 69 | 1.29 | 89 |
| 10 | Sept. 18 | J. L. Rhead..... | 106 | 1.60 | 63 | 1.42 | 89 |
| 11 | Dec. 29 | S. Fortier ..... | 10 | 1.63 | 66 | 1.43 | 94 |

*Rating table of Ogden River near Eden, Utah, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.0 | 24 | 2.3 | 200 | 3.6 | 460 | 4.9 | 720 |
| 1.1 | 30 | 2.4 | 220 | 3.7 | 480 | 5.0 | 740 |
| 1.2 | 38 | 2.5 | 240 | 3.8 | 500 | 5.1 | 760 |
| 1.3 | 47 | 2.6 | 260 | 3.9 | 520 | 5.2 | 780 |
| 1.4 | 58 | 2.7 | 280 | 4.0 | 540 | 5.3 | 800 |
| 1.5 | 70 | 2.8 | 300 | 4.1 | 560 | 5.4 | 820 |
| 1.6 | 82 | 2.9 | 320 | 4.2 | 580 | 5.5 | 840 |
| 1.7 | 95 | 3.0 | 340 | 4.3 | 600 | 5.6 | 860 |
| 1.8 | 110 | 3.1 | 360 | 4.4 | 620 | 5.7 | 880 |
| 1.9 | 125 | 3.2 | 380 | 4.5 | 640 | 5.8 | 900 |
| 2.0 | 140 | 3.3 | 400 | 4.6 | 660 | 5.9 | 920 |
| 2.1 | 160 | 3.4 | 420 | 4.7 | 680 | 6.0 | 940 |
| 2.2 | 180 | 3.5 | 440 | 4.8 | 700 | | |

*Estimated monthly discharge of Ogden River at Eden, Utah.*

[Drainage area, 360 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 140 | 58 | 83 | 5,104 | 0.26 | 0.23 |
| February | 95 | 82 | 87 | 5,003 | 0.26 | 0.24 |
| March | 1,240 | 95 | 230 | 14,142 | 0.74 | 0.64 |
| June 11 to 30 | 940 | 200 | 475 | 18,843 | 0.98 | 1.32 |
| July | 220 | 110 | 141 | 8,679 | 0.45 | 0.39 |
| August | 125 | 82 | 90 | 5,534 | 0.29 | 0.25 |
| September | 95 | 82 | 84 | 4,998 | 0.26 | 0.23 |
| October | 82 | 82 | 82 | 5,042 | 0.26 | 0.23 |
| November | 240 | 70 | 95 | 5,653 | 0.29 | 0.26 |
| December | 260 | 82 | 91 | 5,595 | 0.29 | 0.25 |

## UINTA STATION ON WEBER RIVER.

This station is described in Bulletin 131, page 57, and in Bulletin 140, page 231. It is located near the watchman's house at the railroad bridge, 5 miles east of Uinta, in the vicinity of Devils Gate, on the Union Pacific Railroad, in latitude 41° 9′ and longitude 111° 51′. Observations have been continued through 1896 and a number of discharge measurements made. The observer is Morgan Flaherty, a watchman, living about 100 feet from the gage. His post-office address is Uinta, Utah. The gage is vertical, and is supported from above by a projecting timber placed out of the reach of high water. The elevation of a staple in a telegraph pole near by is 17.44 feet above the zero. The equipment consists of cable, car, and tag wire. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No 11, page 78.

*List of discharge measurements made on Weber River at Uinta, Utah.*

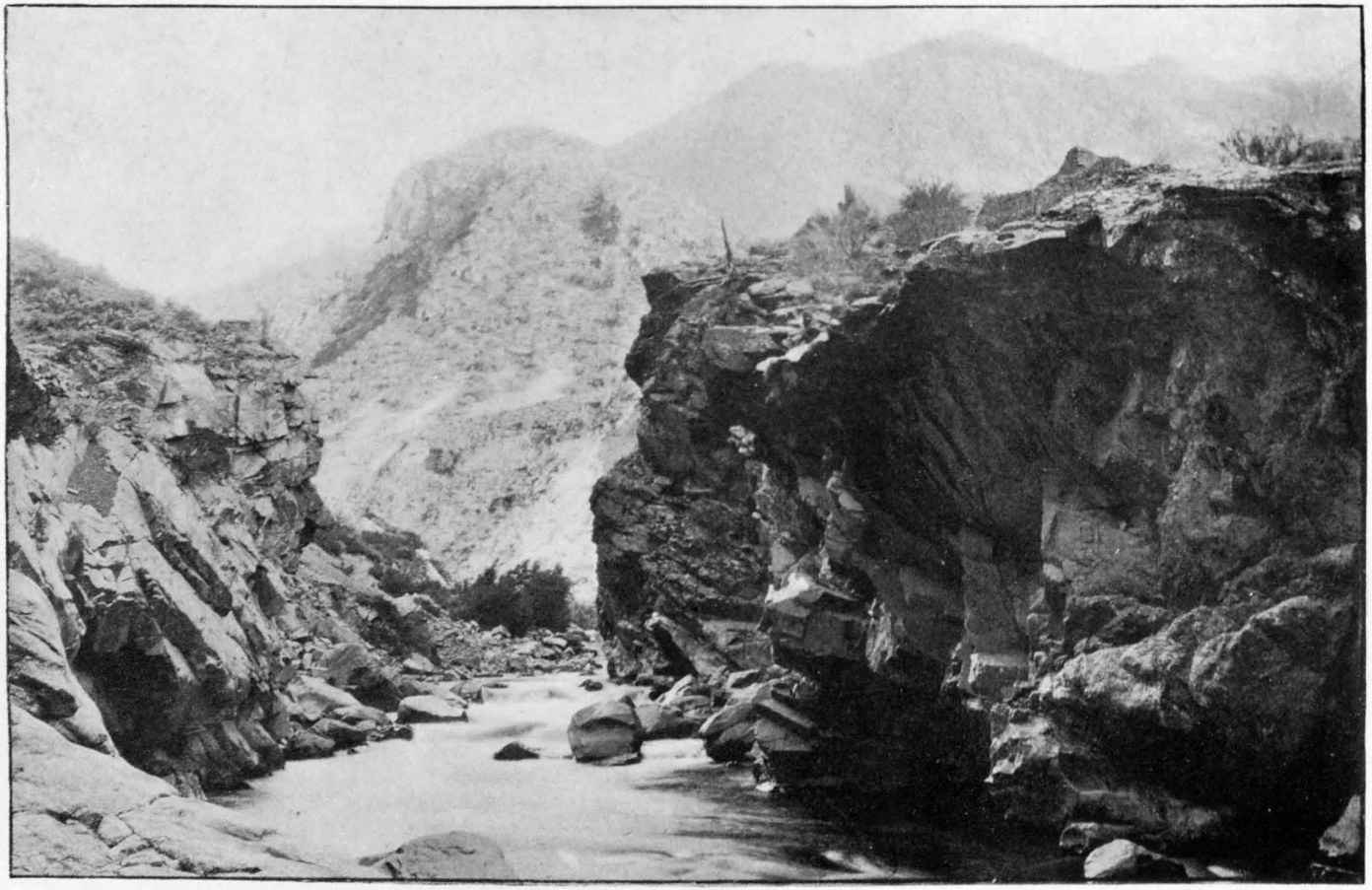
| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 9 | July 20 | S. Fortier | 106 | *a* 1.10 | 140 | 2.84 | 396 |
| 10 | Aug. 15 | do | 106 | 0.50 | 82 | 1.73 | 141 |
| | 1895. | | | | | | |
| 11 | Jan. 28 | J. L. Rhead | 106 | *b* 0.85 | 127 | 1.31 | 166 |
| 12 | June 17 | do | 106 | 2.20 | 236 | 4.04 | 955 |
| 13 | July 23 | A. P. Davis | 55 | 1.20 | 115 | 1.93 | 222 |
| 14 | Aug. 17 | J. L. Rhead | 106 | 0.85 | 71 | 1.40 | 100 |
| 15 | Sept. 14 | S. Fortier | 106 | 0.85 | 69 | 1.37 | 94 |
| 16 | Nov. 5 | J. L. Rhead | 106 | 1.41 | 122 | 2.25 | 274 |
| | 1896. | | | | | | |
| 17 | Apr. 27 | J. L. Rhead | 106 | 3.50 | 363 | 4.91 | 1,782 |
| 18 | Aug. 24 | do | 103 | 1.29 | 108 | 2.04 | 220 |
| 19 | Sept. 19 | do | 106 | 1.35 | 107 | 2.08 | 233 |

*a* Gage height unreliable; gage having been moved by ice.
*b* Ice in river makes this of doubtful value.

*Rating table of Weber River near Uinta, Utah, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.1 | 23 | 2.5 | 1,175 | 4.9 | 3,765 | 7.3 | 6,315 |
| 0.2 | 28 | 2.6 | 1,275 | 5.0 | 3,875 | 7.4 | 6,425 |
| 0.3 | 35 | 2.7 | 1,390 | 5.1 | 3,980 | 7.5 | 6,535 |
| 0.4 | 45 | 2.8 | 1,505 | 5.2 | 4,085 | 7.6 | 6,645 |
| 0.5 | 57 | 2.9 | 1,615 | 5.3 | 4,190 | 7.7 | 6,755 |
| 0.6 | 68 | 3.0 | 1,725 | 5.4 | 4,295 | 7.8 | 6,865 |
| 0.7 | 80 | 3.1 | 1,835 | 5.5 | 4,400 | 7.9 | 6,975 |
| 0.8 | 105 | 3.2 | 1,945 | 5.6 | 4,505 | 8.0 | 7,085 |
| 0.9 | 125 | 3.3 | 2,055 | 5.7 | 4,610 | 8.1 | 7,195 |
| 1.0 | 155 | 3.4 | 2,165 | 5.8 | 4,715 | 8.2 | 7,305 |
| 1.1 | 185 | 3.5 | 2,275 | 5.9 | 4,820 | 8.3 | 7,415 |
| 1.2 | 220 | 3.6 | 2,380 | 6.0 | 4,925 | 8.4 | 7,525 |
| 1.3 | 270 | 3.7 | 2,485 | 6.1 | 5,030 | 8.5 | 7,635 |
| 1.4 | 310 | 3.8 | 2,590 | 6.2 | 5,135 | 8.6 | 7,750 |
| 1.5 | 360 | 3.9 | 2,700 | 6.3 | 5,240 | 8.7 | 7,865 |
| 1.6 | 415 | 4.0 | 2,805 | 6.4 | 5,345 | 8.8 | 7,980 |
| 1.7 | 480 | 4.1 | 2,910 | 6.5 | 5,450 | 8.9 | 8,095 |
| 1.8 | 545 | 4.2 | 3,020 | 6.6 | 5,555 | 9.0 | 8,210 |
| 1.9 | 615 | 4.3 | 3,125 | 6.7 | 5,660 | 9.1 | 8,325 |
| 2.0 | 700 | 4.4 | 3,230 | 6.8 | 5,775 | 9.2 | 8,440 |
| 2.1 | 785 | 4.5 | 3,340 | 6.9 | 5,880 | 9.3 | 8,555 |
| 2.2 | 880 | 4.6 | 3,445 | 7.0 | a5,985 | 9.4 | 8,670 |
| 2.3 | 975 | 4.7 | 3,550 | 7.1 | 6,095 | 9.5 | 8,785 |
| 2.4 | 1,075 | 4.8 | 3,655 | 7.2 | 6,205 | | |

a Only approximate from 7 feet up.



DEVILS GATE ON WEBER RIVER, UTAH, ONE-HALF MILE BELOW GAGING STATION.

*Estimated monthly discharge of Weber River at Uinta, Utah.*

[Drainage area, 1,600 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 480 | 415 | 478 | 29,391 | 0.35 | 0.30 |
| February | 480 | 480 | 480 | 27,610 | 0.32 | 0.30 |
| March | 2,055 | 480 | 945 | 58,115 | 0.68 | 0.59 |
| April | 3,230 | 785 | 1,671 | 99,431 | 1.40 | 1.04 |
| May | 7,980 | 1,390 | 3,172 | 195,039 | 2.28 | 1.98 |
| June | 7,980 | 785 | 3,348 | 199,220 | 2.33 | 2.09 |
| July | 700 | 360 | 536 | 32,957 | 0.39 | 0.34 |
| August | 615 | 155 | 292 | 17,954 | 0.21 | 0.18 |
| September | 310 | 270 | 274 | 16,304 | 0.19 | 0.17 |
| October | 415 | 310 | 357 | 21,951 | 0.25 | 0.22 |
| November | 700 | 415 | 548 | 32,668 | 0.38 | 0.34 |
| December | 480 | 360 | 420 | 25,825 | 0.30 | 0.26 |
| Per annum | 7,980 | 155 | 1,044 | 666,465 | 9.08 | 0.67 |

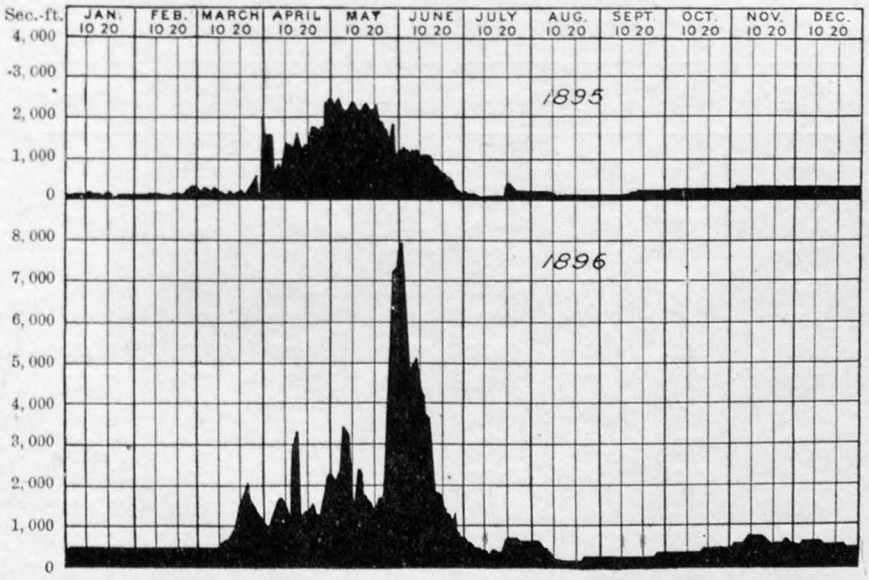



FIG. 54.—Discharge of Weber River at Devil's Gate above Uinta, Utah, 1895–96.

## PROVO STATION ON PROVO RIVER.

This station is described in Bulletin No. 131, page 59, and in Bulletin No. 140, page 234. It is located in the canyon about 6 miles from the city of Provo, Utah. It is latitude 40° 19′ and longitude 111° 40′. It may be

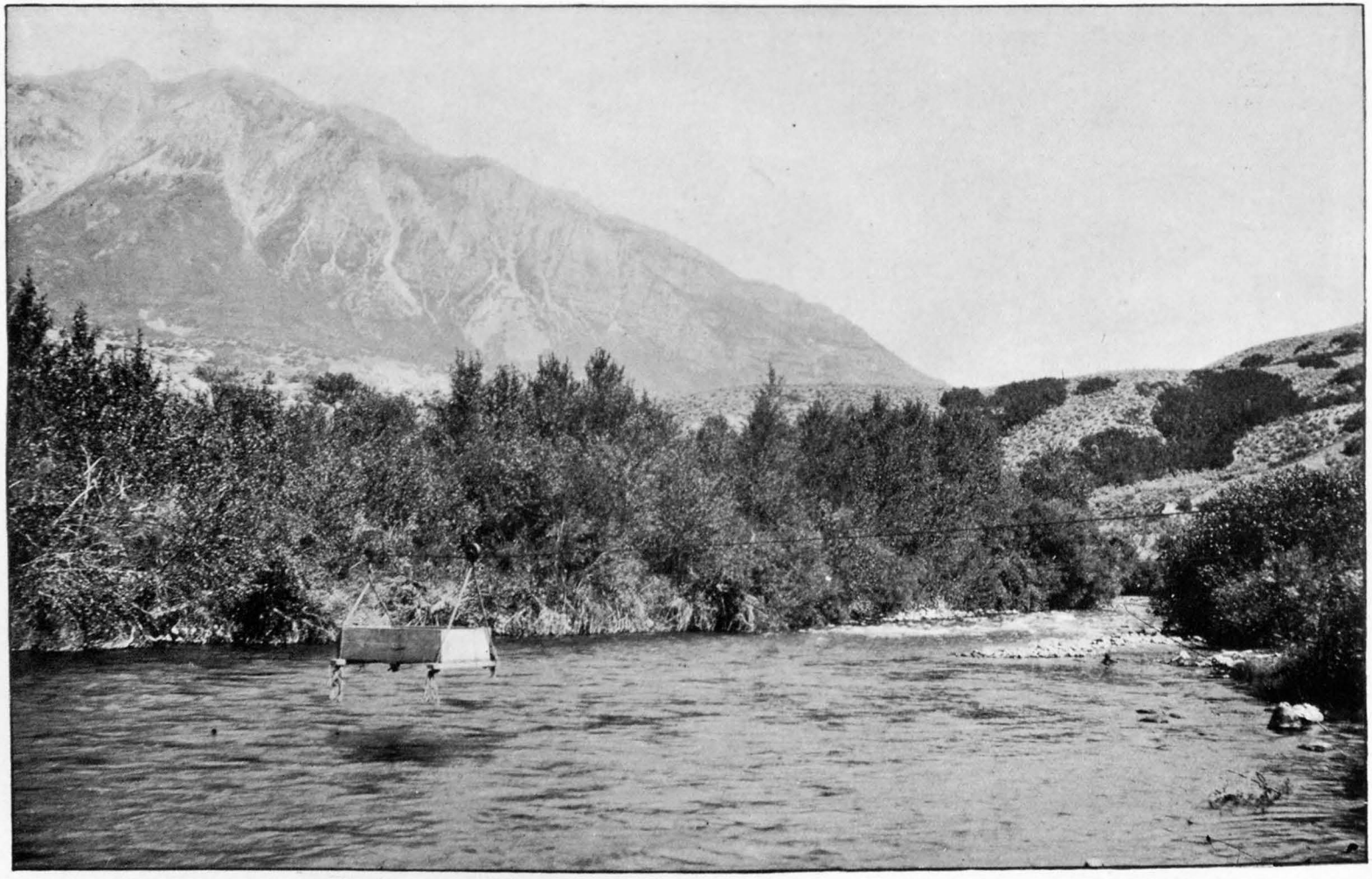
found on the Salt Lake sheet of the Topographic Atlas. The observer is Mr. Henry V. Smith, a farmer. The gage is inclined and fastened to stakes set in the ground. The bench mark is a stone firmly bedded in a bank near the wagon road, about 100 feet southwest of the gage. It is marked "B. M." in black paint, and is 6.95 feet above the zero of the gage. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 79.

*List of discharge measurements made on Provo River near Provo, Utah.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 14 | Dec. 24 | S. Fortier ..... | 103 | 4.40 | 154 | 2.53 | 390 |
| | 1895. | | | | | | |
| 15 | June 15 | J. L. Rhead ..... | 106 | 4.80 | 185 | 3.69 | 680 |
| 16 | July 20 | A. P. Davis ..... | 55 | 4.10 | 124 | 2.19 | 270 |
| | 1896. | | | | | | |
| 17 | Sept. 7 | S. Fortier ..... | 10 | 4.21 | 117 | 2.36 | 275 |
| 18 | Nov. 7 | C. C. Babb ..... | 63 | 4.25 | 122 | 2.20 | 269 |

*Rating table for Provo River near Provo, Utah, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.00 | 61 | 4.40 | 390 | 5.80 | 1,440 | 7.20 | 2,715 |
| 3.10 | 69 | 4.50 | 444 | 5.90 | 1,518 | 7.30 | 2,815 |
| 3.20 | 77 | 4.60 | 511 | 6.00 | 1,600 | 7.40 | 2,920 |
| 3.30 | 88 | 4.70 | 581 | 6.10 | 1,686 | 7.50 | 3,025 |
| 3.40 | 99 | 4.80 | 652 | 6.20 | 1,775 | 7.60 | 3,130 |
| 3.50 | 112 | 4.90 | 728 | 6.30 | 1,865 | 7.70 | 3,235 |
| 3.60 | 128 | 5.00 | 801 | 6.40 | 1,955 | 7.80 | 3,345 |
| 3.70 | 145 | 5.10 | 881 | 6.50 | 2,045 | 7.90 | 3,455 |
| 3.80 | 168 | 5.20 | 970 | 6.60 | 2,135 | 8.00 | 3,565 |
| 3.90 | 193 | 5.30 | 1,050 | 6.70 | 2,230 | 8.10 | 3,680 |
| 4.00 | 221 | 5.40 | 1,130 | 6.80 | 2,325 | 8.20 | 3,800 |
| 4.10 | 256 | 5.50 | 1,206 | 6.90 | 2,420 | 8.30 | 3,920 |
| 4.20 | 292 | 5.60 | 1,283 | 7.00 | 2,515 | 8.40 | 4,025 |
| 4.30 | 339 | 5.70 | 1,360 | 7.10 | 2,615 | 8.50 | 4,150 |



PROVO STATION ON PROVO RIVER, UTAH.

*Estimated monthly discharge of Provo River at Provo, Utah.*

[Drainage area, 640 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 444 | 256 | 322 | 19,798 | 0.58 | 0.50 |
| February | 339 | 292 | 298 | 17,141 | 0.50 | 0.46 |
| March | 728 | 292 | 398 | 24,471 | 0.71 | 0.62 |
| April | 1,518 | 390 | 629 | 37,428 | 1.09 | 0.98 |
| May | 4,150 | 581 | 1,166 | 71,694 | 2.10 | 1.82 |
| June | 3,345 | 444 | 1,558 | 92,707 | 2.72 | 2.44 |
| July | 728 | 292 | 384 | 23,611 | 0.69 | 0.60 |
| August | 444 | 292 | 311 | 19,122 | 0.56 | 0.49 |
| September | 339 | 292 | 309 | 18,387 | 0.54 | 0.48 |
| October | 339 | 339 | 339 | 20,844 | 0.61 | 0.53 |
| November | 511 | 339 | 421 | 25,041 | 0.73 | 0.66 |
| December | 390 | 390 | 390 | 23,980 | 0.70 | 0.61 |
| Per annum | 4,150 | 292 | 544 | 394,224 | 11.53 | 0.85 |

## UTAH LAKE.

A discussion of Utah Lake drainage was made in the Twelfth Annual Report of this Survey, Part II, page 334. A continuous record of the height of the lake has been kept by Mr. James Aitken, living at Lake Shore, near Spanish Fork, Utah, at the head of the lake.

There have been considerable trouble and a number of lawsuits between the property holders along the lake front and the owners of a dam in the Jordan River about 7 miles below the outlet of the lake, where the water is diverted for irrigation. The former parties claimed that the presence of the dam flooded and destroyed the utility of their property. A compromise was finally effected which practically bound the companies claiming water from Utah Lake to the agreement to maintain the level of the lake below a certain point called "compromise point," which was to be 3 feet 3½ inches above low-water mark, called "compromise low-water mark." This latter level was taken at the low-water point of 1879, which was, however, 8½ inches above the lowest water known at the time the agreement was made in 1885, and which is said to have occurred between 1857 and 1860. The level reached 10½ inches below compromise low water, or 2 inches below low water of 1857 to 1860.

On November 6, 1896, a gage was established on the lake at Geneva, 3 miles south of American Fork. It is a vertical rod driven into the

sand at the southern end of a bath house and nailed firmly to the floor of the house. A sandstone monument, the bench mark of the lake commissioners, was found, and its elevation—14.644 feet above compromise point—was marked on the pavilion near by. From these figures the compromise point on the gage rod was found, which was marked

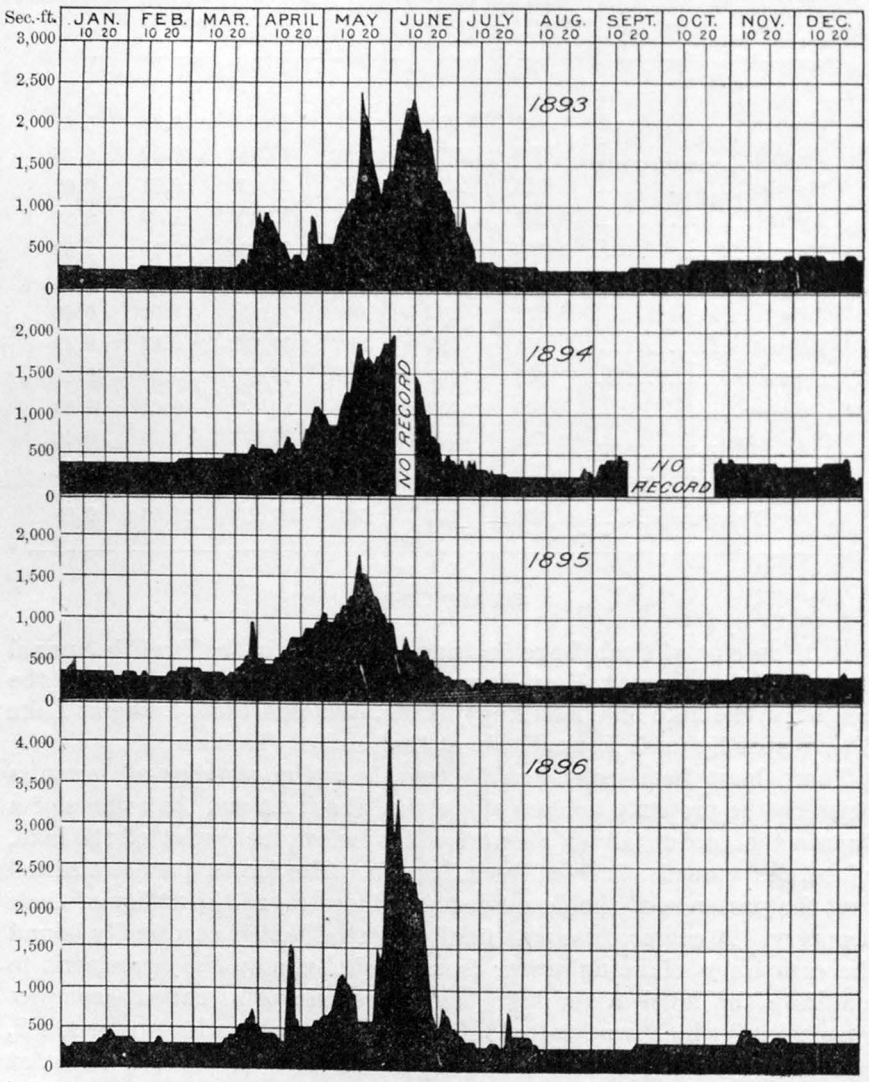



FIG. 55.—Discharge of Provo River in Provo Canyon near Provo, Utah, 1893–1896.

4.0 feet, and the rod then divided into feet and tenths. Mr. John Dallin, post-office Pleasant Grove, Utah, is the observer. This station may be found on the Salt Lake sheet of the Topographic Atlas, in latitude 40° 21′ and longitude 112° 10′.

*Daily gage height of Utah Lake, near Spanish Fork, Utah.*

| Date. | Gage height. | Date. | Gage height. | Date. | Gage height. | Date. | Gage height. |
|---|---|---|---|---|---|---|---|
| 1889. | | 1890. | | 1892. | | 1894. | |
| Feb. 22 | 1.58 | Aug. 15 | 2.46 | Mar. 13 | 3.50 | Feb. 28 | 3.58 |
| Apr. 1 | 1.67 | Sept. 1 | 2.17 | Apr. 9 | 3.58 | Mar. 13 | 3.79 |
| Apr. 26 | 1.42 | Sept. 21 | 1.83 | Apr. 29 | 3.50 | Mar. 22 | 3.92 |
| May 12 | 1.17 | Oct. 10 | 1.67 | May 15 | 3.58 | Apr. 1 | 4.00 |
| June 2 | 1.08 | Nov. 10 | 1.46 | June 5 | 3.96 | Apr. 16 | 4.08 |
| June 15 | 0.92 | Nov. 28 | 1.58 | June 25 | 4.21 | May 11 | 4.08 |
| July 7 | 0.42 | Dec. 29 | 1.75 | July 27 | 3.42 | May 28 | 4.17 |
| July 20 | 0.38 | 1891. | | Aug. 14 | 3.00 | June 14 | 4.21 |
| July 30 | 0.21 | Jan. 9 | 1.83 | Sept. 3 | 2.58 | June 26 | 3.96 |
| Aug. 18 | —0.13 | Feb. 2 | 2.00 | Oct. 3 | 2.17 | June 30 | 3.92 |
| Sept. 1 | —0.25 | Feb. 15 | 2.13 | Oct. 25 | 2.00 | July 11 | 3.67 |
| Sept. 15 | —0.50 | Mar. 3 | 2.42 | Nov. 30 | 2.25 | Aug. 6 | 3.08 |
| Sept. 30 | —0.67 | Mar. 26 | 2.71 | Dec. 30 | 2.79 | Oct. 7 | 2.33 |
| Oct. 15 | —0.83 | Apr. 3 | 2.75 | 1893. | | Nov. 7 | 2.38 |
| Oct. 22 | —0.88 | May 1 | 2.92 | Jan. 14 | 2.88 | Dec. 1 | 2.38 |
| Dec. 10 | 0.00 | May 8 | 3.08 | Mar. 16 | 3.21 | 1895. | |
| Dec. 24 | 0.17 | May 12 | 3.29 | Mar. 18 | 3.83 | Mar. 21 | 3.71 |
| 1890. | | May 30 | 3.67 | Apr. 16 | 4.29 | Apr. 25 | 3.88 |
| Jan. 12 | 0.50 | June 7 | 3.92 | May 1 | 4.50 | May 18 | 3.96 |
| Jan. 27 | 0.75 | June 15 | 4.17 | May 15 | 4.75 | May 31 | 4.25 |
| Feb. 17 | 0.92 | June 27 | 4.08 | June 2 | 5.08 | June 12 | 3.92 |
| Mar. 13 | 1.50 | July 10 | 3.58 | June 15 | 5.29 | June 24 | 3.46 |
| Apr. 3 | 1.58 | July 20 | 3.38 | July 10 | 4.79 | July 16 | 3.00 |
| Apr. 19 | 1.67 | July 30 | 3.17 | Aug. 1 | 4.08 | Aug. 1 | 2.33 |
| May 3 | 2.08 | Aug. 16 | 2.83 | Aug. 15 | 3.58 | Aug. 16 | 2.08 |
| May 17 | 2.33 | Aug. 25 | 2.58 | Sept. 5 | 3.08 | Sept. 2 | 1.63 |
| May 25 | 2.75 | Sept. 14 | 2.42 | Sept. 16 | 3.00 | Sept. 16 | 1.50 |
| June 1 | 3.08 | Nov. 8 | 2.00 | Sept. 29 | 2.88 | 1896. | |
| June 7 | 3.33 | Dec. 15 | 2.08 | Oct. 21 | 2.54 | Mar. 13 | 2.88 |
| June 14 | 3.58 | 1892. | | Nov. 20 | 2.67 | Apr. 25 | 3.25 |
| June 19 | 3.42 | Jan. 16 | 2.38 | Dec. 10 | 2.83 | May 18 | 3.54 |
| July 1 | 3.29 | Feb. 2 | 2.88 | Dec. 28 | 3.13 | June 13 | 4.00 |
| July 15 | 3.00 | Feb. 12 | 3.08 | 1894. | | July 10 | 3.38 |
| Aug. 1 | 2.75 | Mar. 1 | 3.38 | Jan. 31 | 3.21 | Aug. 10 | 2.54 |

From Mr. James Aitken; 0.0 is compromise low water mark.

*Daily gage height of Utah Lake at Geneva, Utah, for 1896.*

| Day. | Nov. | Dec. | Day. | Nov. | Dec. | Day. | Nov. | Dec. | Day. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ..... | 1.20 | 9 | 1.10 | 1.20 | 17 | ..... | ..... | 25 | 1.20 | ..... |
| 2 | ..... | ..... | 10 | ..... | ..... | 18 | 1.10 | 1.10 | 26 | ..... | 1.30 |
| 3 | ..... | 1.20 | 11 | ..... | ..... | 19 | ..... | 1.10 | 27 | 1.20 | ..... |
| 4 | ..... | ..... | 12 | ..... | 1.20 | 20 | 1.20 | ..... | 28 | a1.20 | 1.30 |
| 5 | ..... | 1.20 | 13 | 1.10 | ..... | 21 | ..... | 1.20 | 29 | ..... | ..... |
| 6 | 1.10 | ..... | 14 | ..... | 1.20 | 22 | ..... | ..... | 30 | ..... | 1.30 |
| 7 | ..... | 1.20 | 15 | ..... | ..... | 23 | 1.10 | 1.25 | 31 | ..... | 1.35 |
| 8 | ..... | ..... | 16 | 1.10 | 1.20 | 24 | ..... | 1.25 | | | |

*a* Lake frozen over.

## COLUMBIA BASIN.

The Columbia River receives the run-off of an area covering nearly 60,000 square miles. It drains the greater portion of the States of Washington, Oregon, and Idaho, with small parts of Wyoming, Utah, and Nevada. It discharges an immense quantity of water, the greater portion of which is from the arid region, but throughout much of its course the surface of the river is so much below the irrigable lands that its utilization for irrigation is expensive and difficult.

### SNAKE RIVER.

This stream rises in the mountains of western Wyoming and flows entirely across the southern part of Idaho. Its general course is westerly, and it empties into the Columbia River near Pasco Junction, in the State of Washington. Measurements on this river and its tributaries have been during 1896 under the supervision of Mr. Lyman B. Kendall. Valuable cooperation was extended by the State engineer of Idaho, Mr. F. J. Mills.

### BLACKFOOT RIVER.

During the past year constructive work has been in progress on a system of canals, diverting water from the Snake River for the irrigation of the Fort Hall Indian Reservation. With the idea that ultimately a larger water supply would be required than could be furnished from the Snake River, it was decided to make a survey of the reservoir site at the marshes of the Blackfoot River, about 40 miles southeast of Blackfoot, Idaho. The survey was made by Mr. Cyrus C. Babb with the assistance of the engineer corps of the Fort Hall Indian Reservation.

The reservoir site is excellent, with a 50-foot dam, covering 20,060 acres. The dam site is located at the head of the Blackfoot River Canyon in sec. 12, T. 5 S., R. 40 E. The top length of a 50-foot dam,

the height for which the survey was made, would be 470 feet, and the bottom width about 300 feet. The geological formation at this point is volcanic. The following table gives the capacity of the reservoir for every 10 feet up to 50 feet:

The river was gaged in the canyon at the dam site on September 30, giving a discharge of 252 second-feet. On October 3 the Little Blackfoot was gaged at its mouth near the head of the reservoir. The discharge was 81 second-feet. On October 5 the main river was gaged again at the upper bridge near the head of the marshes, in sec. 31, T. 6 S., R. 42 E. The discharge was 104 second-feet. A number of smaller creeks enter the river between the mouth of Little Blackfoot and the dam site. The above measurements were made during low water, and it is probably safe to assume as the low-water run-off of the Blackfoot River, 250 second-feet. The drainage area at the dam site, as measured from the Land Office map, is 666 square miles, or 426,240 acres.

*Blackfoot River reservoir site.*

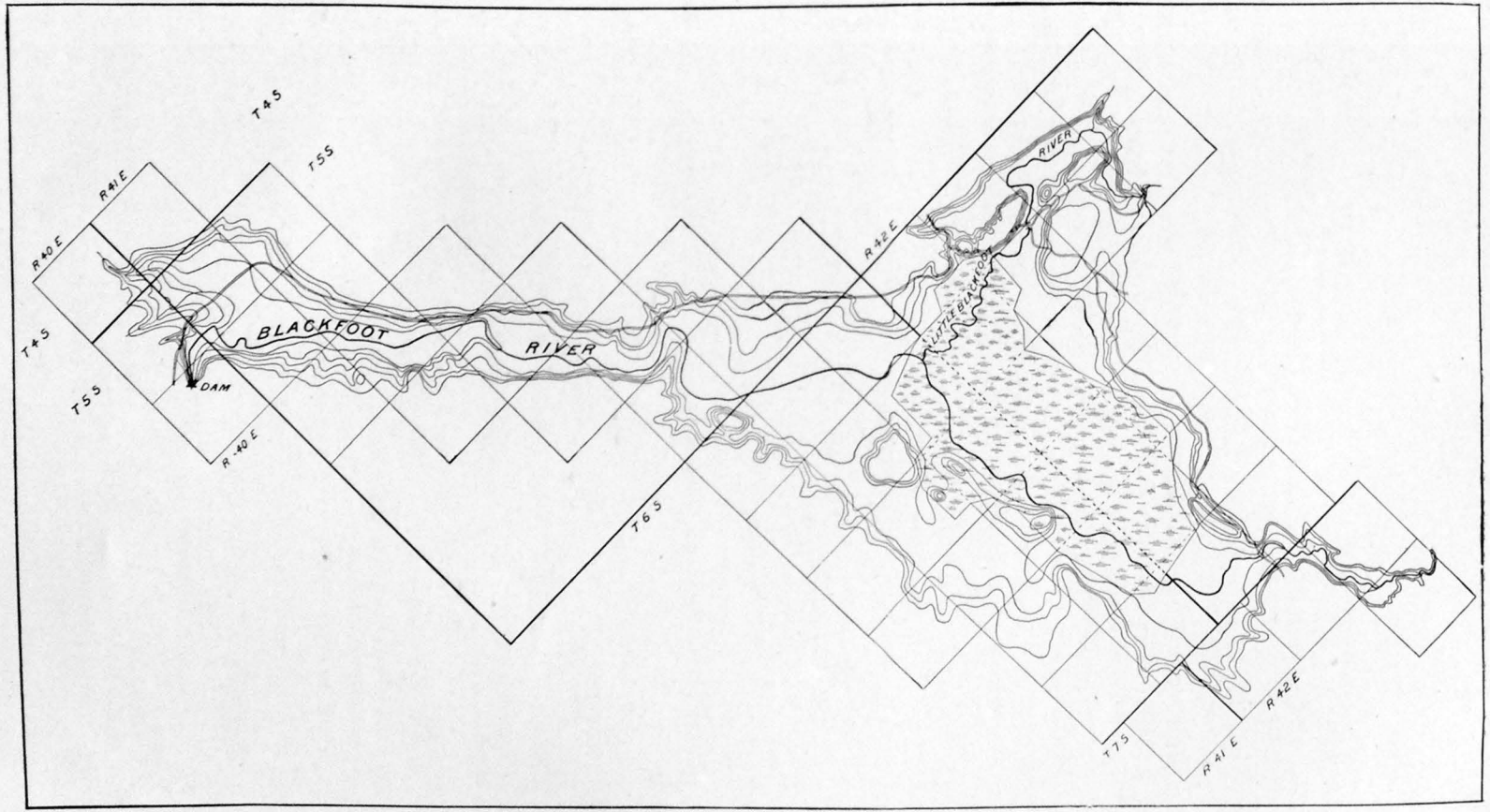
| Contour. | Area. | Capacity between sections. | Total capacity. |
|---|---|---|---|
| | *Acres.* | *Acre-feet.* | *Acre-feet.* |
| 0 | 0 | 0 | 0 |
| 10 | 1,210 | 6,050 | 6,050 |
| 20 | 10,915 | 60,625 | 66,675 |
| 30 | 14,752 | 128,335 | 195,010 |
| 40 | 17,623 | 161,875 | 356,885 |
| 50 | 20,060 | 188,415 | 545,300 |
| | | 545,300 | |

*List of land embraced in Blackfoot River reservoir site.*

BOISE MERIDIAN.

| | Acres. |
|---|---|
| SE. ¼ NE. ¼ sec. 36, T. 4 S., R. 40 E., unsurveyed | 40 |
| E. ½ SE. ¼ sec. 36, T. 4 S., R. 40 E., unsurveyed | 80 |
| SW. ¼ SE. ¼ sec. 36, T. 4 S., R. 40 E | 40 |
| E. ½ NW. ¼ sec. 1, T. 5 S., R. 40 E | 80 |
| E. ½ sec. 1, T. 5 S., R. 40 E | 320 |
| NE. ¼ NW. ¼ sec. 12, T. 5 S., R. 40 E | 40 |
| N. ½ NE. ¼ sec. 12, T. 5 S., R. 40 E | 80 |
| SW. ¼ sec. 31, T. 4 S., R. 41 E., unsurveyed | 160 |
| SW. ¼ SE. ¼ sec. 31, T. 4 S., R. 41 E., unsurveyed | 40 |
| W. ½ sec 5, T. 5 S., R. 41 E | 320 |
| All of sec. 6, T. 5 S., R. 41 E | 640 |
| N. ½ sec. 7, T. 5 S., R. 41 E | 320 |
| SE. ¼ sec. 7, T. 5 S., R. 41 E | 160 |
| N. ½ SW. ¼ sec. 7, T. 5 S., R. 41 E | 80 |
| SE. ¼ SW. ¼ sec. 7, T. 5 S., R. 41 E | 40 |
| W. ½ sec. 8, T. 5 S., R. 41 E | 320 |

| | Acres. |
|---|---|
| W. ½ SE. ¼ sec. 8, T. 5 S., R. 41 E. | 80 |
| SW. ¼ NW. ¼ sec. 16, T. 5 S., R. 41 E. | 40 |
| SW. ¼ sec. 16, T. 5 S., R. 41 E. | 160 |
| SW. ¼ SE. ¼ sec. 16, T. 5 S., R. 41 E. | 40 |
| All of sec. 17, T. 5 S., R. 41 E. | 640 |
| NE. ¼ NW. ¼ sec. 18, T. 5 S., R. 41 E. | 40 |
| NE. ¼ sec. 18, T. 5 S., R. 41 E. | 160 |
| NE. ¼ SE. ¼ sec. 18, T. 5 S., R. 41 E. | 40 |
| N. ½ NW. ¼ sec. 20, T. 5 S., R. 41 E. | 80 |
| SE. ¼ NW. ¼ sec. 20, T. 5 S., R. 41 E. | 40 |
| NE. ¼ sec. 20, T. 5 S., R. 41 E. | 160 |
| NE. ¼ SE. ¼ sec. 20, T. 5 S., R. 41 E. | 40 |
| All of sec. 21, T. 5 S., R. 41 E. | 640 |
| SW. ¼ NW. ¼ sec. 22, T. 5 S., R. 41 E. | 40 |
| SW. ¼ sec. 22, T. 5 S., R. 41 E. | 160 |
| W. ½ sec. 26, T. 5 S., R. 41 E. | 320 |
| SW. ¼ SE. ¼ sec. 26, T. 5 S., R. 41 E. | 40 |
| NW. ¼ sec. 27, T. 5 S., R. 41 E. | 160 |
| W. ½ NE. ¼ sec. 27, T. 5 S., R. 41 E. | 80 |
| SE. ¼ NE. ¼ sec. 27, T. 5 S., R. 41 E. | 40 |
| S. ½ sec. 27, T. 5 S., R. 41 E. | 320 |
| NE. ¼ NW. ¼ sec. 28, T. 5 S., R. 41 E. | 40 |
| NE. ¼ sec. 28, T. 5 S., R. 41 E. | 160 |
| NE. ¼ SE. ¼ sec. 28, T. 5 S., R. 41 E. | 40 |
| E. ½ sec. 34, T. 5 S., R. 41 E. | 320 |
| E. ½ NW. ¼ sec. 34, T. 5 S., R. 41 E. | 80 |
| SW. ¼ NW. ¼ sec. 34, T. 5 S., R. 41 E. | 40 |
| SW. ¼ sec. 34, T. 5 S., R. 41 E. | 160 |
| All of sec. 35, T. 5 S., R. 41 E. | 640 |
| SW. ¼ NW. ¼ sec. 36, T. 5 S., R. 41 E. | 40 |
| SW. ¼ sec. 36, T. 5 S., R. 41 E. | 160 |
| W. ½ SE. ¼ sec. 36, T. 5 S., R. 41 E. | 80 |
| All of sec. 1, T. 6 S., R. 41 E. | 640 |
| All of sec. 2, T. 6 S., R. 41 E. | 640 |
| E. ½ of sec. 3, T. 6 S., R. 41 E. | 320 |
| NE. ¼ NW. ¼ sec. 3, T. 6 S., R. 41 E. | 40 |
| E. ½ of sec. 10, T. 6 S., R. 41 E. | 320 |
| All of sec. 11, T. 6 S., R. 41 E. | 640 |
| All of sec. 12, T. 6 S., R. 41 E. | 640 |
| All of sec. 13, T. 6 S., R. 41 E. | 640 |
| All of sec. 14, T. 6 S., R. 41 E. | 640 |
| E. ½ NE. ¼ sec. 15, T. 6 S., R. 41 E. | 80 |
| E. ½ SE. ¼ sec. 15, T. 6 S., R. 41 E. | 80 |
| SW. ¼ SE. ¼ sec. 15, T. 6 S., R. 41 E. | 40 |
| NE. ¼ sec. 22, T. 6 S., R. 41 E. | 160 |
| N. ½ SE. ¼ sec. 22, T. 6 S., R. 41 E. | 80 |
| All of sec. 23, T. 6 S., R. 41 E. | 640 |
| All of sec. 24, T. 6 S., R. 41 E. | 640 |
| All of sec. 25, T. 6 S., R. 41 E. | 640 |
| N. ½ sec. 26, T. 6 S., R. 41 E. | 320 |
| N. ½ SE. ¼ sec. 26, T. 6 S., R. 41 E. | 80 |
| N. ½ SW. ¼ sec. 26, T. 6 S., R. 41 E. | 80 |
| SE. ¼ SW. ¼ sec. 26, T. 6 S., R. 41 E. | 40 |
| E. ½ SE. ¼ sec. 35, T. 6 S., R. 41 E. | 80 |
| All of sec. 36, T. 6 S., R. 41 E. | 640 |




RESERVOIR SITE ON BLACKFOOT RIVER, IDAHO.

| | Acres. |
|---|---|
| E. ½ NE. ¼ sec. 1, T. 7 S., R. 41 E | 80 |
| NW. ¼ SE. ¼ sec. 3, T. 6 S., R. 42 E | 40 |
| SW. ¼ sec. 3, T. 6 S., R. 42 E | 160 |
| S. ½ NW. ¼ sec. 4, T. 6 S., R. 42 E | 80 |
| S. ½ NE. ¼ sec. 4, T. 6 S., R. 42 E | 80 |
| S. ½ sec. 4, T. 6 S., R. 42 E | 320 |
| All of sec. 5, T. 6 S., R 42 E | 640 |
| S. ½ NW. ¼ sec. 6, T. 6 S., R. 42 E | 80 |
| E. ½ sec. 6, T. 6 S., R. 42 E | 320 |
| SW. ¼ sec. 6, T. 6 S., R. 42 E | 160 |
| All of sec. 7, T. 6 S., R. 42 E | 640 |
| All of sec. 8, T. 6 S., R. 42 E | 640 |
| All of sec. 9, T. 6 S., R. 42 E | 640 |
| N. ½ NW. ¼ sec. 10, T. 6 S., R. 42 E | 80 |
| SW. ¼ NW. ¼ sec. 10, T. 6 S., R. 42 E | 40 |
| W. ½ SW. ¼ sec. 10, T. 6 S., R. 42 E | 80 |
| NW. ¼ sec. 16, T. 6 S., R. 42 E | 160 |
| NW. ¼ NE. ¼ sec. 16, T. 6 S., R. 42 E | 40 |
| N. ½ sec. 17, T. 6 S., R. 42 E | 320 |
| SW. ¼ sec. 17, T. 6 S., R. 42 E | 160 |
| SE. ¼ sec. 17, T. 6 S., R. 42 E | 160 |
| All of sec. 18, T. 6 S., R. 42 E | 640 |
| All of sec. 19, T 6 S., R. 42 E | 640 |
| W. ½ sec. 20, T. 6 S., R. 42 E | 320 |
| SW. ¼ SE. ¼ sec. 20, T. 6 S., R. 42 E | 40 |
| NW. ¼ sec. 29, T. 6 S., R. 42 E | 160 |
| NW. ¼ NE. ¼ sec. 29, T. 6 S., R. 42 E | 40 |
| W. ½ SW. ¼ sec. 29, T. 6 S., R. 42 E | 80 |
| All of sec. 30, T. 6 S., R. 42 E | 640 |
| All of sec. 31, T. 6 S., R 42 E | 640 |
| W. ½ NW. ¼ sec. 32, T. 6 S., R. 42 E | 80 |
| SW. ¼ sec. 32, T. 6 S., R. 42 E | 160 |
| SW. ¼ SE. ¼ sec. 32, T. 6 S., R. 42 E | 40 |
| W. ½ sec. 4, T. 7 S., R. 42 E | 320 |
| N. ½ NW. ¼ sec. 5, T 7 S., R. 42 E | 80 |
| SW. ¼ NW. ¼ sec. 5, T. 7 S., R. 42 E | 40 |
| N. ½ NE. ¼ sec. 5, T. 7 S., R. 42 E | 80 |
| SE. ¼ NE. ¼ sec. 5, T. 7 S., R. 42 E | 40 |
| E. ½ SE. ¼ sec. 5, T. 7 S., R. 42 E | 80 |
| N. ½ sec. 6, T. 7 S., R 42 E | 320 |
| NE. ¼ SE. ¼ sec 6, T. 7 S., R. 42 E | 40 |
| SW. ¼ sec. 6, T. 7 S., R. 42 E | 160 |
| N. ½ sec 9, T 7 S., R. 42 E | 320 |
| W. ½ NW. ¼ sec. 10, T. 7 S., R. 42 E | 80 |

## M'CAMMON STATION ON PORTNEUF RIVER, IDAHO.

This station was established April 13, 1896, by Mr. F. J. Mills, State engineer. It is located at the wagon bridge, directly back of the grist mill. The rod is fastened to one of the wooden piers of the bridge. The section is not good for low-water measurements, owing to the location of a dam a short distance below the bridge. The station was discontinued on July 18. A better location for a station on this river

could be found near Pocatello. It would be necessary, however, to erect a cable at this point. The record of daily gage heights for 1896, from April 14 to July 18, is given in Water-Supply and Irrigation Paper No. 11, page 79.

*List of discharge measurements made on Portneuf River at McCammon, Idaho.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Apr. 13 | F. J. Mills | ..... | 3.42 | 312 | 0.85 | 266 |
| June 12 | L. B. Kendall | 23 | 4.20 | 341 | 1.80 | 612 |

*Rating table for Portneuf River at McCammon, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.90 | 85 | 3.40 | 255 | 3.90 | 475 | 4.30 | 685 |
| 3.00 | 115 | 3.50 | 295 | 4.00 | 525 | 4.40 | 740 |
| 3.10 | 150 | 3.60 | 335 | 4.10 | 575 | 4.50 | 800 |
| 3.20 | 185 | 3.70 | 380 | 4.20 | 630 | 4.60 | 860 |
| 3.30 | 220 | 3.80 | 425 | | | | |

*Estimated monthly discharge of Portneuf River at McCammon, Idaho.*

[Drainage area, 500 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| April 13 to 30 | 335 | 295 | 309 | 11,032 | 0.41 | 0.62 |
| May | 800 | 295 | 417 | 25,640 | 0.95 | 0.83 |
| June | 800 | 185 | 541 | 32,191 | 1.20 | 1.08 |
| July 1 to 18 | 115 | 70 | 91 | 3,249 | 0.12 | 0.18 |

## MONTGOMERY STATION ON SNAKE RIVER, IDAHO.

This station is described in Bulletin No. 140, page 241. Observations were continued from April to October, inclusive. The river is at a low stage during the months of January, February, and March, and the discharges for these months have been estimated. Taking the year from September, 1895, to August, 1896, inclusive, the total discharge of the river was 6,408,785 acre-feet, or a yearly run-off of 5.28 inches. The average run-off in second-feet per square mile was 0.39. The

observer is Mr. George Montgomery. The record of daily gage heights for 1896, from April 5 to October 24, is given in Water-Supply and Irrigation Paper No. 11, page 80.

*List of discharge measurements made on Snake River at Montgomery Ferry, Idaho.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Aug. 9 | A. P. Davis | 55 | 2.80 | 3,400 | 1.59 | 5,413 |
| Oct. 23 | G. F. Sherman | 23 | 2.28 | 3,162 | 1.45 | 4,592 |
| 1896. | | | | | | |
| June 13 | L. B. Kendall | 23 | 11.05 | 10,570 | 3.69 | 38,938 |
| Aug. 17 | C. C. Babb | 23 | 2.85 | 3,726 | 1.38 | 5,137 |

*Rating table for Snake River at Montgomery Ferry, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.00 | 4,340 | 4.60 | 7,685 | 7.20 | 15,215 | 9.80 | 28,220 |
| 2.10 | 4,420 | 4.70 | 7,890 | 7.30 | 15,580 | 9.90 | 28,940 |
| 2.20 | 4,505 | 4.80 | 8,105 | 7.40 | 15,950 | 10.00 | 29,680 |
| 2.30 | 4,595 | 4.90 | 8,330 | 7.50 | 16,330 | 10.10 | 30,440 |
| 2.40 | 4,685 | 5.00 | 8,560 | 7.60 | 16,715 | 10.20 | 31,220 |
| 2.50 | 4,780 | 5.10 | 8,795 | 7.70 | 17,105 | 10.30 | 32,020 |
| 2.60 | 4,875 | 5.20 | 9,040 | 7.80 | 17,505 | 10.40 | 32,840 |
| 2.70 | 4,975 | 5.30 | 9,290 | 7.90 | 17,910 | 10.50 | 33,680 |
| 2.80 | 5,075 | 5.40 | 9,550 | 8.00 | 18,320 | 10.60 | 34,540 |
| 2.90 | 5,180 | 5.50 | 9,815 | 8.10 | 18,740 | 10.70 | 35,420 |
| 3.00 | 5,285 | 5.60 | 10,085 | 8.20 | 19,170 | 10.80 | 36,320 |
| 3.10 | 5,395 | 5.70 | 10,360 | 8.30 | 19,615 | 10.90 | 37,240 |
| 3.20 | 5,520 | 5.80 | 10,645 | 8.40 | 20,075 | 11.00 | 38,180 |
| 3.30 | 5,630 | 5.90 | 10,935 | 8.50 | 20,550 | 11.10 | 39,140 |
| 3.40 | 5,755 | 6.00 | 11,230 | 8.60 | 21,040 | 11.20 | 40,130 |
| 3.50 | 5,885 | 6.10 | 11,530 | 8.70 | 21,545 | 11.30 | 41,150 |
| 3.60 | 6,020 | 6.20 | 11,840 | 8.80 | 22,060 | 11.40 | 42,200 |
| 3.70 | 6,160 | 6.30 | 12,155 | 8.90 | 22,590 | 11.50 | 43,280 |
| 3.80 | 6,300 | 6.40 | 12,475 | 9.00 | 23,140 | 11.60 | 44,390 |
| 3.90 | 6,450 | 6.50 | 12,800 | 9.10 | 23,710 | 11.70 | 45,530 |
| 4.00 | 6,605 | 6.60 | 13,130 | 9.20 | 24,300 | 11.80 | 46,700 |
| 4.10 | 6,765 | 6.70 | 13,465 | 9.30 | 24,910 | 11.90 | 47,900 |
| 4.20 | 6,935 | 6.80 | 13,805 | 9.40 | 25,540 | 12.00 | 49,140 |
| 4.30 | 7,110 | 6.90 | 14,150 | 9.50 | 26,180 | 12.10 | 50,420 |
| 4.40 | 7,295 | 7.00 | 14,500 | 9.60 | 26,840 | 12.20 | 51,740 |
| 4.50 | 7,485 | 7.10 | 14,855 | 9.70 | 27,520 | 12.30 | 53,100 |

*Estimated monthly discharge of Snake River at Montgomery Ferry, Idaho.*

[Drainage area, 22,600 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| August 5 to 31 | 5,285 | 4,505 | 4,773 | 246,142 | 0.20 | 0.21 |
| September | 4,595 | 4,420 | 4,518 | 268,840 | 0.22 | 0.20 |
| October | 4,685 | 4,595 | 4,615 | 283,765 | 0.23 | 0.20 |
| November | 4,875 | 4,685 | 4,807 | 286,037 | 0.23 | 0.21 |
| December | 5,885 | 4,595 | 4,782 | 294,034 | 0.24 | 0.21 |
| 1896. | | | | | | |
| January | ..... | ..... | *a* 4,800 | 295,141 | 0.24 | 0.21 |
| February | ..... | ..... | *a* 4,800 | 276,100 | 0.23 | 0.21 |
| March | ..... | ..... | *a* 5,000 | 307,438 | 0.25 | 0.22 |
| April | 6,020 | 4,875 | 5,264 | 313,230 | 0.26 | 0.23 |
| May | 20,075 | 6,300 | 9,357 | 575,340 | 0.47 | 0.41 |
| June | 53,100 | 23,710 | 39,551 | 2,353,447 | 1.95 | 1.75 |
| July | 22,060 | 6,605 | 13,341 | 820,306 | 0.68 | 0.59 |
| August | 6,450 | 5,075 | 5,450 | 335,107 | 0.28 | 0.24 |
| September | 5,075 | 4,875 | 4,972 | 295,854 | 0.25 | 0.22 |
| October 1 to 24 | 4,975 | 4,975 | 4,975 | 236,825 | 0.19 | 0.22 |

*a* Estimated.

## CAMAS STATION ON LITTLE CAMAS CREEK.

This station was established in March, 1896, by Mr. F. J. Mills, State engineer of Idaho. It is in the upper portion of Little Camas Prairie, at Little Camas store, in the Camas Prairie quadrangle, in latitude 43° 19′, longitude 115° 23′. The entire drainage basin is mapped upon the Camas Prairie atlas sheet, and has an area of 55 square miles. The stream here is in three channels; a gage was placed in each channel and separate readings recorded for each. This station was discontinued at the end of the irrigating season. A measurement of the stream on June 15, 1896, by Mr. L. B. Kendall, showed a gage height of 1.20 feet; area, 35 square feet; mean velocity, 1.37, and discharge, 48 second-feet. The record of daily gage heights for 1896, from March 29 to August 15, is given in Water-Supply and Irrigation Paper No. 11, page 80.

## TOPONIS STATION ON MALAD AND LITTLE WOOD RIVERS, IDAHO.

Gages were established on June 2, 1896, by Mr. F. J. Mills, State engineer of Idaho, on Malad and Little Wood rivers, at the wagon bridge near the railroad station of Toponis, Idaho. The heights were

read on temporary gages until August 18, when wire gages were placed.

On the Malad River the rod is fastened to the stringer of the bridge, upper side. The 5-foot mark is opposite the center vertical. The distance from the end of the weight to the index marker is 13.6 feet. The outside edge of the pulley wheel is 1 foot from the zero of the rod. The bed of the river is of gravel, and not liable to change. During low stages the water is confined under the north span, but in floods it is under the two spans. The banks are not subject to overflow. The bridge over the Malad is one-half mile north of railroad station. The drainage area, including lava plains, is 2,190 square miles, from about 15 per cent of which all water either evaporates or seeps down through the lava. The record of daily gage heights for 1896, from June 2 to September 29, is given in Water-Supply and Irrigation Paper No. 11, page 81.

On the Little Wood River the station is one-half mile south of the railroad. The rod is fastened to the floor of the bridge, the 1.8-foot mark being opposite the iron vertical on the upper side of the bridge. The distance from the end of the weight to the index marker is 10.37 feet. The distance from the end of the rod to the outside edge of the pulley wheel is 1.97 feet. The channel is good and not obstructed by piers, but the banks overflow during flood stages. The observer, Mr. M. Fleming, section foreman, reads both gages three times a week. The drainage area is 1,270 square miles, a large part of which is lava desert, water seeping through and evaporating in the many small lava lake beds.

*List of discharge measurements made on Malad and Little Wood rivers at Toponis, Idaho.*

MALAD RIVER.

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 14 | L. B. Kendall ..... | 23 | 8.50 | 689 | 5.64 | 3,886 |
| 2 | Aug. 18 | C. C. Babb..... | 23 | 2.04 | 132 | 1.39 | 184 |

LITTLE WOOD RIVER.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | June 14 | L. B. Kendall ..... | 23 | 6.40 | 365 | 1.56 | 568 |
| 2 | Aug. 18 | C. C. Babb..... | (*a*) | 1.18 | 16 | 0.15 | 2.4 |

*a* Flatboats.

*Rating table for Malad River at Toponis, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.60 | 101 | 3.60 | 528 | 5.60 | 1,362 | 7.60 | 2,762 |
| 1.70 | 119 | 3.70 | 557 | 5.70 | 1,416 | 7.70 | 2,867 |
| 1.80 | 137 | 3.80 | 587 | 5.80 | 1,471 | 7.80 | 2,977 |
| 1.90 | 155 | 3.90 | 619 | 5.90 | 1,527 | 7.90 | 3,092 |
| 2.00 | 174 | 4.00 | 652 | 6.00 | 1,584 | 8.00 | 3,212 |
| 2.10 | 193 | 4.10 | 686 | 6.10 | 1,642 | 8.10 | 3,337 |
| 2.20 | 213 | 4.20 | 721 | 6.20 | 1,701 | 8.20 | 3,467 |
| 2.30 | 233 | 4.30 | 758 | 6.30 | 1,761 | 8.30 | 3,502 |
| 2.40 | 253 | 4.40 | 797 | 6.40 | 1,823 | 8.40 | 3,642 |
| 2.50 | 274 | 4.50 | 837 | 6.50 | 1,887 | 8.50 | 3,787 |
| 2.60 | 294 | 4.60 | 879 | 6.60 | 1,953 | 8.60 | 3,937 |
| 2.70 | 315 | 4.70 | 922 | 6.70 | 2,021 | 8.70 | 4,097 |
| 2.80 | 336 | 4.80 | 966 | 6.80 | 2,091 | 8.80 | 4,267 |
| 2.90 | 358 | 4.90 | 1,012 | 6.90 | 2,163 | 8.90 | 4,447 |
| 3.00 | 380 | 5.00 | 1,059 | 7.00 | 2,237 | 9.00 | 4,642 |
| 3.10 | 403 | 5.10 | 1,107 | 7.10 | 2,314 | 9.10 | 4,852 |
| 3.20 | 426 | 5.20 | 1,156 | 7.20 | 2,394 | 9.20 | 5,062 |
| 3.30 | 450 | 5.30 | 1,206 | 7.30 | 2,477 | 9.30 | 5,302 |
| 3.40 | 475 | 5.40 | 1,257 | 7.40 | 2,563 | 9.40 | 5,562 |
| 3.50 | 501 | 5.50 | 1,309 | 7.50 | 2,663 | 9.50 | 5,842 |

*Estimated monthly discharge of Malad River at Toponis, Idaho.*

[Drainage area, 2,190 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| June | 5,942 | 2,477 | 3,787 | 225,342 | 1.93 | 1.73 |
| July | 2,394 | 273 | 1,162 | 71,548 | 0.61 | 0.53 |
| August | 233 | 137 | 178 | 10,944 | 0.08 | 0.07 |
| September | 155 | 101 | 131 | 7,795 | 0.07 | 0.06 |

*Rating table for Little Wood River at Toponis, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 1 | 2 60 | 72 | 4.20 | 203 | 5.70 | 415 |
| 1.10 | 3 | 2.70 | 78 | 4.30 | 215 | 5.80 | 433 |
| 1.20 | 7 | 2.80 | 84 | 4.40 | 227 | 5.90 | 452 |
| 1.30 | 11 | 2.90 | 91 | 4.50 | 239 | 6.00 | 471 |
| 1.40 | 15 | 3.00 | 98 | 4.60 | 251 | 6.10 | 493 |
| 1.50 | 19 | 3.10 | 105 | 4.70 | 264 | 6.20 | 516 |
| 1.60 | 23 | 3.20 | 112 | 4.80 | 277 | 6.30 | 540 |
| 1.70 | 27 | 3.30 | 119 | 4.90 | 291 | 6.40 | 563 |
| 1.80 | 31 | 3.40 | 127 | 5.00 | 305 | 6.50 | 593 |
| 1.90 | 35 | 3.50 | 135 | 5.10 | 319 | 6.60 | 622 |
| 2.00 | 40 | 3.60 | 143 | 5.20 | 334 | 6.70 | 652 |
| 2.10 | 45 | 3.70 | 152 | 5.30 | 349 | 6.80 | 684 |
| 2.20 | 50 | 3.80 | 161 | 5.40 | 365 | 6.90 | 715 |
| 2.30 | 55 | 3.90 | 171 | 5.50 | 381 | 7.00 | 751 |
| 2.40 | 60 | 4.00 | 181 | 5.60 | 398 | 7.10 | 791 |
| 2.50 | 66 | 4.10 | 192 | | | | |

*Estimated monthly discharge of Little Wood River at Toponis, Idaho.*

[Drainage area, 1,270 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| June | 791 | 192 | 554 | 32,965 | 0.49 | 0.44 |
| July | 215 | 7 | 134 | 8,238 | 0.12 | 0.10 |
| August | 7 | 1 | 5 | 307 | 0.00 | 0.00 |
| September | 91 | 15 | 51 | 3,034 | 0.04 | 0.04 |

## GRAND VIEW STATION ON BRUNEAU RIVER.

This station is described in Bulletin 140, pages 239 and 240. The point of measurement is 10 miles east of Grand View, below the head of the Bruneau ditch. Observations of gage height are regularly kept, and estimates of discharge are made from them by Mr. Andrew J. Wiley, chief engineer of the Owyhee Land and Irrigation Company. The record of daily gage heights for the first six months of 1896 is given in Water-Supply and Irrigation Paper No. 11, page 81. The following

table of discharge has been prepared from the values of daily discharge estimated by Mr. Wiley:

*List of discharge measurements made on Bruneau River near Grand View, Idaho.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 3 | A. P. Davis..... | 55 | 1.33 | 114 | 0.44 | 50 |
| 2 | Dec. 21 | A. J. Wiley..... | 7 | ..... | 150 | 0.85 | 127 |
| | 1896. | | | | | | |
| 3 | May 24 | A. J. Wiley ..... | 5 | 2.90 | 267 | 2.67 | 712 |
| 4 | June 14 | .....do ..... | 5 | 4.60 | 453 | 4.41 | 2,000 |
| 5 | Sept. 23 | .....do ..... | 7 | ..... | 124 | 0.52 | 64 |

*Estimated monthly discharge of Bruneau River at its mouth.*

[Drainage area, 1,800 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January..... | 130 | 94 | 115 | 7,071 | 0.07 | 0.06 |
| February..... | 130 | 94 | 119 | 7,081 | 0.07 | 0.07 |
| March..... | 1,200 | 130 | 321 | 19,738 | 0.21 | 0.18 |
| April..... | 1,420 | 330 | 620 | 38,122 | 0.39 | 0.35 |
| May ..... | 3,070 | 470 | 943 | 56,112 | 0.60 | 0.52 |
| June..... | 3,630 | 890 | 1,982 | 117,937 | 1.23 | 1.01 |
| July ..... | 850 | 100 | 325 | 19,983 | 0.21 | 0.18 |
| August..... | 110 | 45 | 63 | 3,874 | 0.04 | 0.04 |
| September ..... | 70 | 40 | 48 | 2,856 | 0.03 | 0.03 |
| October..... | 80 | 50 | 62 | 3,812 | 0.04 | 0.03 |
| November..... | 360 | 60 | 137 | 8,152 | 0.08 | 0.08 |
| December..... | 200 | 75 | 130 | 7,736 | 0.08 | 0.07 |
| Per annum ..... | 3,630 | 40 | 405 | 292,474 | 3.05 | 0.47 |

## BOISE STATION ON BOISE RIVER, IDAHO.

This station is described in Bulletin No. 131, page 66, and in Bulletin No. 140, page 236. It is located about 8 miles above Boise, at the mouth of the canyon, in the Boise quadrangle, in latitude 43° 33′, longitude 116° 6′. The area drained is 2,450 square miles, and is mapped in contours on the Boise, Idaho Basin, Garden Valley, Bear Valley, Rocky Bar, Red Fish Lake, Camas Prairie, and Mountain Home

atlas sheets. The observer is Mrs. Ed. Marnell. The gage consists of an inclined rod fastened to stakes set in the ground. The bench mark is a bridge spike driven into a cottonwood tree 20 feet from the gage. Its elevation is 11.40 feet. A secondary gage for determining the slope of the water surface is placed 425 feet below the upper one, and is referred to the same datum. The cable at this point was carried out by the high water in June, but was replaced in August. A measure-

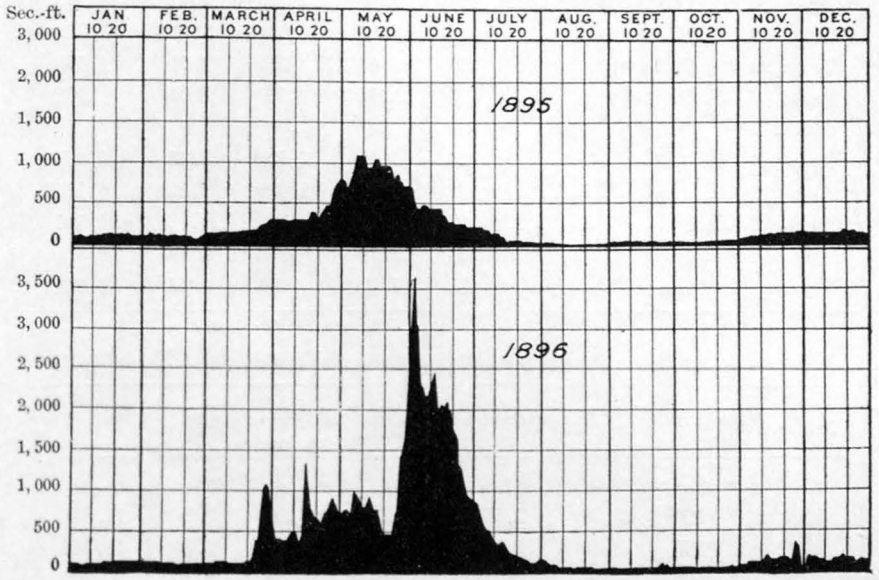



FIG. 56.—Discharge of Bruneau River near Grand View, Idaho, 1895–96.

ment of the river was made during the high stage, on June 6, at the Star bridge, 16 miles below Boise and 9 miles above Caldwell; mean velocity, 5.55; area, 3,290; discharge, 22,166 second-feet. The discharges on this date at the Caldwell and Boise stations were computed to be 22,000 and 24,500 second-feet, respectively. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 81.

*List of discharge measurements made on Boise River, above Boise, Idaho.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Apr. 20 | V. C. Tompkins | 26 | 5.00 | 1,394 | 3.42 | 4,770 |
| May 11 | do | 26 | 5.30 | 1,480 | 3.76 | 5,562 |
| June 24 | do | 23 | 4.60 | 1,515 | 2.71 | 4,115 |
| July 18 | G. F. Sherman | 23 | 2.80 | 864 | 1.98 | 1,708 |
| July 26 | A. P. Davis | 55 | 2.40 | 705 | 2.20 | 1,552 |
| Sept. 7 | G. F. Sherman | 23 | 1.75 | 567 | 1.75 | 938 |
| 1896. | | | | | | |
| Apr. 25 | L. B. Kendall | 23 | 5.40 | 1,600 | 3.78 | 6,075 |
| Apr. 29 | do | 23 | 6.50 | 1,658 | 3.80 | 6,301 |
| June 6 | do | 23 | 8.70 | ..... | ..... | *a* 24,500 |
| Aug. 14 | C. C. Babb | 23 | 2.25 | 776 | 1.78 | 1,373 |
| Sept. 4 | do | 63 | 1.90 | 656 | 1.54 | 1,011 |

*a* Gaging made at Star bridge; mean velocity, 5.55; area, 3,290; discharge, 22,166.

*Rating table for Boise River at foot of Boise Canyon, Idaho, for 1895 and 1896.*

| Gage height. | Discharge. | Gage height. | Discharge | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.00 | 520 | 3.30 | 2,190 | 5.60 | 6,130 | 7.90 | 14,655 |
| 1.10 | 570 | 3.40 | 2,310 | 5.70 | 6,360 | 8.00 | 15,325 |
| 1.20 | 620 | 3.50 | 2,430 | 5.80 | 6,600 | 8.10 | 16,040 |
| 1.30 | 670 | 3.60 | 2,560 | 5.90 | 6,845 | 8.20 | 16,792 |
| 1.40 | 720 | 3.70 | 2,690 | 6.00 | 7,095 | 8.30 | 17,592 |
| 1.50 | 770 | 3.80 | 2,830 | 6.10 | 7,355 | 8.40 | 18,442 |
| 1.60 | 830 | 3.90 | 2,970 | 6.20 | 7,630 | 8.50 | 19,342 |
| 1.70 | 890 | 4.00 | 3,120 | 6.30 | 7,895 | 8.60 | 20,292 |
| 1.80 | 950 | 4.10 | 3,270 | 6.40 | 8,175 | 8.70 | 21,292 |
| 1.90 | 1,010 | 4.20 | 3,430 | 6.50 | 8,465 | 8.80 | 22,352 |
| 2.00 | 1,070 | 4.30 | 3,590 | 6.60 | 8,765 | 8.90 | 23,472 |
| 2.10 | 1,140 | 4.40 | 3,760 | 6.70 | 9,075 | 9.00 | 24,652 |
| 2.20 | 1,210 | 4.50 | 3,930 | 6.80 | 9,405 | 9.10 | 25,892 |
| 2.30 | 1,280 | 4.60 | 4,105 | 6.90 | 9,735 | 9.20 | 27,202 |
| 2.40 | 1,350 | 4.70 | 4,285 | 7.00 | 10,110 | 9.30 | 28,572 |
| 2.50 | 1,430 | 4.80 | 4,470 | 7.10 | 10,510 | 9.40 | 30,012 |
| 2.60 | 1,510 | 4.90 | 4,660 | 7.20 | 10,935 | 9.50 | 31,522 |
| 2.70 | 1,590 | 5.00 | 4,855 | 7.30 | 11,375 | 9.60 | 33,102 |
| 2.80 | 1,680 | 5.10 | 5,055 | 7.40 | 11,845 | 9.70 | 34,752 |
| 2.90 | 1,770 | 5.20 | 5,260 | 7.50 | 12,345 | 9.80 | 36,472 |
| 3.00 | 1,870 | 5.30 | 5,470 | 7.60 | 12,875 | 9.90 | 38,262 |
| 3.10 | 1,970 | 5.40 | 5,685 | 7.70 | 13,435 | 10.00 | 40,132 |
| 3.20 | 2,080 | 5.50 | 5,905 | 7.80 | 14,025 | | |

*Estimated monthly discharge of Boise River above Boise, Idaho.*

[Drainage area, 2,450 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 1,470 | 950 | 1,271 | 78,151 | 0.58 | 0.50 |
| February | 1,470 | 1,070 | 1,231 | 68,365 | 0.54 | 0.50 |
| March | 3,430 | 1,350 | 1,662 | 102,192 | 0.70 | 0.61 |
| April | 6,845 | 2,135 | 3,941 | 234,505 | 1.89 | 1.69 |
| May | 7,095 | 5,055 | 6,026 | 370,525 | 2.85 | 2.46 |
| June | 4,470 | 2,970 | 3,768 | 224,211 | 1.72 | 1.54 |
| July | 3,590 | 1,280 | 2,458 | 151,136 | 1.15 | 1.00 |
| August | 1,280 | 890 | 1,026 | 63,086 | 0.46 | 0.40 |
| September | 1,070 | 830 | 967 | 57,540 | 0.45 | 0.39 |
| October | 950 | 890 | 919 | 56,507 | 0.43 | 0.37 |
| November | 1,010 | 720 | 916 | 54,506 | 0.41 | 0.37 |
| December | 1,010 | 620 | 797 | 49,005 | 0.38 | 0.33 |
| Per annum | 7,095 | 620 | 2,082 | 1,509,729 | 11.56 | 0.85 |
| 1896. | | | | | | |
| January | 1,870 | 620 | 1,184 | 72,800 | 0.55 | 0.48 |
| February | 1,870 | 950 | 1,128 | 64,883 | 0.50 | 0.46 |
| March | 7,355 | 1,070 | 2,477 | 152,304 | 1.16 | 1.01 |
| April | 9,075 | 2,830 | 4,751 | 282,703 | 2.16 | 1.94 |
| May | 31,520 | 4,105 | 8,088 | 497,310 | 3.81 | 3.30 |
| June | 40,130 | 8,175 | 22,206 | 1,311,349 | 11.10 | 9.06 |
| July | 10,110 | 1,870 | 5,534 | 340,088 | 2.62 | 2.26 |
| August | 2,190 | 950 | 1,322 | 81,287 | 0.60 | 0.52 |
| September | 1,210 | 890 | 951 | 56,588 | 0.44 | 0.39 |
| October | 1,010 | 830 | 875 | 53,801 | 0.41 | 0.36 |
| November | ..... | ..... | *a* 900 | 53,554 | 0.41 | 0.37 |
| December | ..... | ..... | *a* 850 | 52,264 | 0.40 | 0.35 |
| Per annum | 40,130 | 620 | 4,189 | 3,018,931 | 24.16 | 1.78 |

*a* Estimated.

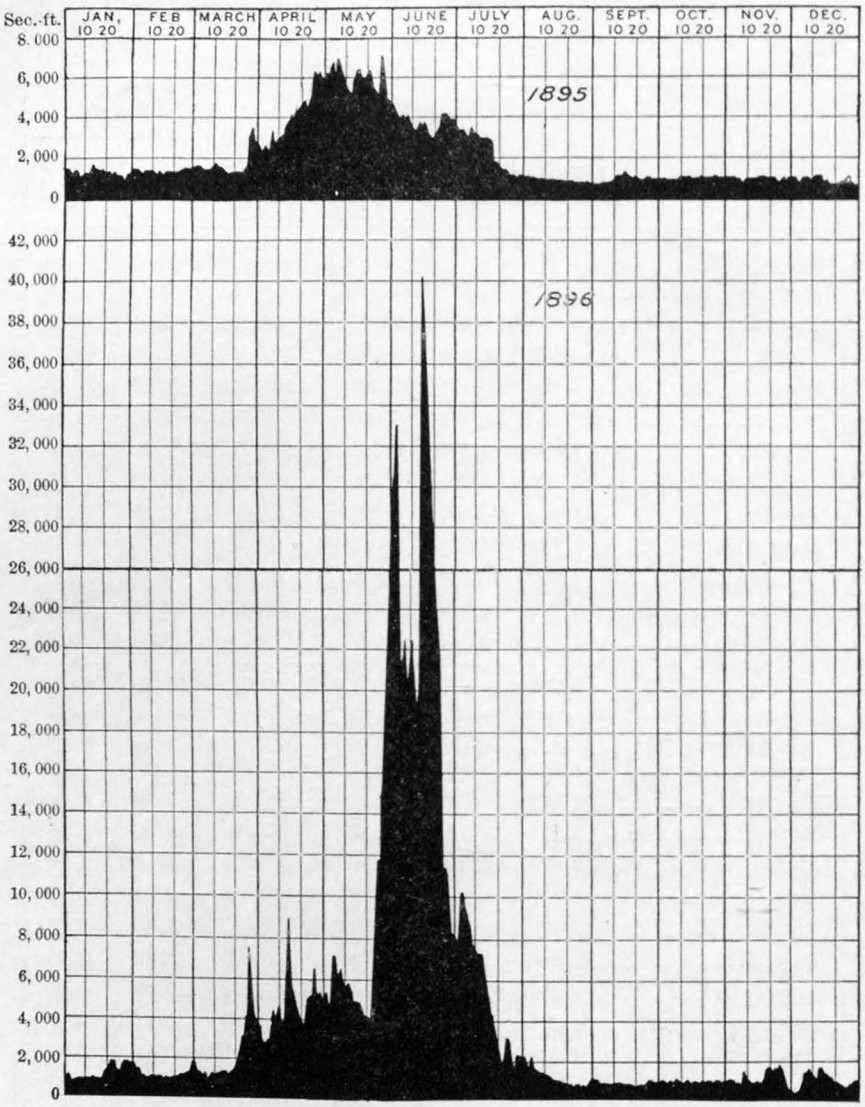



FIG. 57.—Discharge of Boise River above Boise, Idaho, 1895–96.

## CALDWELL STATION ON BOISE RIVER, IDAHO.

This station is described in Bulletin No. 140, page 237. It is at the highway bridge, 1 mile north of Caldwell, in the Nampa quadrangle, latitude 43° 42′, longitude 116° 42′. The area drained is 3,360 square miles, and is mapped on the Nampa, Boise, Idaho Basin, Garden Valley, Bear Valley, Rocky Bar, Red Fish Lake, Camas Prairie, Mountain Home, and Bisuka atlas sheets. The gage consists of an inclined rod divided into vertical tenths of a foot, the distance along the rod between the marks being 0.22 of a foot. The gage is spiked and bolted to two

piles and to a stake driven into the river. The bench mark is a nail in the top of the pile at the upper end of the gage. Its elevation is 13 feet. Owing to the change in the section of the river during the high water of June, 1896, the rating table is not applicable for 1896. The report of daily gage heights for 1896, from March 4 to September 30, is given in Water-Supply and Irrigation Paper No. 11, page 82.

*List of discharge measurements, made on Boise River at Caldwell, Idaho.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | July 28 | A. P. Davis..... | 55 | 3.80 | 189 | 4.00 | 756 |
| 2 | Aug. 17 | G. F. Sherman.... | 23 | 3.15 | 81 | 2.78 | 226 |
| 3 | Oct. 16 | .....do ..... | 15 | 3.35 | 103 | 3.05 | 315 |
| | 1896. | | | | | | |
| 4 | Apr. 29 | L. B. Kendall .... | 23 | 6.50 | 1,658 | 4.12 | 6,450 |
| 5 | June 6 | .....do ..... | ..... | 9.90 | ..... | ..... | a22,000 |
| 6 | Aug. 6 | C. C. Babb..... | 63 | 4.20 | 1,095 | 1.45 | 1,585 |

a Computed from measurement at Star bridge. See Boise Station.

*Rating table for lower Boise River at Caldwell, Idaho, for 1895 and 1896.*

| Gage height. | Discharge. | Gage height | Discharge. | Gage height | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet.* |
| 2.90 | 150 | 3.50 | 430 | 4.00 | 1,045 | 4.50 | 1,875 |
| 3.00 | 175 | 3.60 | 520 | 4.10 | 1,200 | 4.60 | 2,085 |
| 3.10 | 205 | 3.70 | 630 | 4.20 | 1,355 | 4.70 | 2,320 |
| 3.20 | 245 | 3.80 | 755 | 4.30 | 1,515 | 4.80 | 2,580 |
| 3.30 | 295 | 3.90 | 895 | 4.40 | 1,685 | 4.90 | 2,870 |
| 3.40 | 355 | | | | | | |

*Estimated monthly discharge of Boise River at Caldwell, Idaho.*

[Drainage area, 3,360 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| August 18 to 31..... | 205 | 150 | 174 | 4,485 | 0.03 | 0.05 |
| September ..... | 895 | 150 | 427 | 25,508 | 0.14 | 0.13 |
| October ..... | 755 | 270 | 450 | 27,669 | 0.15 | 0.13 |
| November 1 to 20 ..... | 895 | 630 | 772 | 30,624 | 0.17 | 0.23 |

## NYSSA STATION ON OWYHEE RIVER, OREGON.

This station was described in Bulletin No. 131, page 66, and in Bulletin No. 140, page 242. The gage is inclined, of 5 by 5 inch timber, marked 1 foot to 13 feet. The distance between foot marks on the lower half is 2.77 feet. The bench mark consists of a spike driven in a large stump about 20 feet from the left bank of the river and 300 feet below the gage. It is the same bench mark formerly used, and is 4.35 feet above the 11-foot mark. The channel is sandy and shifting. The observations at this point during 1896 are not considered wholly reliable. A large ditch takes water out above the station, so that the river measurements do not give the total discharge of the river during the irrigation season. The record of daily gage heights for 1896, from January 1 to February 29 and from April 26 to October 3, is given in Water-Supply and Irrigation Paper No. 11, page 82.

*List of discharge measurements made on Owyhee River at Nyssa, Oregon.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 25 | V. C. Tompkins.... | 26 | 2.40 | 690 | 1.12 | 773 |
| 2 | June 30 | .....do ..... | 23 | 1.30 | 267 | 0.80 | 213 |
| 3 | July 20 | G. F. Sherman ..... | 23 | 1.00 | 119 | 0.54 | 64 |
| | 1896. | | | | | | |
| 4 | Jan. 25 | G. F. Sherman ..... | 23 | 1.60 | 314 | 1.30 | 408 |
| 5 | June 19 | L. B. Kendall ..... | ..... | 3.20 | 837 | 2.09 | 1,749 |
| 6 | Aug. 8 | C. C. Babb..... | 63 | 1.00 | 289 | 0.59 | 169 |

*Rating table for Owyhee River at Nyssa, Oregon, for 1895.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.90 | 32 | 2.10 | 621 | 3.20 | 1,567 | 4.30 | 3,458 |
| 1.00 | 70 | 2.20 | 685 | 3.30 | 1,688 | 4.40 | 3,712 |
| 1.10 | 110 | 2.30 | 752 | 3.40 | 1,817 | 4.50 | 3,984 |
| 1.20 | 152 | 2.40 | 823 | 3.50 | 1,954 | 4.60 | 4,275 |
| 1.30 | 196 | 2.50 | 898 | 3.60 | 2,100 | 4.70 | 4,586 |
| 1.40 | 242 | 2.60 | 977 | 3.70 | 2,256 | 4.80 | 4,918 |
| 1.50 | 290 | 2.70 | 1,061 | 3.80 | 2,423 | 4.90 | 5,272 |
| 1.60 | 340 | 2.80 | 1,150 | 3.90 | 2,602 | 5.00 | 5,649 |
| 1.70 | 392 | 2.90 | 1,245 | 4.00 | 2,794 | 5.10 | 6,051 |
| 1.80 | 446 | 3.00 | 1,346 | 4.10 | 3,000 | 5.20 | 6,480 |
| 1.90 | 502 | 3.10 | 1,453 | 4.20 | 3,221 | 5.30 | 7,038 |
| 2.00 | 560 | | | | | | |

*Rating table for Owyhee River at Nyssa, Oregon, for 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.90 | 125 | 2.20 | 726 | 3.50 | 2,297 | 4.80 | 6,782 |
| 1.00 | 161 | 2.30 | 795 | 3.60 | 2,484 | 4.90 | 7,248 |
| 1.10 | 198 | 2.40 | 870 | 3.70 | 2,679 | 5.00 | 7,717 |
| 1.20 | 236 | 2.50 | 952 | 3.80 | 2,882 | 5.10 | 8,149 |
| 1.30 | 275 | 2.60 | 1,042 | 3.90 | 3,193 | 5.20 | 8,629 |
| 1.40 | 315 | 2.70 | 1,141 | 4.00 | 3,512 | 5.30 | 9,105 |
| 1.50 | 357 | 2.80 | 1,250 | 4.10 | 3,838 | 5.40 | 9,600 |
| 1.60 | 401 | 2.90 | 1,369 | 4.20 | 4,171 | 5.50 | 10,005 |
| 1.70 | 447 | 3.00 | 1,499 | 4.30 | 4,510 | 5.60 | 10,610 |
| 1.80 | 496 | 3.10 | 1,639 | 4.40 | 4,955 | 5.70 | 11,120 |
| 1.90 | 548 | 3.20 | 1,789 | 4.50 | 5,405 | 5.80 | 11,640 |
| 2.00 | 603 | 3.30 | 1,949 | 4.60 | 5,860 | 5.90 | 12,170 |
| 2.10 | 662 | 3.40 | 2,118 | 4.70 | 6,319 | | |

*Estimated monthly discharge of Owyhee River at Nyssa, Oregon.*

[Drainage area, 9,875 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 1,510 | 340 | 651 | 40,028 | 0.08 | 0.07 |
| February | 2,423 | 446 | 787 | 43,708 | 0.09 | 0.08 |
| March | 2,602 | 446 | 801 | 47,663 | 0.09 | 0.08 |
| April | 6,480 | 1,061 | 3,925 | 233,554 | 0.45 | 0.40 |
| May | 6,760 | 590 | 3,182 | 195,654 | 0.37 | 0.32 |
| June | 560 | 152 | 293 | 17,434 | 0.03 | 0.03 |
| July | 152 | 32 | 88 | 5,411 | 0.01 | 0.01 |
| August | 110 | 32 | 67 | 4,120 | 0.01 | 0.01 |
| September | 152 | 70 | 94 | 5,593 | 0.01 | 0.01 |
| October | 152 | 110 | 137 | 8,423 | 0.01 | 0.01 |
| November | 196 | 152 | 158 | 9,402 | 0.02 | 0.02 |
| December | 242 | 196 | 206 | 12,669 | 0.02 | 0.02 |
| Per annum | 6,760 | 32 | 866 | 623,659 | 1.19 | 0.09 |
| 1896. | | | | | | |
| January | 12,075 | 275 | 1,024 | 62,964 | 0.15 | 0.13 |
| February | 401 | 275 | 333 | 19,155 | 0.03 | 0.03 |
| April 26 to 30 | 2,679 | 2,118 | 2,451 | 24,307 | 0.07 | 0.25 |
| May | 14,905 | 2,484 | 6,894 | 423,896 | 0.81 | 0.70 |
| June | 13,280 | 795 | 3,444 | 204,932 | 0.39 | 0.35 |
| July | 726 | 161 | 343 | 21,090 | 0.03 | 0.03 |
| August | 315 | 125 | 186 | 11,438 | 0.02 | 0.02 |
| September | 275 | 125 | 172 | 10,235 | 0.02 | 0.02 |

## VALE STATION ON MALHEUR RIVER, OREGON.

This station has been described in Bulletin No. 131, page 68, and in Bulletin No. 140, page 242. The observer is Mr. E. R. Murray, postmaster, Vale, Oregon. The station is distant from the observer's house about one-fourth of a mile. The gage is inclined, and is in two parts. The lower part is graduated from 1.6 to 9.1 feet, the distance between the footmarks being 1.95 feet. The upper part is graduated from 9.1 to 11.7 feet, the distance between the footmarks being 3 feet. The channel is composed of earth and sand and is shifting. The bench mark is on a flat rock, nearly buried, above the right bank of the river, 50 feet southeast of south abutment of new bridge, and is 1.32 feet above the 11-foot mark on the gage. Measurements are made from the iron highway bridge. The one on August 8, 1896, was made by wading, a short distance above the bridge, at a better section. The record of daily gage heights for 1896, from January 1 to February 29, and from April 26 to September 30, is given in Water-Supply and Irrigation Paper No. 11, page 83.

*List of discharge measurements made on Malheur River at Vale, Oregon.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 26 | V. C. Tompkins ... | 26 | 3.00 | 705 | 0.74 | 521 |
| 2 | May 24 | .....do ..... | 26 | 2.10 | 374 | 0.70 | 261 |
| 3 | June 29 | .....do ..... | 23 | 0.80 | 43 | 0.63 | 28 |
| 4 | July 21 | G. F. Sherman..... | 23 | 0.58 | 9 | 1.00 | 9 |
| | 1896. | | | | | | |
| 5 | Jan. 25 | G. F. Sherman ..... | 23 | 3.20 | 545 | 1.56 | 852 |
| 6 | June 20 | L. B. Kendall ..... | ..... | 3.40 | 456 | 2.21 | 1,018 |
| 7 | July 19 | .....do ..... | 23 | 1.62 | 211 | 0.79 | 168 |
| 8 | Aug. 8 | C. C. Babb..... | 63 | 0.72 | 26 | 1.31 | 33 |

*Rating table for Malheur River at Vale, Oregon, for 1895 and 1896.*

[Constructed by Lyman B. Kendall, from discharge measurements Nos. 1 to 8.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.40 | 0 | 1.60 | 156 | 2.80 | 513 | 3.90 | 1,969 |
| 0.50 | 4 | 1.70 | 175 | 2.90 | 573 | 4.00 | 2,171 |
| 0.60 | 12 | 1.80 | 195 | 3.00 | 642 | 4.10 | 2,375 |
| 0.70 | 22 | 1.90 | 216 | 3.10 | 722 | 4.20 | 2,580 |
| 0.80 | 33 | 2.00 | 238 | 3.20 | 815 | 4.30 | 2,785 |
| 0.90 | 45 | 2.10 | 261 | 3.30 | 924 | 4.40 | 2,990 |
| 1.00 | 58 | 2.20 | 286 | 3.40 | 1,053 | 4.50 | 3,195 |
| 1.10 | 72 | 2.30 | 313 | 3.50 | 1,203 | 4.60 | 3,400 |
| 1.20 | 87 | 2.40 | 343 | 3.60 | 1,375 | 4.70 | 3,610 |
| 1.30 | 103 | 2.50 | 377 | 3.70 | 1,571 | 4.80 | 3,820 |
| 1.40 | 120 | 2.60 | 416 | 3.80 | 1,769 | 4.90 | 4,035 |
| 1.50 | 138 | 2.70 | 461 | | | | |

NOTE.—Cross section very changeable and table unreliable. The same is prepared at this time, believing that the future observation at this cross section will not improve matters.

*Estimated monthly discharge of Malheur River at Vale, Oregon.*

[Drainage area, 9,900 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 313 | 216 | 277 | 17,032 | 0.03 | 0.03 |
| February | 924 | 138 | 347 | 19,959 | 0.04 | 0.04 |
| March | 2,990 | 261 | 650 | 39,967 | 0.08 | 0.07 |
| April | 1,375 | 573 | 851 | 50,637 | 0.10 | 0.09 |
| May | 573 | 216 | 361 | 22,195 | 0.04 | 0.04 |
| June | 261 | 33 | 139 | 8,275 | 0.01 | 0.01 |
| July | 45 | 4 | 19 | 1,168 | 0.00 | 0.00 |
| August | 12 | 12 | 12 | 738 | 0.00 | 0.00 |
| September | 156 | 12 | 89 | 5,296 | 0.01 | 0.01 |
| October | 138 | 120 | 129 | 7,932 | 0.01 | 0.01 |
| November | 216 | 138 | 161 | 8,579 | 0.02 | 0.02 |
| December | 216 | 156 | 175 | 10,760 | 0.02 | 0.02 |
| Per annum | 2,990 | 4 | 268 | 192,538 | 0.36 | 0.03 |

*Estimated monthly discharge of Malheur River at Vale, Oregon*—Continued.

[Drainage area, 9,900 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January 1 to 16, 25 to 31 | 815 | 175 | 300 | 13,686 | 0.02 | 0.03 |
| February | 608 | 250 | 331 | 19,039 | 0.03 | 0.03 |
| April 26 to 30 | 642 | 642 | 642 | 6,367 | 0.01 | 0.06 |
| May | 4,030 | 642 | 1,600 | 98,380 | 0.18 | 0.16 |
| June | 3,195 | 377 | 1,602 | 95,326 | 0.18 | 0.16 |
| July | 313 | 58 | 185 | 11,375 | 0.02 | 0.02 |
| August | 238 | 12 | 33 | 2,029 | 0.00 | 0.00 |
| September | 156 | 72 | 83 | 4,939 | 0.01 | 0.01 |

PAYETTE STATION ON PAYETTE RIVER, IDAHO.

This station has been described in Bulletin No. 131, page 66, and in Bulletin No. 140, page 237. It is in the Weiser quadrangle, in latitude 44° 02′, longitude 116° 58′. The area drained is 3,565 square miles, and is partly mapped on the Weiser, Nampa, Boise, Squaw Creek, Garden Valley, Idaho Basin, and Bear Valley atlas sheets. The observer is J. A. Ballinger, the town marshal at Payette. The station is distant from the observer's house about one-half mile. The gage is vertical, of pine plank, spiked to a wooden pier, graduated from 0 to 12.5 feet. It is easily read from the bridge. The character of the channel is sandy and shifting. The point 12.5 on the gage is level with the top of the pier, on which is the mark "B. M." Measurements of discharge are made from the same bridge. The record of daily gage heights for 1896, from May 12 to September 30, is given in Water-Supply and Irrigation Paper No. 11, page 83.

*List of discharge measurements made on Payette River at Payette, Idaho.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Dec. 7 | A. P. Davis..... | 24 | 1.30 | 627 | 2.56 | 1,603 |
| | 1895. | | | | | | |
| 2 | June 28 | V. C. Tompkins.. | 23 | 3.50 | 1,585 | 2.35 | 3,723 |
| 3 | July 22 | G. F. Sherman... | 23 | 1.53 | 819 | 2.29 | 1,882 |
| 4 | Dec. 11 | .....do ..... | 23 | 0.36 | 454 | 2.21 | 1,003 |
| | 1896. | | | | | | |
| 5 | June 22 | L. B. Kendall.... | Floats. | 8.80 | 3,231 | 8.00 | 25,710 |
| 6 | Aug. 7 | C. C. Babb..... | 63 | 1.45 | 818 | 3.43 | 2,804 |
| 7 | Sept. 6 | .....do ..... | 63 | 1.30 | 547 | 2.94 | 1,603 |

*Rating table for Payette River at Payette, Idaho.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.20 | 930 | 2.50 | 3,940 | 4.80 | 9,985 | 7.10 | 18,670 |
| 0.30 | 970 | 2.60 | 4,160 | 4.90 | 10,350 | 7.20 | 19,085 |
| 0.40 | 1,020 | 2.70 | 4,385 | 5.00 | 10,630 | 7.30 | 19,505 |
| 0.50 | 1,065 | 2.80 | 4,610 | 5.10 | 10,965 | 7.40 | 19,925 |
| 0.60 | 1,110 | 2.90 | 4,840 | 5.20 | 11,305 | 7.50 | 20,350 |
| 0.70 | 1,170 | 3.00 | 5,070 | 5.30 | 11,655 | 7.60 | 20,775 |
| 0.80 | 1,230 | 3.10 | 5,305 | 5.40 | 12,010 | 7.70 | 21,200 |
| 0.90 | 1,295 | 3.20 | 5,545 | 5.50 | 12,370 | 7.80 | 21,630 |
| 1.00 | 1,370 | 3.30 | 5,785 | 5.60 | 12,735 | 7.90 | 22,060 |
| 1.10 | 1,455 | 3.40 | 6,030 | 5.70 | 13,105 | 8.00 | 22,495 |
| 1.20 | 1,550 | 3.50 | 6,280 | 5.80 | 13,480 | 8.10 | 22,930 |
| 1.30 | 1,660 | 3.60 | 6,535 | 5.90 | 13,860 | 8.20 | 23,370 |
| 1.40 | 1,785 | 3.70 | 6,795 | 6.00 | 14,240 | 8.30 | 23,810 |
| 1.50 | 1,925 | 3.80 | 7,060 | 6.10 | 14,625 | 8.40 | 24,250 |
| 1.60 | 2,080 | 3.90 | 7,330 | 6.20 | 15,015 | 8.50 | 24,690 |
| 1.70 | 2,250 | 4.00 | 7,605 | 6.30 | 15,410 | 8.60 | 25,130 |
| 1.80 | 2,435 | 4.10 | 7,885 | 6.40 | 15,810 | 8.70 | 25,570 |
| 1.90 | 2,635 | 4.20 | 8,170 | 6.50 | 16,210 | 8.80 | 26,010 |
| 2.00 | 2,845 | 4.30 | 8,460 | 6.60 | 16,615 | 8.90 | 26,460 |
| 2.10 | 3,060 | 4.40 | 8,755 | 6.70 | 17,020 | 9.00 | 26,910 |
| 2.20 | 3,280 | 4.50 | 9,055 | 6.80 | 17,430 | 9.10 | 27,370 |
| 2.30 | 3,500 | 4.60 | 9,360 | 6.90 | 17,840 | 9.20 | 27,810 |
| 2.40 | 3,720 | 4.70 | 9,670 | 7.00 | 18,255 | 9.30 | 28,260 |

*Estimated monthly discharge of Payette River at Payette, Idaho.*

[Drainage area, 3,565 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 4,610 | 1,550 | 1,687 | 103,729 | 0.54 | 0.47 |
| February | 3,060 | 1,660 | 2,012 | 111,744 | 0.60 | 0.56 |
| March | 3,720 | 1,660 | 2,102 | 129,246 | 0.68 | 0.59 |
| April 1 to 13 | 5,785 | 2,845 | 4,262 | 109,949 | 0.58 | 1.20 |
| May 25 to 31 | 15,015 | 10,965 | 13,137 | 182,398 | 0.91 | 3.70 |
| June | 10,630 | 5,785 | 7,004 | 416,767 | 2.23 | 2.00 |
| July | 6,030 | 1,550 | 3,179 | 195,469 | 0.93 | 0.81 |
| August | 1,550 | 975 | 1,128 | 69,358 | 0.36 | 0.31 |
| September | 1,295 | 975 | 1,074 | 63,907 | 0.33 | 0.30 |
| October | 1,020 | 975 | 988 | 60,751 | 0.31 | 0.28 |
| November | 1,020 | 975 | 988 | 58,790 | 0.31 | 0.28 |
| December | 1,110 | 1,020 | 1,044 | 64,192 | 0.32 | 0.29 |
| 1896. | | | | | | |
| May 12 to 31 | 21,200 | 5,785 | 10,907 | 430,046 | 2.10 | 3.09 |
| June | 28,260 | 19,080 | 24,482 | 1,456,780 | 7.69 | 6.90 |
| July | 20,350 | 3,500 | 10,652 | 654,965 | 3.46 | 3.00 |
| August | 3,280 | 1,425 | 2,220 | 136,503 | 0.69 | 0.60 |
| September | 2,635 | 1,120 | 1,519 | 90,387 | 0.48 | 0.43 |

## WEISER STATION ON WEISER RIVER, IDAHO.

This station is described in Bulletin No. 131, page 66, and in Bulletin No. 140, page 238. The station is about 10 miles above the town of Weiser, in the Weiser quadrangle, latitude 44° 15′, longitude 116° 47′. The area drained is 1,670 square miles, and is partly mapped on the Weiser and Squaw Creek atlas sheets. The gage is firmly fastened to posts driven into the ground. The 6-foot mark is 13.46 feet below a bench mark on a large bowlder 30 feet south of the gage. The observer is J. W. Lane, whose house is about one-fourth of a mile from the gage. The record of daily gage heights for 1896, from January 1 to October 17, is given in Water-Supply and Irrigation Paper No. 11, page 84.

*List of discharge measurements made on Weiser River above Weiser, Idaho.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square (feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1894. | | | | | | |
| 1 | Dec. 6 | A. P. Davis..... | 24 | 1.80 | 245 | 1.10 | 277 |
| | 1895. | | | | | | |
| 2 | Apr. 24 | V. C. Tompkins.... | 26 | 4.60 | 727 | 2.90 | 2,110 |
| 3 | May 28 | .....do ..... | 26 | 4.95 | 843 | 2.55 | 2,149 |
| 4 | June 26 | .....do ..... | ..... | 2.30 | 313 | 1.28 | 400 |
| 5 | July 23 | G. F. Sherman ..... | 23 | 1.70 | 222 | 0.54 | 121 |
| 6 | July 29 | A. P. Davis..... | 55 | 1.58 | 197 | 0.74 | 141 |
| 7 | Dec. 10 | G. F. Sherman ..... | 23 | 1.65 | 241 | 0.80 | 171 |
| | 1896. | | | | | | |
| 8 | Jan. 27 | G. F. Sherman ..... | 23 | 4.00 | 627 | 2.88 | 1,806 |
| 9 | June 21 | L. B. Kendall ..... | 23 | 6.40 | 1,625 | 3.90 | 6,347 |
| 10 | Aug. 21 | C. C. Babb. ..... | 63 | 1.77 | 205 | 0.70 | 144 |
| 11 | Sept. 3 | .....do ..... | 63 | 1.95 | 236 | 0.97 | 229 |

*Rating table for Weiser River at Weiser, Idaho, for 1895 and 1896.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.30 | 40 | 3.40 | 1,175 | 5.50 | 4,085 | 7.60 | 10,510 |
| 1.40 | 70 | 3.50 | 1,260 | 5.60 | 4,305 | 7.70 | 10,870 |
| 1.50 | 100 | 3.60 | 1,350 | 5.70 | 4,535 | 7.80 | 11,230 |
| 1.60 | 130 | 3.70 | 1,445 | 5.80 | 4,775 | 7.90 | 11,590 |
| 1.70 | 165 | 3.80 | 1,545 | 5.90 | 5,025 | 8.00 | 11,950 |
| 1.80 | 200 | 3.90 | 1,650 | 6.00 | 5,285 | 8.10 | 12,315 |
| 1.90 | 235 | 4.00 | 1,760 | 6.10 | 5,555 | 8.20 | 12,680 |
| 2.00 | 275 | 4.10 | 1,875 | 6.20 | 5,835 | 8.30 | 13,045 |
| 2.10 | 315 | 4.20 | 1,995 | 6.30 | 6,125 | 8.40 | 13,415 |
| 2.20 | 355 | 4.30 | 2,120 | 6.40 | 6,425 | 8.50 | 13,785 |
| 2.30 | 400 | 4.40 | 2,250 | 6.50 | 6,735 | 8.60 | 14,155 |
| 2.40 | 450 | 4.50 | 2,385 | 6.60 | 7,055 | 8.70 | 14,525 |
| 2.50 | 505 | 4.60 | 2,525 | 6.70 | 7,385 | 8.80 | 14,895 |
| 2.60 | 570 | 4.70 | 2,670 | 6.80 | 7,720 | 8.90 | 15,265 |
| 2.70 | 640 | 4.80 | 2,820 | 6.90 | 8,060 | 9.00 | 15,640 |
| 2.80 | 710 | 4.90 | 2,975 | 7.00 | 8,400 | 9.10 | 16,015 |
| 2.90 | 780 | 5.00 | 3,135 | 7.10 | 8,745 | 9.20 | 16,395 |
| 3.00 | 855 | 5.10 | 3,305 | 7.20 | 9,095 | 9.30 | 17,175 |
| 3.10 | 930 | 5.20 | 3,485 | 7.30 | 9,445 | 9.40 | 17,555 |
| 3.20 | 1,010 | 5.30 | 3,675 | 7.40 | 9,800 | 9.50 | 17,940 |
| 3.30 | 1,090 | 5.40 | 3,875 | 7.50 | 10,155 | | |

*Estimated monthly discharge of Weiser River at Weiser, Idaho.*

[Drainage area, 1,670 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 1,545 | 165 | 499 | 30,683 | 0.35 | 0.30 |
| February | 1,350 | 130 | 320 | 17,772 | 0.19 | 0.19 |
| March | 6,125 | 315 | 1,787 | 109,878 | 1.23 | 1.07 |
| April | 3,675 | 1,090 | 2,258 | 134,361 | 1.51 | 1.35 |
| May | 4,085 | 1,875 | 2,679 | 164,726 | 1.84 | 1.60 |
| June | 1,545 | 355 | 838 | 47,864 | 0.56 | 0.50 |
| July | 315 | 130 | 259 | 15,926 | 0.17 | 0.15 |
| August | 100 | 40 | 64 | 3,935 | 0.04 | 0.04 |
| September | 235 | 70 | 120 | 7,141 | 0.08 | 0.07 |
| October | 130 | 130 | 130 | 7,993 | 0.09 | 0.08 |
| November | 165 | 130 | 140 | 8,331 | 0.09 | 0.08 |
| December | 640 | 130 | 291 | 17,892 | 0.20 | 0.17 |
| Per annum | 6,125 | 40 | 782 | 566,502 | 6.35 | 0.47 |
| 1896. | | | | | | |
| January | 13,045 | 400 | 2,642 | 162,450 | 1.83 | 1.59 |
| February | 1,995 | 505 | 863 | 49,640 | 0.55 | 0.50 |
| March | 6,735 | 780 | 2,211 | 135,949 | 1.52 | 1.32 |
| April | 3,485 | 1,445 | 2,079 | 123,709 | 1.38 | 1.24 |
| May | 17,940 | 2,525 | 5,845 | 359,395 | 4.04 | 3.50 |
| June | 15,265 | 2,970 | 6,830 | 406,413 | 4.56 | 4.09 |
| July | 2,975 | 275 | 996 | 61,242 | 0.68 | 0.59 |
| August | 275 | 200 | 222 | 13,649 | 0.16 | 0.14 |
| September | 275 | 200 | 231 | 13,745 | 0.16 | 0.14 |
| October | 200 | 165 | 200 | 12,298 | 0.14 | 0.12 |
| November | ..... | ..... | *a* 150 | 8,926 | 0.10 | 0.09 |
| December | ..... | ..... | *a* 250 | 15,372 | 0.17 | 0.15 |
| Per annum | 17,940 | 165 | 1,877 | 1,362,788 | 15.29 | 1.13 |

*a* Estimated.

## YAKIMA RIVER.

### NORTH YAKIMA STATION ON NACHES RIVER, WASHINGTON.

This station is described in Bulletins Nos. 131 and 140, on pages 73 and 244, respectively. It was established August 14, 1893. The vertical rod was nailed to the crib bulwark on the right-hand side of the river just above the railroad bridge. When the station was visited in July, 1896, it was found that the channel under the railroad bridge, from which previous gagings had been made, had been greatly changed by the deposition of several carloads of rock by the railroad company and by the building of a short wing dam placed just above the gage rod. On July 28 the rod was removed and fastened to the bulwark just above the highway bridge, and about 100 yards above its old position. The gage height in its old position when removed was 3.8, in its new position when placed 2.4. When the station was visited October 21, it was found that the water had fallen below the end of the rod, and it was therefore removed and fastened again to the bulwark just below the highway bridge and lowered in elevation 1 foot. Before changing, the gage height was —0.24 foot; after the change it was 0.76 foot. The gage-height records for 1896 are referred to this gage. The observer is Mr. J. T. Davis, living in the house nearest to the south end of the bridge. Drainage area, 1,000 square miles. The record of daily gage heights for 1896, from January 1 to February 29 and from July 28 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 84.

*List of discharge measurements made on Naches River above North Yakima, Washington.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 1 | Aug. 14 | F. H. Newell..... | 24 | 1.00 | 322 | 3.70 | 1,193 |
| | 1894. | | | | | | |
| 2 | Nov. 21 | A. P. Davis..... | 24 | 2.50 | 490 | 2.44 | *a* 1,196 |
| | 1895. | | | | | | |
| 3 | Aug. 16 | A. P. Davis..... | 55 | 1.62 | 289 | 1.61 | 466 |
| 4 | Dec. 2 | S. Storrow..... | 55 | ..... | 243 | 1.44 | 349 |
| | 1896. | | | | | | |
| 5 | Feb. 13 | S. Storrow..... | 55 | 1.85 | 344 | 1.93 | 664 |
| 6 | July 25 | C. C. Babb..... | 63 | 3.00 | 484 | 4.24 | 2,049 |
| 7 | Aug. 24 | .....do ..... | 63 | 1.55 | 227 | 2.22 | 504 |
| 8 | Oct. 21 | .....do ..... | 63 | 0.76 | 187 | 1.79 | 335 |

*a* Measurement made at Nelson's bridge, 4 miles above mouth of river.

*Rating table for Naches River at North Yakima, Washington.*

[Constructed by C. C. Babb from discharge measurements Nos. 6 to 8.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.50 | 300 | 1.80 | 630 | 3.10 | 1,525 | 4.30 | 2,425 |
| 0.60 | 310 | 1.90 | 690 | 3.20 | 1,600 | 4.40 | 2,500 |
| 0.70 | 320 | 2.00 | 750 | 3.30 | 1,675 | 4.50 | 2,575 |
| 0.80 | 335 | 2.10 | 810 | 3.40 | 1,750 | 4.60 | 2,650 |
| 0.90 | 350 | 2.20 | 870 | 3.50 | 1,825 | 4.70 | 2,725 |
| 1.00 | 365 | 2.30 | 930 | 3.60 | 1,900 | 4.80 | 2,800 |
| 1.10 | 380 | 2.40 | 1,000 | 3.70 | 1,975 | 4.90 | 2,875 |
| 1.20 | 400 | 2.50 | 1,075 | 3.80 | 2,050 | 5.00 | 2,950 |
| 1.30 | 425 | 2.60 | 1,150 | 3.90 | 2,125 | 5.10 | 3,025 |
| 1.40 | 450 | 2.70 | 1,225 | 4.00 | 2,200 | 5.20 | 3,100 |
| 1.50 | 490 | 2.80 | 1,300 | 4.10 | 2,275 | 5.30 | 3,175 |
| 1.60 | 530 | 2.90 | 1,375 | 4.20 | 2,350 | 5.40 | 3,250 |
| 1.70 | 580 | 3.00 | 1,450 | | | | |

*Estimated monthly discharge of Naches River at North Yakima, Washington.*

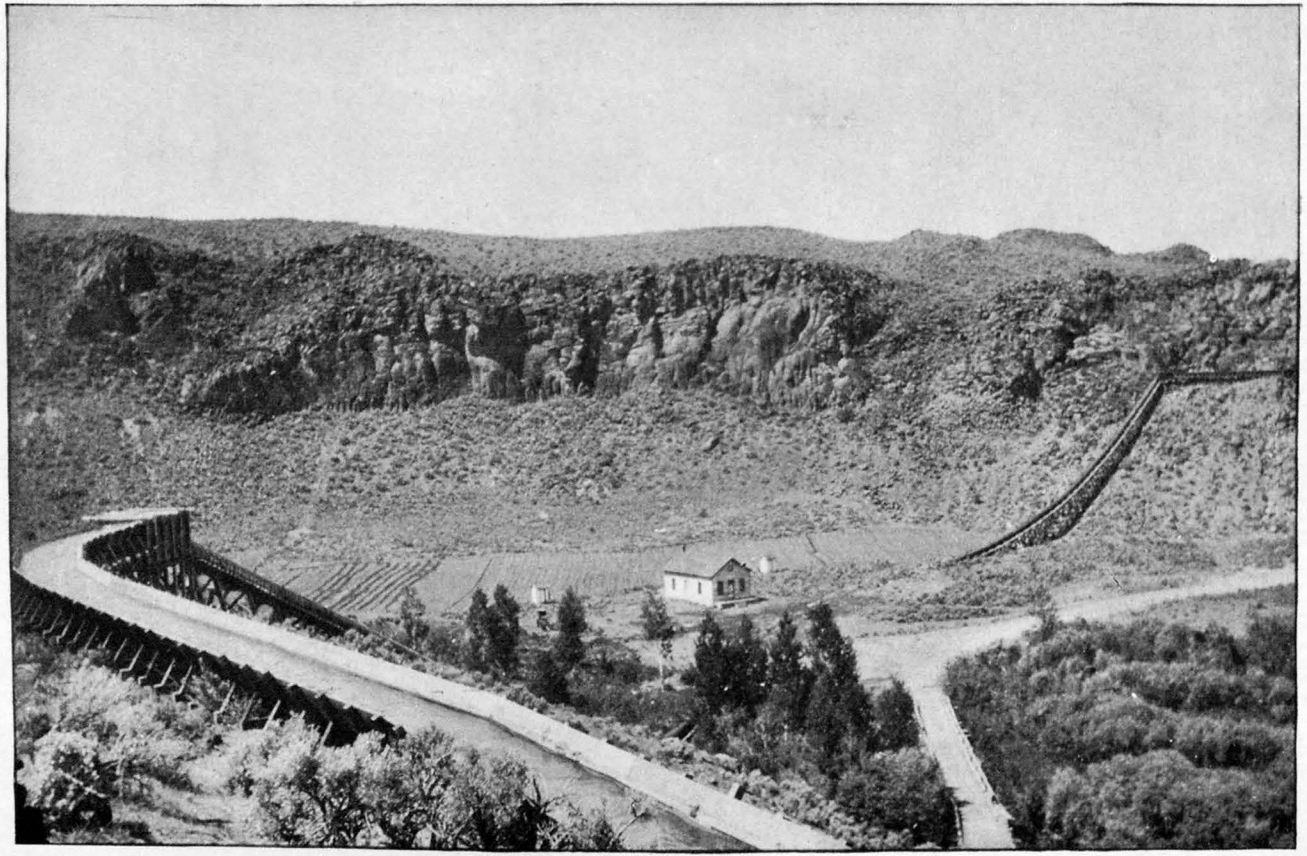
[Drainage area, 1,000 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 1,640 | 490 | 849 | 52,203 | 0.98 | 0.85 |
| September | 490 | 350 | 417 | 24,814 | 0.47 | 0.42 |
| October | 450 | 310 | 347 | 21,336 | 0.40 | 0.35 |
| November | 5,200 | 365 | 1,707 | 104,945 | 1.91 | 1.71 |
| December | 2,950 | 1,450 | 1,940 | 117,071 | 2.24 | 1.94 |

## YAKIMA STATION ON YAKIMA RIVER, WASHINGTON.

This station is described on page 245, Bulletin No. 140. The gage rod is inclined, following the slope of the bank, the distance between the vertical footmarks being 1.95 feet. It is attached to a willow stump and to posts set into the ground, and loaded with rock. The bench mark is a stone, marked "B. M.," 39 feet west of the gage and 8.5 feet east of the railroad track. It is 18.85 feet above the 11-foot mark. The gaging cable is about 50 yards above the rod, or 500 yards below the highway bridge.

The channel of the river is straight for several hundred feet, both above and below the cable. During floods a portion of the water passes through a depression in the left bank, and this must be measured



FLUMES AND PRESSURE PIPE ON YAKIMA VALLEY CANAL.

from the bridge. The right bank is high and will not overflow. Gage-height readings were taken through January and February, and were then discontinued until August 1. After that readings were continuous until the end of the year. The rating table for this year is applicable from August 1 to November 14. The next day the river was in flood and on November 16 reached a gage height of 15 feet, breaking and carrying away the cable. The rating table is not applicable after this date, owing to the probable modification of the channel. The observer is Mr. Ed. Farmer, section foreman. His post-office address is North Yakima. The drainage area at this point is 3,300 square miles. The record of daily gage heights for 1896, from January 1 to February 29 and from August 1 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 85.

*List of discharge measurements made on Yakima River at Yakima, Washington.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1893. | | | | | | |
| 1 | Aug. 14 | F. H. Newell..... | 24 | 0.90 | 960 | 3.09 | 2,963 |
| 2 | Sept 26 | Samuel Storrow... | 27 | —0.25 | 453 | 2.62 | 1,186 |
| | 1894. | | | | | | |
| 3 | Nov. 25 | A. P. Davis..... | 24 | ..... | 875 | 5.74 | 5,026 |
| | 1895. | | | | | | |
| 4 | Aug. 19 | A. P. Davis..... | 55 | 4.10 | 949 | 1.13 | 1,070 |
| 5 | Nov. 18 | Samuel Storrow... | ..... | 4.66 | ..... | 1.63 | 1,889 |
| | 1896. | | | | | | |
| 6 | Jan. 8 | Samuel Storrow... | 55 | 5.60 | 1,379 | 2.83 | 3,889 |
| 7 | July 28 | C. C. Babb..... | 63 | 6.00 | 1,429 | 2.11 | 3,015 |
| 8 | Aug. 24 | .....do..... | 63 | 4.90 | 1,146 | 1.09 | 1,243 |
| 9 | Oct. 21 | .....do..... | 63 | 4.41 | 1,015 | 0.85 | 858 |

*Rating table for Yakima River at Yakima, Washington.*

[Constructed by C. C. Babb from discharge measurements Nos. 7 to 9.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.00 | 600 | 4.80 | 1,170 | 5.60 | 2,200 | 6.40 | 3,800 |
| 4.10 | 660 | 4.90 | 1,260 | 5.70 | 2,400 | 6.50 | 4,000 |
| 4.20 | 720 | 5.00 | 1,350 | 5.80 | 2,600 | 6.60 | 4,200 |
| 4.30 | 780 | 5.10 | 1,450 | 5.90 | 2,800 | 6.70 | 4,400 |
| 4.40 | 840 | 5.20 | 1,560 | 6.00 | 3,000 | 6.80 | 4,600 |
| 4.50 | 910 | 5.30 | 1,690 | 6.10 | 3,200 | 6.90 | 4,800 |
| 4.60 | 990 | 5.40 | 1,840 | 6.20 | 3,400 | 7.00 | 5,000 |
| 4.70 | 1,080 | 5.50 | 2,000 | 6.30 | 3,600 | | |

*Estimated monthly discharge of Yakima River at Yakima, Washington.*

[Drainage area, 3,300 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 2,600 | 1,170 | 1,650 | 98,687 | 0.58 | 0.50 |
| September | 1,170 | 910 | 1,071 | 63,728 | 0.39 | 0.35 |
| October | 910 | 840 | 888 | 54,600 | 0.31 | 0.27 |
| November 1 to 14 | 2,600 | 910 | 1,830 | 50,806 | 0.29 | 0.56 |

## KIONA STATION ON YAKIMA RIVER, WASHINGTON.

This station, as mentioned in Bulletin No. 140, page 248, was established on August 20, 1895. Measurements are made from the bridge. The original gage consisted of two sections, the upper one vertical and the lower inclined at an angle of about 30°. On August 28, 1896, a wire gage was placed on the lower side of the bridge. The distance from the end of the weight to the index marker is 27.21 feet. From the end of the rod to the outside edge of the pulley wheel it is 2 feet. The new and old gages were made to read the same on this date—that is, 4.7. On the old or inclined gage 1 foot elevation equals 2.06 feet along its length. The gage readings previous to this date have all been recomputed and referred to the new gage. The rating table is applicable from August 1 to November 14, and only approximately outside of those dates. The observer is W. A. Kelso, postmaster at Kiona. The record of daily gage heights for 1896, for a part of January, and from August 2 to December 31, is given in Water-Supply and Irrigation Paper No. 11, page 83.

*List of discharge measurements made on Yakima River at Kiona, Washington.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 20 | A. P. Davis | 55 | 3.30 | 753 | 1.27 | 954 |
| | 1896. | | | | | | |
| 2 | July 30 | C. C. Babb | 63 | 6.40 | 1,240 | 2.63 | 3,265 |
| 3 | Aug. 28 | do | 63 | 4.70 | 849 | 1.18 | 987 |
| 4 | Oct. 20 | do | 63 | 3.93 | 732 | 1.09 | 796 |

*Rating table for Yakima River at Kiona, Washington.*

[Constructed by C. C. Babb from discharge measurements Nos. 2 to 4. This table is applicable only from August 1, 1896, to November 14, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.50 | 705 | 4.40 | 890 | 5.30 | 1,350 | 6.20 | 2,880 |
| 3.60 | 720 | 4.50 | 920 | 5.40 | 1,450 | 6.30 | 3,080 |
| 3.70 | 740 | 4.60 | 950 | 5.50 | 1,550 | 6.40 | 3,280 |
| 3.80 | 760 | 4.70 | 990 | 5.60 | 1,700 | 6.50 | 3,480 |
| 3.90 | 780 | 4.80 | 1,030 | 5.70 | 1,880 | 6.60 | 3,680 |
| 4.00 | 800 | 4.90 | 1,080 | 5.80 | 2,080 | 6.70 | 3,880 |
| 4.10 | 820 | 5.00 | 1,130 | 5.90 | 2,280 | 6.80 | 4,080 |
| 4.20 | 840 | 5.10 | 1,190 | 6.00 | 2,480 | 6.90 | 4,280 |
| 4.30 | 860 | 5.20 | 1,270 | 6.10 | 2,680 | 7.00 | 4,480 |

*Estimated monthly discharge of Yakima River at Kiona, Washington.*

[Drainage area, 5,230 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| August | 2,780 | 990 | 1,511 | 92,908 | 0.33 | 0.29 |
| September | 1,010 | 830 | 917 | 54,565 | 0.20 | 0.18 |
| October | 820 | 780 | 799 | 49,128 | 0.17 | 0.15 |
| November 1 to 14 | 2,080 | 850 | 1,254 | 59,209 | 0.12 | 0.24 |

## SPOKANE AND UMATILLA RIVERS.

### SPOKANE STATION ON SPOKANE RIVER.

An examination of the Spokane River near Spokane, Washington, was made in the latter part of August for the location of a gaging station. Nine bridges cross the river in this vicinity. The lower ones, or those in the heart of the town, cross the falls directly. Proceeding upstream above the falls, the first bridge is that at Division street, the water under which is ponded and is 25 feet or more in depth. The old railroad bridge, just above, has also a poor section. Olive street bridge has a poor section, and crosses the river diagonally. The Oregon Rail way and Navigation Company's bridge has a good section, and the station was located here later. The channel is straight above and below for some distance, and the bottom is of gravel. The banks are high on either side, and are only overflowed during extraordinary floods. The velocity is quite swift, even during low water. The bridge has three spans. The piers are wooden cribs with vertical sides.

A gaging from this bridge was made August 27, giving a mean velocity of 3.68 feet per second, area 799 square feet, and discharge 2,937 second-feet. At this time the water was 16 feet 9.5 inches below top and south end triangular casting at foot of the fifth vertical from the west end of the bridge, upper side. The gage height for this measurement as determined, after the rod was placed, was 2.00. On October 17 a wire gage was placed on the Oregon Railway and Navigation Company's bridge. The length of the wire cable from the end of the weight to the wire index is 22 feet. The distance from the end of the rod to the outside edge of the pulley is 1.80 feet. This gage was connected with a bench mark of the city engineering department, and referred to sea level. At the time of the placing of the rod the elevation of the water surface was 1,881.46, and the gage was made to read 1.46. The result of the gaging on October 17 was: Gage height, 1.46; mean velocity, 2.92; area, 590; discharge, 1,722 second-feet. The observer is Z. Taylor, telegraph operator, residing within one-fourth mile of the station.

A record of the height of water in the Spokane River has been kept at the dam of the Washington Water Power Company from March, 1891, to the present date, and through the courtesy of the engineer of that company, Mr. John B. Fiskin, it is given in Water-Supply and Irrigation Paper No. 11, pages 85–88. The rod is attached near the head gates of the pipe line in the south abutment. The zero of the rod is at the level of the dam. There are two waste gates in the north abutment, which are opened during high stages, and considerable water passes through them. In time of low water a row of flashboards 3 feet high is placed on the dam. They are allowed to be carried out by the water during floods. Notes of the opening and closing of the waste gates are made in the record. They are only changed once or twice a year. As there is no way of determining the discharge either through the company's pipe line or through the waste gates, the gage height records show only approximately the amount of water in the river. The gage of the Washington Water Power Company is about 1.5 miles below the United States Geological Survey gage. The drainage area at this point is 4,005 square miles.

*List of discharge measurements made on Spokane River at Spokane, Washington.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Aug. 27 | C. C. Babb | 63 | 2.00 | 799 | 3.68 | 2,937 |
| Oct. 17 | do | 63 | 1.46 | 590 | 2.92 | 1,722 |

### GIBBON STATION ON UMATILLA RIVER.

This station was established on July 22. It is in the NW. ¼ of NW. ¼ of sec. 31, T. 3 N., R. 36 E., Willamette meridian, and about 0.5 mile west of the railroad station. For a description of the drainage basin, see Bulletin No. 131, page 69. The rod consists of two vertical sections of 2 by 4 inch scantling. One section reads from 0 to 5.5 feet. It is driven into the bed of the stream, and spiked and braced to an old tree in the center of the river, which is firmly buried in the gravel of the river bed. The second section for flood measurements, and reading from 5.5 feet to 10.0 feet, is fastened to an alder tree, 10 inches in diameter, on the edge of the bank. It is about 50 yards south of the other rod. Bench mark 1 is a hub on the root of a cottonwood tree, 18 inches diameter, facing river and 14.5 feet east of upper rod. It reads 6.38 on rod. Bench mark 2 is nail in trunk of tree opposite 4.48 feet.

Measurements of discharge are made from a car suspended from a one-half-inch steel cable stretched across the river 50 yards above the river rod. The channel is straight for a short distance above and below the station. The current is swift above and medium below. The bed of the river is gravelly and not liable to change. Mr. W. Swart, telegraph operator at Gibbon, is the observer. Three measurements of discharge have been made at this point the past season, but are not sufficiently comprehensive for a rating table. The record of daily gage heights for 1896, from July 22 to December 30, is given in Water-Supply and Irrigation Paper No. 11, page 88.

*List of discharge measurements made on Umatilla River at Gibbon, Oregon.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | July 16 | C. C. Babb | 63 | 0.90 | 77 | 1.34 | 103 |
| 2 | Aug. 31 | do | 63 | 0.90 | 83 | 1.00 | 84 |
| 3 | Oct. 23 | do | 63 | 0.82 | 87 | 0.93 | 81 |

## SAN FRANCISCO BAY DRAINAGE.

### SACRAMENTO RIVER.

On the upper portions of this stream observations of river height have been made at Tehama, Redbluff, and Jellys Ferry. The record at Tehama has been kept continuously since 1877 by the Southern Pacific Railway Company. No gagings have been made at this point by this Survey, as the channel is shifting and the current during the greater portion of the year is sluggish.

REDBLUFF STATION ON SACRAMENTO RIVER.

This station, established and maintained by the Weather Bureau, is described in Bulletin No. 131, page 76, and in Bulletin No. 140, page 250. It is at a wagon bridge in the town, and only a few blocks from the hotel or depot. The regular Weather Bureau observer, Mr. Maurice Connell, is also the observer on the river. The time of daily observation and record is at 3 p. m. In time of high water the observations are taken with greater frequency (as often as once an hour), and when the river reaches such stage as would indicate from past experience that dangerous overflow will follow below information is sent by telegraph to the lower points on the river. While these observations are regular and precise, no attempt is made by the Weather Bureau to make an estimate of discharge.

The Redbluff gage is a vertical rod 30 feet long, nailed to a large sycamore tree on the left bank of the river about 25 feet above the bridge. The space between the marks on the rod is one-tenth of a foot. The rod is rather old, and it is not referred to any bench mark, but the datum is about lowest watermark.

In the measurements made at this point by the United States Geological Survey the initial point of the sounding has been at the extreme western iron post of the foot walk of the bridge. The channel of the river is the objectionable feature of this station. It is not only broken by piers in three places, but the stream does not flow at right angles to the bridge, deflecting from the normal about 30°. The water is very swift in the high stages of the river, and the striking of the piers at an oblique angle produces swirls. The right bank, on which the town is situated, is high and not liable to overflow.

When the water reaches an elevation of about 15 feet on the gage at the bridge it begins to run through sloughs or back channels on the left bank. One of these is called the "Big Slough," and has an area of 900 square feet and a discharge of about 2,150 second-feet when the gage at the bridge stands at 19 feet. As the river continues to rise other of these channels begin to discharge. With the rod at 20.8 feet it is estimated that the sloughs are flowing approximately 10,500 second-feet. The bed of the stream at the bridge is of gravel and not subject to great change.

From the 17th to the 29th of January, 1896, the Sacramento was in high flood, doing a great deal of damage to the lower valleys. Travel was completely cut off for a number of days on both sides of the river from the city of Sacramento north. On January 21 the river was gaged at Redbluff, and again on the 22d. On the 21st it was also visited at Jellys Ferry with a view of making a measurement. The rod at this point read 25.9, and the river was full of waves with white caps, which made it impossible to handle the boat that was fastened to the ferry cable in the river. This cable was tied up in the trees with ropes

that were not very secure. Trees that had been uprooted, with limbs extending from 10 to 15 feet above the water, were occasionally floating past, with a velocity of about 12 feet per second, and striking the cable. A portion of the water was also going through a slough that could not be measured very well. For these reasons it was determined to make the gaging below, at the Redbluff bridge. The gaging at the bridge was found very difficult. The Haskell meter was tried first, and it was found impossible to count the revolutions, they were so rapid, and the meter could not be controlled in the water with any steadiness. With all of the battery that could be desired, and using the Price meter, which has a slower revolution, the recorder was unable to move with sufficient swiftness to make the count. By marking every tenth beat and not counting beyond ten the revolutions of the Price meter were determined as high as 4.1 revolutions per second by using the sounder and counting by ear. This represented a maximum velocity of 12.25 feet per second. With 44 pounds of lead on a 30-foot line the meter could not be sunk in the ordinary way. It would run through the water in much the same way as a trout on a line. The results of the velocity measurements on the 21st for this reason were not considered reliable and were discarded in favor of those made on the following day. The most potent element in steadying the meter was an increase in the length of the tail in the weights. A board 4 inches wide and 3 feet long was driven into the slot of the lead weight to act as a rudder. This controlled it in position, and it was found that by hanging the weights to the meter by means of 3 feet of baling wire, instead of fastening them directly to the meter standard, the meter could be sunk to depths of 15 feet and held steadily in the swiftest current. As bottom velocities could not be taken and the mid-depths were uncertain, the surface velocities only were used and the mean velocity assumed as 95 per cent. With the rod at 20.8 the discharge was found to be 109,000 second-feet, the sloughs being included. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 89.

The rainfall at Redbluff during the year 1896 was as follows:

| | Inches. |
|---|---|
| January | 7.30 |
| February | 0.27 |
| March | 3.06 |
| April | 3.67 |
| May | 2.42 |
| June | T. |
| July | 0.00 |
| August | 0.54 |
| September | 0.63 |
| October | 0.66 |
| November | 3.41 |
| December | 6.20 |
| Year | 28.16 |
| Mean annual | 23.79 |

*List of discharge measurements made on the Sacramento River at Redbluff, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Mar. 19 | J. B. Lippincott. | 24 | 4.8 | 2,886 | 5.36 | *a*15,461 |
| 2 | Apr. 27 | .....do ..... | 24 | 8.4 | 4,676 | 7.74 | 36,181 |
| | 1896. | | | | | | |
| 3 | Jan. 21 | J. B. Lippincott. | 63 | 20.8 | 13,022 | 7.60 | *b*109,432 |
| 4 | Jan. 22 | .....do ..... | 65 | 17.7 | 10,775 | 7.55 | *c*83,558 |

*a* Strong wind upstream.
*b* Including 10,465 feet in slough.
*c* Including 2,150 feet in slough.

*Rating table for Sacramento River at Redbluff, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.5 | 5,750 | 7.0 | 26,100 | 13.5 | 62,800 | 19.5 | 98,900 |
| 1.0 | 6,150 | 7.5 | 28,950 | 14.0 | 65,600 | 20.0 | 102,200 |
| 1.5 | 6,825 | 8.0 | 31,800 | 14.5 | 68,400 | 20.5 | 106,100 |
| 2.0 | 7,500 | 8.5 | 34,400 | 15.0 | 71,200 | 21.0 | 110,000 |
| 2.5 | 8,600 | 9.0 | 37,000 | 15.5 | 74,050 | 21.5 | 114,500 |
| 3.0 | 9,700 | 9.5 | 39,900 | 16.0 | 76,900 | 22.0 | 119,000 |
| 3.5 | 11,100 | 10.0 | 42,800 | 16.5 | 79,850 | 22.5 | 124,000 |
| 4.0 | 12,500 | 10.5 | 45,700 | 17.0 | 82,800 | 23.0 | 129,000 |
| 4.5 | 14,200 | 11.0 | 48,600 | 17.5 | 86,000 | 23.5 | 134,000 |
| 5.0 | 15,900 | 11.5 | 51,500 | 18.0 | 89,200 | 24.0 | 139,000 |
| 5.5 | 18,250 | 12.0 | 54,400 | 18.5 | 92,400 | 24.5 | 144,000 |
| 6.0 | 20,600 | 12.5 | 57,200 | 19.0 | 95,600 | 25.0 | 149,000 |
| 6.5 | 23,350 | 13.0 | 60,000 | | | | |

*Estimated discharge of Sacramento River at Redbluff, California.*[1]

[Drainage area, 9,356 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January..... | 140,000 | 6,150 | 51,702 | 3,179,032 | 6.41 | 5.53 |
| February .... | 46,860 | 9,040 | 15,231 | 876,120 | 1.76 | 1.63 |
| March ..... | 74,050 | 9,700 | 25,533 | 1,569,981 | 3.15 | 2.73 |
| April ..... | 72,910 | 16,370 | 30,708 | 1,827,271 | 3.61 | 3.28 |
| May ..... | 81,030 | 19,660 | 35,019 | 2,153,252 | 4.35 | 3.74 |
| June..... | 21,150 | 8,600 | 13,599 | 809,215 | 1.62 | 1.45 |
| July ..... | 8,380 | 5,990 | 6,907 | 424,694 | 0.85 | 0.74 |
| August..... | 5,910 | 5,660 | 5,738 | 352,858 | 0.70 | 0.61 |
| September ... | 5,830 | 5,660 | 5,696 | 338,977 | 0.68 | 0.61 |
| October..... | 6,555 | 5,660 | 5,730 | 352,336 | 0.70 | 0.61 |
| November.... | 57,200 | 5,660 | 11,260 | 670,058 | 1.34 | 1.20 |
| December .... | 106,880 | 11,380 | 33,316 | 2,048,546 | 4.09 | 3.56 |
| Per annum. | 140,000 | 5,660 | 20,037 | 14,602,340 | 29.26 | 3.56 |

[1] Rod observations by the United States Weather Bureau. Rating and computation by the United States Geological Survey.

This station has not been visited since January 21, 1896, and has been abandoned because of obstructions in the channel. The measurements are continued at Jellys Ferry.

### JELLYS FERRY STATION ON SACRAMENTO RIVER.

This station is described in Bulletin No. 131, page 76, and in Bulletin No. 140, page 251. It is about 12 miles above the town of Redbluff, at a crossing of a county road over Jellys Ferry. It is above the "Iron Canyon," where a number of measurements have been made by the California State authorities. This station was established by Mr. J. B. Lippincott, April 30, 1895. The observer, Mr. Fred Lemstrom, is the ferryman. A daily observation is taken at 8 a. m. and 4 p. m. The ferry cable is used in the measurement, a small boat being swung from it with a rope and the gagings taken from the boat. A car has been made and hung to the ferry cable, to be used in case of high water. The gage consists of a vertical rod marked to tenths of a foot. It is made in three sections and nailed firmly to trees. The first section reads from 4 to 8 feet, and is located on the north bank, 30 feet above the cable; the second section reads from 8 to 20 feet, and is placed 20 feet below the cable; the third section reads from 20 to 40 feet, and is

attached to a large sycamore tree at the north end of the cable. Besides the gage rod at this point, another rod is located 1,206 feet upstream from the gage, and another 350 feet downstream, in order to determine the slope of the water surface. There are two bench marks. Bench mark No. 1 is on an oak tree on the left bank, 1,206 feet upstream from

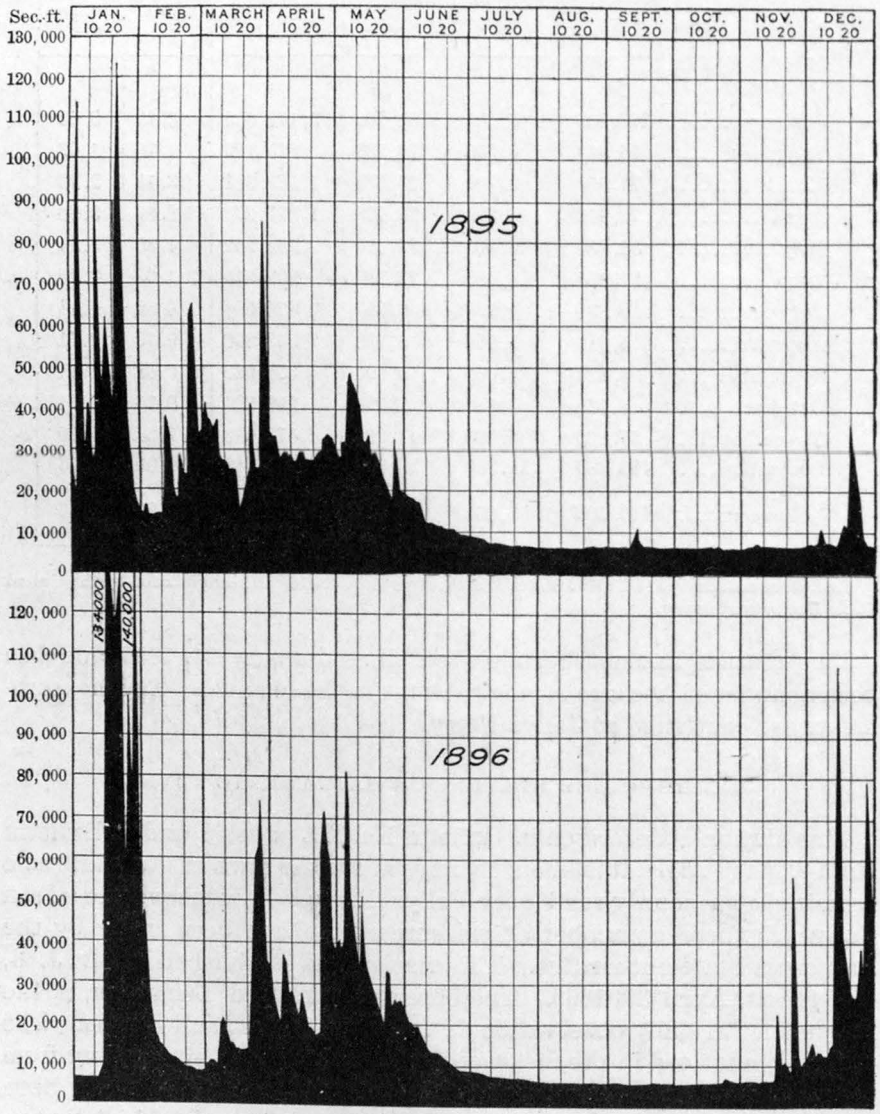
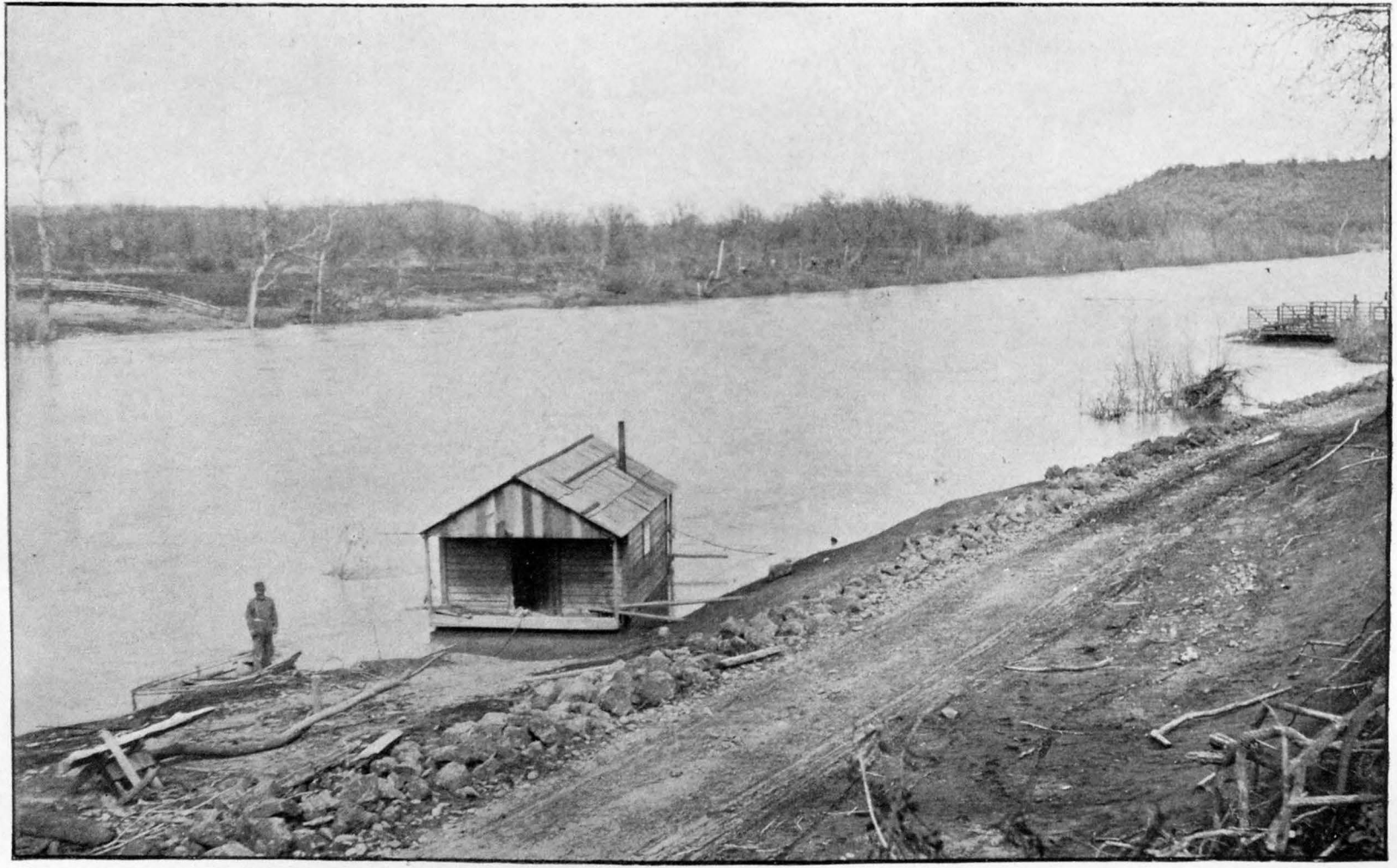



FIG. 58.—Discharge of Sacramento River at Redbluff, California, 1895–96.

the ferry and 65 feet north of the upper rod. Bench mark No. 2 is on an oak tree on the left bank of the river 300 feet below the cable. Assuming the zero of the river gage at the ferry cable as the datum plane, bench mark No. 1 is at an elevation of 22.724 feet, and bench



JELLYS FERRY STATION ON SACRAMENTO RIVER, CALIFORNIA.

mark No. 2 is at an elevation of 22.429 feet. The zero of the upstream gage, 1,206 feet above the cable, is at a height of 5.106 feet, and the zero of the lowest rod, 350 feet below the cable, is at a height of 3.846 feet.

The channel for 1,000 feet above and below the station is nearly straight, and the water during the summer has a mean velocity of about 2.5 feet per second. The right bank is high, but the left bank is liable to be overflowed when the water rises above the 25-foot mark. The bed of the stream consists of gravel and changes slightly. There has been very little change in the channel of the river for the last year and a half. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 89.

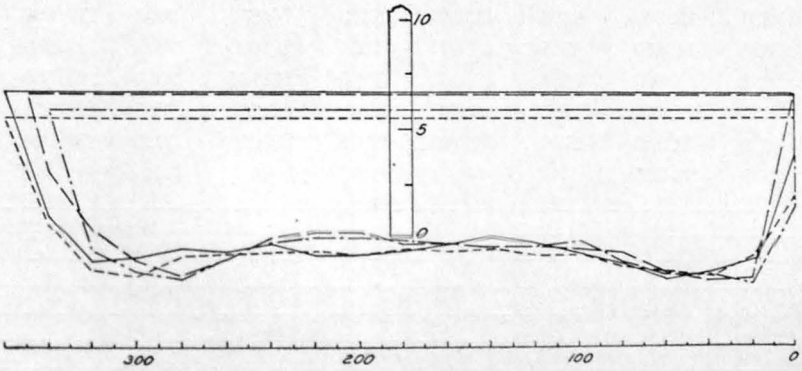



FIG. 59.—Cross sections of Sacramento River at Jellys Ferry, California.

*List of discharge measurements made on Sacramento River at Jellys Ferry, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Apr. 30 | J. B. Lippincott. | H. 24 | 12.00 | 4,573 | 5.96 | 27,255 |
| 2 | June 30 | .....do ..... | H. 24 | 6.75 | 2,552 | 3.31 | 8,456 |
| 3 | Aug. 25 | A. P. Davis and J. B. Lippincott.. | H. 24 | 5.55 | 2,262 | 2.41 | 5,452 |
| 4 | Oct. 5 | J. B. Lippincott. | H. 24 | 5.55 | 2,270 | 2.66 | 6,046 |
| | 1896. | | | | | | |
| 5 | Jan. 21 | J. B. Lippincott. | Price. | 25.90 | ..... | ..... | *a*105,000 |
| 6 | Jan. 22 | .....do ..... | Price. | 22.70 | ..... | ..... | *a*82,000 |
| 7 | July 7 | C. C. Babb ..... | P. 63 | 6.60 | 2,316 | 2.99 | 6,924 |
| 8 | Nov. 1 | R. Gernon..... | P. 12 | 5.90 | 2,214 | 3.06 | 6,773 |

*a* Measured at Redbluff and estimated for ferry.

*Rating table for Sacramento River at Jellys Ferry, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 4.0 | 4,300 | 11.0 | 23,350 | 17.5 | 53,950 | 24.0 | 93,000 |
| 4.5 | 4,738 | 11.5 | 25,400 | 18.0 | 56,700 | 24.5 | 96,250 |
| 5.0 | 5,300 | 12.0 | 27,450 | 18.5 | 59,500 | 25.0 | 99,500 |
| 5.5 | 6,000 | 12.5 | 29,575 | 19.0 | 62,300 | 25.5 | 102,750 |
| 6.0 | 6,900 | 13.0 | 31,700 | 19.5 | 65,150 | 26.0 | 106,000 |
| 6.5 | 8,000 | 13.5 | 34,000 | 20.0 | 68,000 | 26.5 | 109,250 |
| 7.0 | 9,200 | 14.0 | 36,300 | 20.5 | 70,950 | 27.0 | 112,500 |
| 7.5 | 10,650 | 14.5 | 38,650 | 21.0 | 73,900 | 27.5 | 115,750 |
| 8.0 | 12,300 | 15.0 | 41,000 | 21.5 | 76,950 | 28.0 | 119,000 |
| 8.5 | 14,050 | 15.5 | 43,500 | 22.0 | 80,000 | 28.5 | 122,250 |
| 9.0 | 15,900 | 16.0 | 46,000 | 22.5 | 83,150 | 29.0 | 125,500 |
| 9.5 | 17,600 | 16.5 | 48,600 | 23.0 | 86,300 | 29.5 | 128,750 |
| 10.0 | 19,300 | 17.0 | 51,200 | 23.5 | 89,650 | 30.0 | 132,000 |
| 10.5 | 21,325 | | | | | | |

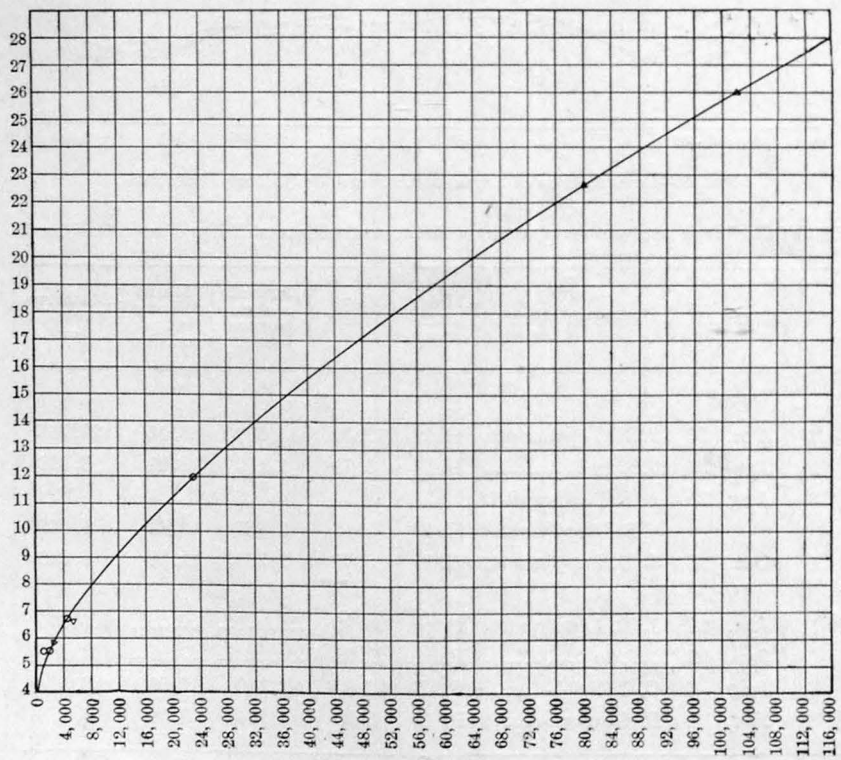



FIG. 60.—Rating curve for station at Jellys Ferry, California.

*Estimated discharge of Sacramento River at Jellys Ferry, California.*

[Drainage area, 9,134 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 130,050 | 6,360 | 46,152 | 2,837,813 | 5.86 | 5.05 |
| February | 34,460 | 10,070 | 15,468 | 889,764 | 1.82 | 1.69 |
| March | 62,870 | 11,310 | 24,099 | 1,481,801 | 3.05 | 2.64 |
| April | 59,500 | 16,920 | 25,793 | 1,534,819 | 3.14 | 2.82 |
| May | 75,120 | 19,300 | 30,941 | 1,902,543 | 3.91 | 3.39 |
| June | 20,515 | 9,200 | 14,217 | 846,018 | 1.74 | 1.56 |
| July | 8,960 | 6,720 | 7,591 | 466,789 | 0.95 | 0.83 |
| August | 6,720 | 6,180 | 6,394 | 393,201 | 0.81 | 0.70 |
| September | 6,360 | 6,000 | 6,204 | 369,163 | 0.75 | 0.68 |
| October | 8,000 | 6,000 | 6,163 | 378,960 | 0.77 | 0.67 |
| November | 43,000 | 6,360 | 11,965 | 712,014 | 1.46 | 1.31 |
| December | 93,000 | 8,480 | 22,318 | 1,372,304 | 2.82 | 2.44 |
| Per annum | 130,050 | 6,000 | 18,109 | 13,185,189 | 27.08 | 1.98 |

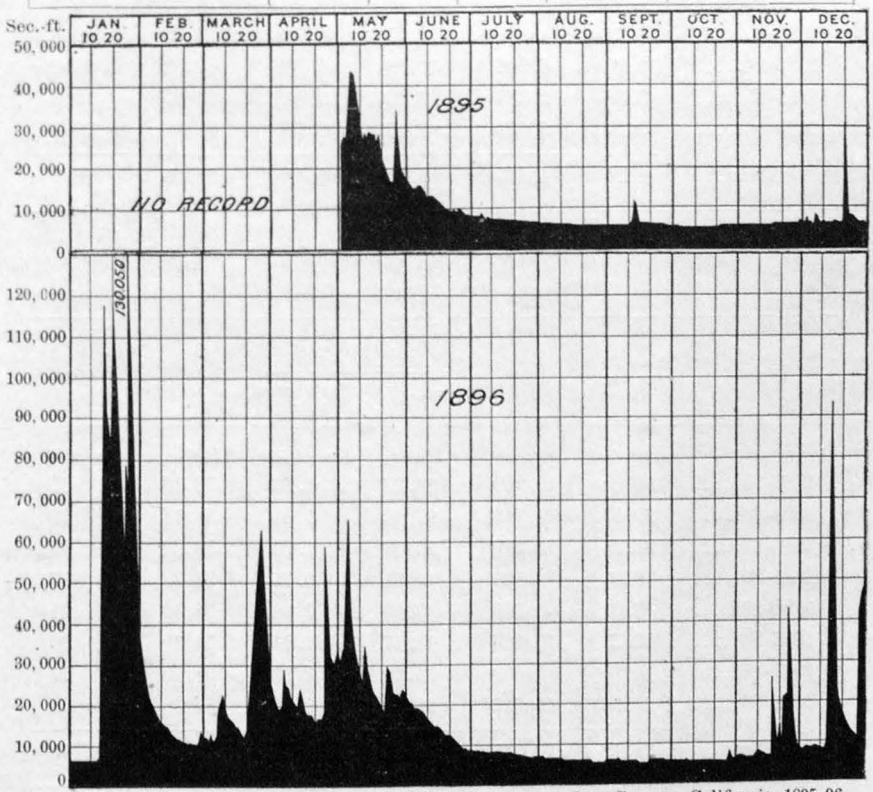



FIG. 61.—Discharge of Sacramento River at Jellys Ferry above Iron Canyon, California, 1895–96.

## SAN MATEO CREEK.

### UPPER CRYSTAL SPRINGS AND PILARCITOS-SAN ANDREAS RESERVOIRS OF SPRING VALLEY WATER COMPANY.

The following tables are the result of observations made by the Spring Valley Water Company on two of their reservoirs in San Mateo County, California. These reservoirs are in the peninsula between San Francisco Bay and the Pacific Ocean. The catchment basins are in the Coast Range.

*Estimated discharge at Upper Crystal Springs Reservoir, San Mateo County, California.*

[Drainage area, 14 square miles.]

| Season. | Mean discharge. | Total. | Run-off. | | Rainfall. | Run-off. |
|---|---|---|---|---|---|---|
| | | | Depth. | Per square mile. | | |
| | *Second-feet.* | *Acre-feet.* | *Inches.* | *Second-feet.* | *Inches.* | *Per cent.* |
| 1878–79..... | 5.32 | 3,852 | 5.16 | 0.380 | 43.12 | 12.0 |
| 1879–80..... | 7.28 | 5,271 | 7.06 | 0.520 | 48.09 | 15.0 |
| 1880–81..... | 13.44 | 9,730 | 13.04 | 0.960 | 38.78 | 35.0 |
| 1881–82..... | 0.22 | 156 | 0.21 | 0.016 | 25.02 | 0.8 |
| 1882–83..... | 0.11 | 78 | 0.11 | 0.008 | 23.06 | 0.4 |
| 1883–84..... | 10.92 | 7,906 | 10.59 | 0.780 | 40.32 | 27.0 |
| 1884–85..... | 3.36 | 2,433 | 3.26 | 0.240 | 25.67 | 13.0 |
| 1885–86..... | 9.24 | 6,690 | 8.95 | 0.660 | 35.58 | 26.0 |
| Mean... | 6.24 | 4,515 | 6.05 | 0.445 | 34.95 | 16.2 |

*Estimated discharge of Pilarcitos and San Andreas Reservoir.*

[Drainage area, 12.5 square miles.]

| Season. | Mean discharge. | Total. | Run-off. | | Rainfall. | Run-off. |
|---|---|---|---|---|---|---|
| | | | Depth. | Per square mile. | | |
| | *Second-feet.* | *Acre-feet.* | *Inches.* | *Second-feet.* | *Inches.* | *Per cent.* |
| 1878–79..... | 15.00 | 10,860 | 16.27 | 1.20 | 56.10 | 27 |
| 1879–80..... | 20.50 | 14,842 | 22.26 | 1.64 | 56.14 | 37 |
| 1880–81..... | 21.25 | 15,382 | 23.06 | 1.70 | 53.81 | 39 |
| 1881–82..... | 9.25 | 6,696 | 10.04 | 0.74 | 34.23 | 27 |
| 1882–83..... | 7.00 | 5,067 | 7.59 | 0.56 | 33.89 | 21 |
| 1883–84..... | 16.75 | 12,125 | 18.17 | 1.34 | 54.99 | 30 |
| 1884–85..... | 10.50 | 7,600 | 11.39 | 0.84 | 38.25 | 27 |
| 1885–86..... | 20.75 | 15,020 | 22.51 | 1.66 | 57.98 | 36 |
| Mean... | 15.12 | 10,945 | 16.41 | 1.21 | 47.41 | 30 |

## SAN JOAQUIN RIVER.

### OAKDALE STATION ON STANISLAUS RIVER.

This station is described in Bulletin No. 140, page 305. It is located one-half mile north of the town, on a road to Knights Ferry. The station is on the Stockton-Oakdale-Merced branch of the Southern Pacific Railroad. The Oakdale station was established on May 3, 1895, by J. B. Lippincott. The observer is Mr. Frank Templin, employed to make daily observations of river height and to make soundings of the depth at the gaging station, which is at the wagon bridge, 1,071 feet above the railroad bridge. Observations are taken as nearly as possible at the time of daily mean height of the river. At least one observation is taken every day, and in time of high water more than one. One rod of the United States Geological Survey is set between the south or left-hand piers of the wagon bridge on the side toward the water, and can be read from the bridge. The datum is 27.92 feet below the top of the southeast iron pier of the wagon bridge and 5.92 feet below the top of the cap on the piles of the south crib pier of the Southern Pacific Railroad bridge, inside of which pier the latter rod is spiked. The rod for the lowest readings of the river, 125 feet below the wagon bridge on the left bank, which was spiked to a willow and which was destroyed in 1895, has been renewed.

There are a number of disturbing elements in the discharge of the Stanislaus River. On the south fork of the river and above Strawberry there are three large regulating reservoirs. Their province is to regulate this portion of the stream as nearly as possible to the capacity of the Tuolumne County ditch, which diverts its waters at Hale's sawmill. This canal was measured at Sugarpine on the 3d of September, 1896, after a heavy rain in the mountains, and was then discharging 60.5 second-feet—a quantity larger than the normal flow. During a greater part of the summer season after July 1 this canal is said to carry practically all of the water of the south fork of the river. Its water is taken to the mines in the vicinity of Sonora. Some portion of it is used for irrigation, and it is nearly all distributed in the basin of the Tuolumne River. During the winter the canal discharges its unused water into the Phœnix Reservoir, about 5 miles northeast of Sonora, where it is held for use during the following summer. The capacity of the Phœnix Reservoir is probably not far from 6,000 acre-feet. It is in the Tuolumne Basin. A large number of small mining canals are taken from the river in various places, but as the water is largely used for river mining a high percentage of this returns to the stream.

On October 20 and 21, 1896, the following observations of discharge were made in the basin of the Stanislaus:

| | Sec. feet. |
|---|---|
| Middle Fork, Eureka Valley | 158.0 |
| Niagara Creek, Sonora and Mono road crossing | 1.5 |
| Mill Creek, Sonora and Mono road crossing | 1.5 |
| Cow Creek, Sonora and Mono road crossing | .5 |
| Cascade Creek, Sonora and Mono road crossing | Dry. |
| South Fork, Strawberry | 3.0 |

The most extensive diversion from the Stanislaus River occurs at Knights Ferry by the Stanislaus and San Joaquin Valley Water Company. This canal was gaged in the flume at Knights Ferry on September 8, 1896, and it was flowing 66.35 second-feet; again at the same point, on October 30, 1896, it was discharging 37.6 second-feet. The water company discontinued the information that was being furnished concerning this canal, but the average flow during the irrigation season, from May 1 to October 1, was probably not far from 50 second-feet and for the remaining portion of the year one-half of that amount. This water is used in the neighborhood of Oakdale and between Knights Ferry and Stockton.

It has been placed on the same datum with the other rods. These rods are solid and in good condition. The initial point of the sounding is 100 feet south of the center of the iron pier on the left bank of the river. The channel of the river is uniform and straight above and below the wagon bridge, and both banks are high enough to prevent overflow in all except extreme conditions of flood. The bed of the stream at this point is of sand and gravel. No material change has occurred in it during the past season. The stream deposits silt during the summer or at low-water stages, which is flushed out by the high-water stage of the spring. The variation in elevation of the bed of the stream between flood and low-water stages is between 1 and 2 feet. This flushing of the stream occurs with such system that the discharge with reference to the rating curve has little variation. The nine measurements that have been made at this station during the past eighteen months practically all lie on the one rating curve. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 90.

During the past season that portion of the drainage basin of the Stanislaus River which is adjacent to the Milton-Sonora-Sugarpine road was visited, and also the basins of the south fork and of the middle fork of the river. With the 1,000-foot contour a red-clay soil begins, and as the elevation increases its covering of the granite becomes less, until at approximately the 6,000-foot contour the granite is nearly bare. The summits of the mountains at an elevation of 10,000 feet have little soil on the rock, and there is not much vegetation. Many of the peaks are so entirely bare that they have the appearance of being snow clad. At approximately 1,000 feet a growth

of scrubby pine begins. At about 2,000 feet the timber is dense and is largely the yellow pine of commerce. This has been cut to a considerable extent for use in the mines. Where the larger trees have been removed a dense growth of young pines has taken their place, forming a retentive mat for the holding of moisture. The yellow pine is supplemented by the sugar pine and fir at an elevation of about 4,000 feet, and these are followed by junipers and tamaracks at elevations of 7,000 and 8,000 feet, respectively, the latter growing in altitudes as high as 10,000 feet.

*Rainfall for the year 1896 at Sonora,[1] Tuolumne County, California.*

| | | | |
|---|---|---|---|
| January | 10.80 | September | 0.25 |
| February | 0.49 | October | 2.85 |
| March | 5.00 | November | 6.74 |
| April | 8.65 | December | 3.97 |
| May | 1.14 | | |
| June | 0.00 | Year | 40.90 |
| July | 0.40 | Nine years' mean annual | 37.13 |
| August | 0.61 | | |

[1] This gage is at an elevation of 1,900 feet in the basin of the Tuolumne.

*List of discharge measurements, made on Stanislaus River, at Oakdale, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square (feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | May 3 | J. B. Lippincott. | H. 24 | 8.70 | 1,970 | 3.92 | 7,744 |
| 2 | July 2 | .....do ..... | H. 24 | 6.15 | 1,242 | 3.02 | 3,754 |
| 3 | Aug. 28 | .....do ..... | H. 24 | 2.40 | 200 | 1.39 | 279 |
| 4 | Oct. 10 | .....do ..... | H. 24 | 2.11 | 170 | 1.13 | 192 |
| 5 | Nov. 29 | .....do ..... | Floats. | 2.13 | 149 | 0.99 | 147 |
| | 1896. | | | | | | |
| 6 | April 17 | J. A. Vogleson .. | P. 63 | 5.40 | 1,148 | 2.44 | 2,801 |
| 7 | July 5 | C. C. Babb ..... | P. 63 | 4.80 | 917 | 2.25 | 2,061 |
| 8 | Sept. 7 | H. S. Crowe..... | P. 12 | 2.50 | 437 | 0.69 | 304 |
| 9 | Oct. 29 | J. B. Lippincott. | P. 67 | 2.40 | 225 | 0.93 | 209 |

*Rating table for Stanislaus River, Oakdale, California, for 1895–96.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.5 | 75 | 3.5 | 880 | 5.5 | 2,900 | 7.5 | 5,680 |
| 1.6 | 90 | 3.6 | 962 | 5.6 | 3,028 | 7.6 | 5,838 |
| 1.7 | 105 | 3.7 | 1,044 | 5.7 | 3,156 | 7.7 | 5,996 |
| 1.8 | 120 | 3.8 | 1,126 | 5.8 | 3,284 | 7.8 | 6,154 |
| 1.9 | 135 | 3.9 | 1,208 | 5.9 | 3,412 | 7.9 | 6,312 |
| 2.0 | 150 | 4.0 | 1,290 | 6.0 | 3,540 | 8.0 | 6,470 |
| 2.1 | 184 | 4.1 | 1,382 | 6.1 | 3,678 | 8.1 | 6,632 |
| 2.2 | 218 | 4.2 | 1,474 | 6.2 | 3,816 | 8.2 | 6,794 |
| 2.3 | 252 | 4.3 | 1,566 | 6.3 | 3,954 | 8.3 | 6,956 |
| 2.4 | 286 | 4.4 | 1,658 | 6.4 | 4,092 | 8.4 | 7,118 |
| 2.5 | 320 | 4.5 | 1,750 | 6.5 | 4,230 | 8.5 | 7,280 |
| 2.6 | 370 | 4.6 | 1,858 | 6.6 | 4,372 | 8.6 | 7,444 |
| 2.7 | 420 | 4.7 | 1,966 | 6.7 | 4,514 | 8.7 | 7,608 |
| 2.8 | 470 | 4.8 | 2,074 | 6.8 | 4,656 | 8.8 | 7,772 |
| 2.9 | 520 | 4.9 | 2,182 | 6.9 | 4,798 | 8.9 | 7,936 |
| 3.0 | 570 | 5.0 | 2,290 | 7.0 | 4,940 | 9.0 | 8,100 |
| 3.1 | 632 | 5.1 | 2,412 | 7.1 | 5,088 | 10.0 | 10,000 |
| 3.2 | 694 | 5.2 | 2,534 | 7.2 | 5,236 | 11.0 | 12,000 |
| 3.3 | 756 | 5.3 | 2,656 | 7.3 | 5,384 | | |
| 3.4 | 818 | 5.4 | 2,778 | 7.4 | 5,532 | | |

*Estimated discharge of Stanislaus River at Oakdale, California.*

[Drainage area, 1,051 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 6,956 | 150 | 1,806 | 111,058 | 1.98 | 1.72 |
| February | 1,208 | 632 | 782 | 45,038 | 0.80 | 0.75 |
| March | 12,000 | 694 | 2,464 | 151,505 | 2.70 | 2.35 |
| April | 9,050 | 1,966 | 3,274 | 194,870 | 3.48 | 3.11 |
| May | 13,050 | 2,290 | 4,717 | 290,092 | 5.17 | 4.57 |
| June | 11,000 | 2,656 | 6,541 | 389,247 | 6.97 | 6.22 |
| July | 3,156 | 470 | 1,293 | 79,503 | 1.42 | 1.23 |
| August | 2,412 | 218 | 385 | 23,703 | 0.42 | 0.37 |
| September | 962 | 252 | 332 | 19,761 | 0.35 | 0.32 |
| October | 370 | 218 | 239 | 14,695 | 0.26 | 0.22 |
| November | 4,514 | 252 | 705 | 41,968 | 0.75 | 0.67 |
| December | 1,750 | 470 | 681 | 41,904 | 0.75 | 0.65 |
| Per annum | 13,050 | 150 | 1,935 | 1,403,344 | 25.05 | 1.85 |

The amounts diverted by the various canals above this gaging station are not included in this table.

*List of discharge measurements on the tributaries of the Stanislaus River.*

[Made by J. B. Lippincott.]

| Date. | Stream. | Locality. | Meter number. | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| Sept. 8 | Stanislaus(flume) | Knights Ferry, Cal. | 12 | 5.60 | 11.85 | 66.35 |
| Sept. 9 | South Fork of Stanislaus | Sugar Pine, Cal.. | 12 | 5.48 | 11.04 | 60.48 |
| Oct. 20 | Main Fork of Stanislaus. | Eureka Valley, Cal. | ..... | 93.40 | 1.69 | 158.00 |
| Oct. 21 | Cow Creek ..... | Sonora Road, Cal. | ..... | ..... | ..... | *a* 0.50 |
| Oct. 21 | Niagara Creek... | .....do ..... | ..... | ..... | ..... | *a* 1.50 |
| Oct. 21 | Mill Creek ..... | .....do ..... | ..... | ..... | ..... | *a* 1.50 |
| Oct. 22 | Cascade Creek... | .....do ..... | ..... | ..... | ..... | Dry. |
| Oct. 22 | South Fork of Stanislaus. | Strawberry, Cal.. | ..... | ..... | ..... | *a* 3.00 |
| Oct. 30 | Stanislaus and San J. Canal. | Knights Ferry, Cal. | ..... | 5.01 | 7.50 | 37.60 |

*a* Estimated.

## THE SALT SPRINGS VALLEY RESERVOIR, NEAR MILTON, CALAVERAS COUNTY, CALIFORNIA.

The Salt Springs Valley Reservoir is located about 37 miles east of Stockton and 7 miles east of Milton, on the Milton-Sonora Road. The reservoir was built for the combined purpose of mining and irrigation. The dam is 2,050 feet long, exclusive of the waste gates, which are 28 in number, each being 4 feet wide in the clear. These waste gates rest on bed rock at the south end of the dam. The bottom of the waste gates is 5 feet below the top of the dam. The dam is built of a red clay soil, the inner face being paved with broken rock, which was laid up dry by hand. A dry-laid retaining wall, from 5 to 20 feet high, is built at the higher portion of the dam on the lower slope, evidently to save material. The dam has been in service since 1859. It was raised in the 70's and again to its present height in 1887. The discharge ditch is 15 feet above the bed rock of the creek, and the bottom of the waste gate 30 feet above the ditch, the top of the dam being 50 feet above the bed rock of the creek. There is a pond of about 60 acres that can not be drawn off by the discharge ditch. In March, 1893, the dam was threatened by a flood, so it was cut at the south end where it is located on the bed rock. The dam was saved by this, but badly scarred. This cut was refilled in the fall of 1896 and the approach to the waste gates enlarged.

The water is measured as follows: First, the amount of water drawn off through the discharge ditch is measured in the conduit, and a synchronous record kept of the water heights in the reservoir, thus establishing the capacity of the reservoir for various depths. From the resulting table the amount of water held over at the end of the rainy season is estimated and accounted for in determining the total for the past and following seasons. Second, during the season 1889–90

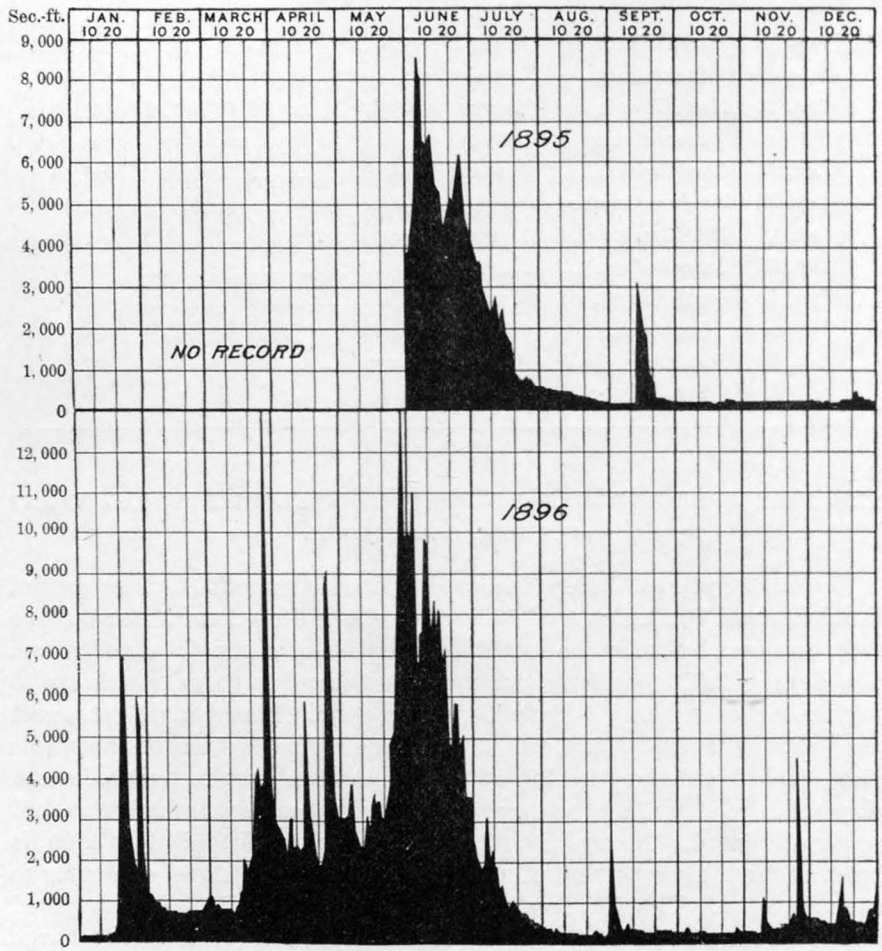



FIG. 62.—Discharge of Stanislaus River at Oakdale, California, 1895–96.

a record was kept of the depth of water passing the waste gates, and from this the discharge was computed according to the rule given by Trautwine for weirs without perfect contractions. For other seasons when there has been waste water passing the flood gates the quantity has been approximated from less frequent observations and from the rainfall.

The following is an estimate of the division of the water from a full reservoir during the dry season, the reservoir being full May 1:

| | Cubic feet. |
|---|---|
| Evaporation from reservoir | 150,000,000 |
| Evaporation and seepage from ditch | 30,000,000 |
| Amount available at North Hill | 428,000,000 |
| Total in reservoir May 1 | 608,000,000 |

The loss of 180,000,000 cubic feet, or 4,132 acre-feet, due to seepage and evaporation should be added to the table given below to determine the total run-off from the drainage basin. The depth of evaporation at the reservoir during the dry season is estimated as 50 inches. Mr. J. H. Southwick, superintendent of the Salt Springs Valley Reservoir, has kindly furnished the information given herewith as to the dam, evaporation, and run-off.

The dam is located at an elevation of 1,100 feet above the level of the sea in the western foothills of the Sierra Nevadas. The soil of the basin is largely of a red clay, which scantily covers a bed rock of granite and slate. The topography of the basin is undulating rather than mountainous, about 20 per cent of the total drainage area of 25 square miles being valley land. There is little agriculture and much grazing in the basin. There is no brush or timber in the valley, and only a scattered growth of oak and scrubby pine on the hills. The rainfall given for North Hill, 6 miles northwest of the dam, is at least 10 per cent less than the mean of the basin. The natural drainage of this basin is into Rock Creek, a branch of Little John Creek, which flows by Farmington into the San Joaquin River.

*Estimated seasonal discharge into Salt Spring Valley Reservoir near Milton, Calaveras County, California.* (*a*)

[Drainage area, 25 square miles.]

| Year. | Mean discharge. | Total for year. | Run-off. | | Rainfall. | Run-off. |
|---|---|---|---|---|---|---|
| | | | Depth. | Per square mile. | | |
| | *Second-feet.* | *Acre-feet.* | *Inches.* | *Second-feet.* | *Inches.* | *Per cent.* |
| 1889–90 | 36.7 | 26,606 | 19.95 | 1.47 | 30.38 | 65 |
| 1890–91 | 6.3 | 4,591 | 3.39 | 0.25 | 13.06 | 26 |
| 1891–92 | 4.9 | 3,560 | 2.71 | 0.20 | 16.98 | 16 |
| 1892–93 | 30.8 | 22,311 | 16.69 | 1.23 | 26.46 | 63 |
| 1893–94 | 22.5 | 16,323 | 12.21 | 0.90 | 25.37 | 48 |
| 1894–95 | 35.4 | 25,664 | 19.27 | 1.42 | 32.31 | 59 |
| 1895–96 | 8.5 | 6,221 | 4.61 | 0.34 | 23.98 | 19 |
| Mean | 20.7 | 15,099 | 11.26 | 0.83 | 24.08 | 42 |

*a* Evaporation not considered in this table.

LAGRANGE STATION ON TUOLUMNE RIVER.

This station, described in Bulletin No. 140, page 301, was established because of the fact that the Modesto station on this river was influenced to a great extent by the height of the San Joaquin River a few miles below and by shifting sand bars. The intention was to get a rating for the dam above the town, where the section would be permanent, but because of the number of gates, there being seven in the dam and some of these being at times only in part open, and also because of the difficulty in finding a reliable observer there, the attempt to establish a rating for the dam was abandoned. The observations at the bridge in the town were maintained, and this station is considered the most reliable on the river.

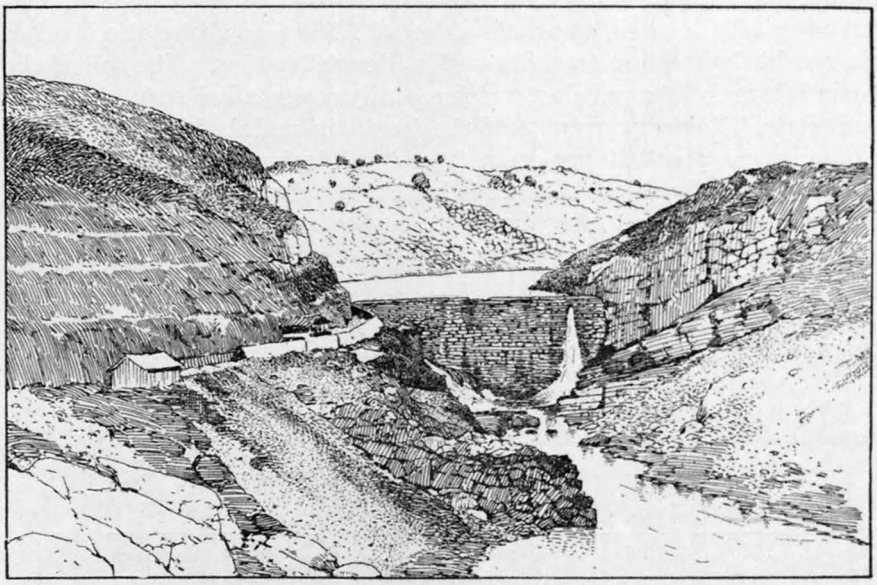


FIG. 63.—Lagrange Dam.

Lagrange is reached from Modesto by team, the distance being 32 miles. The station at the bridge was originally established by Mr. A. P. Davis, August 29, 1895. The first observer was A. H. Pritchard. The observations, discontinued March 1, 1896, were resumed April 15, 1896, Mr. H. S. Crowe, engineer for the Modesto Irrigation district, reading the rod. Mr. Crowe continued observing until July 1, when he left Lagrange, and Mr. W. H. Nelson took his place, and later Miss Ella Smith. Two observations are taken daily, one at 8 a. m. and the other at 5 p. m. The record of mean daily height is given in Water-Supply and Irrigation Paper No. 11, page 90. The gage rod is fastened between the two iron piers on the right bank of the river on the side of the timbers that face the stream. It is a vertical 2 by 4-inch timber,

graduated to tenths, is solid, and well painted. The bench mark is a nail driven into the bottom of the west post of the fifth bent south of the south iron cylinder. The bench is 15.31 feet above the zero of the rod. The channel both above and below the bridge is straight for several hundred feet and the velocity of the stream is quite uniform. The water is rather sluggish on the left half of the channel in stages of low water. Both banks are high and not subject to overflow. The bed is gravel, and is to a considerable extent affected by the "slickens" from the river mining between the bridge and the dam. The high water of the spring of 1896 flushed out the bed of the stream about 2 feet, as was indicated by the April and May

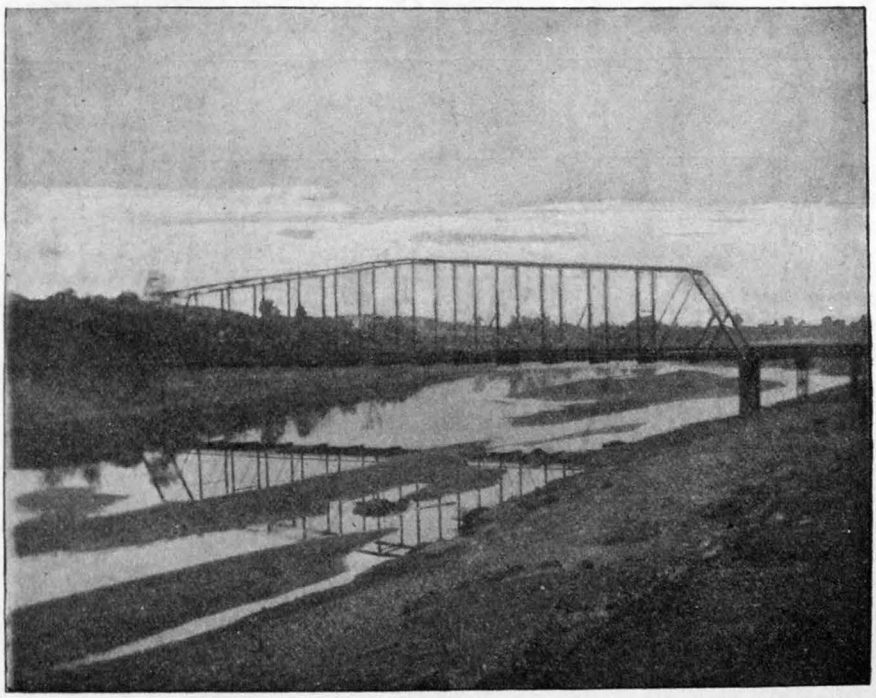


FIG. 64.—Lagrange bridge, looking downstream.

soundings compared with those of October and November, 1895. The June flood cleaned the stream bed out much more, and judging from the section took it down to the bed rock; but the September and October measurements show a section almost identical with that of April and May. All points in both of the years plot closely on one rating curve. No observations were taken from March 1 to April 14, inclusive, and the discharge figures during that time are taken from the Modesto station.

The portion of the basin of the Tuolumne between Sonora and the Yosemite Valley was visited during the summer of 1896. Above the

1,000-foot contour this portion of the basin is granitic, with a shallow covering of red clay, which disappears at about the 7,000-foot contour. Above this the granite is practically bare. Brush and scrubby timber grow in abundance between the 1,000 and 3,000-foot contours. Above this the trees are large wherever there is sufficient soil to support them, and there is little brush, but much moss and small plant growth. The adjoining basins of the Stanislaus and Tuolumne are in striking contrast, that of the Stanislaus being denuded below the 5,000-foot contour by both man and beast. There are numerous large sawmills removing the big timber, and large bands of sheep are ranging in the higher mountains, trampling the soil hard and eating every green

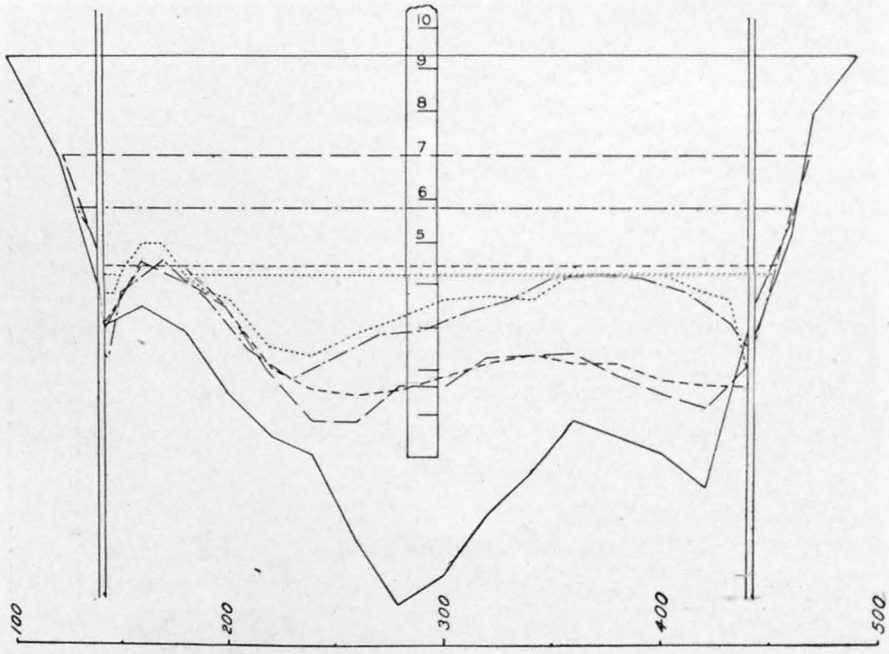



FIG. 65.—Cross section of Tuolumne River at Lagrange bridge, California.

thing that they can reach, stripping the hillside of all the grass, moss, and small shrubs, and giving them a very bare appearance. The Yosemite National Park includes the greater portion of the basin of the Tuolumne. This park is patroled by a troop of cavalry and all stock excluded except that on private lands that are fenced. The ground in the park is covered with a beautiful green growth of grasses, ferns, and moss. The ferns in the lower valleys are very dense, in many instances growing as high as 6 feet.

A mining canal is taken out on the left side of the Tuolumne River, about 5 miles above the dam, the water being used in sluicing the auriferous gravels in the neighborhood of Lagrange. A portion of the waters returns to the river above the gaging station, a part of them

below it. On April 15, 1896, this canal was gaged above the dam and was flowing 32.1 second-feet. The flow, which remains quite constant winter and summer, is not considered in the tables given below.

*Rainfall for the year 1896 at second garotte, Sequoia post-office, Tuolumne County, California.*

| Month. | Second garotte.*a* | Sequoia post-office.*b* |
|---|---|---|
| January | 12.00 | ..... |
| February | 0.00 | ..... |
| March | 5.50 | ..... |
| April | 7.25 | ..... |
| May | 0.25 | ..... |
| June | 0.00 | ..... |
| July | 0.00 | ..... |
| August | 2.50 | 3.10 |
| September | 0.00 | 0.14 |
| October | 3.00 | 2.30 |
| November | 6.00 | 9.18 |
| December | 4.50 | 5.41 |
| Year | 41.00 | ..... |
| Thirteen years' mean annual | 38.98 | ..... |

*a* This rain gage is at an elevation of 2,900 feet and in the basin of the Tuolumne River.

*b* Sequoia post-office is at an elevation of 4 453 feet, near the divide between the Tuolumne and the Merced rivers.

*List of discharge measurements made on Tuolumne River at Lagrange bridge, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Aug. 29 | J. B. Lippincott... | 24 | 4.40 | 93 | 3.20 | *a* 299 |
| 2 | Sept. 14 | .....do ..... | 24 | 5.80 | 757 | 2.41 | 1,824 |
| 3 | Nov. 28 | .....do ..... | 24 | 4.20 | 191 | 0.68 | 129 |
| | 1896. | | | | | | |
| 4 | Apr. 15 | J. A. Vogleson..... | 63 | 6.95 | 1,474 | 2.87 | 4,236 |
| 5 | May 5 | H. S. Crowe..... | 24 | 7.00 | 1,489 | 2.69 | 4,004 |
| 6 | June 17 | .....do ..... | 24 | 9.30 | 3,013 | 2.75 | 8,274 |
| 7 | Sept. 4 | .....do ..... | 12 | 4.90 | 749 | 0.90 | 671 |
| 8 | Oct. 30 | J. B. Lippincott... | 12 | 4.45 | 630 | 0.57 | 361 |

*a* Gaged 1,500 feet below the bridge.

*Rating table for Tuolumne River, Lagrange bridge, Lagrange, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec feet.* | *Feet.* | *Sec. feet* |
| 3.5 | 25 | 5.4 | 1,190 | 7.3 | 4,570 | 9.2 | 8,180 |
| 3.6 | 30 | 5.5 | 1,300 | 7.4 | 4,760 | 9.3 | 8,370 |
| 3.7 | 40 | 5.6 | 1,460 | 7.5 | 4,950 | 9.4 | 8,560 |
| 3.8 | 55 | 5.7 | 1,620 | 7.6 | 5,140 | 9.5 | 8,750 |
| 3.9 | 75 | 5.8 | 1,780 | 7.7 | 5,330 | 9.6 | 8,940 |
| 4.0 | 100 | 5.9 | 1,940 | 7 8 | 5,520 | 9.7 | 9,130 |
| 4.1 | 132 | 6.0 | 2,100 | 7.9 | 5,710 | 9.8 | 9,320 |
| 4.2 | 174 | 6.1 | 2,290 | 8.0 | 5,900 | 9.9 | 9,510 |
| 4.3 | 227 | 6.2 | 2,480 | 8.1 | 6,090 | 10.0 | 9,700 |
| 4.4 | 280 | 6.3 | 2,670 | 8.2 | 6,280 | 10.1 | 9,900 |
| 4.5 | 350 | 6.4 | 2,860 | 8.3 | 6,470 | 10.2 | 10,100 |
| 4.6 | 430 | 6.5 | 3,050 | 8.4 | 6,660 | 10.3 | 10,300 |
| 4.7 | 510 | 6.6 | 3,240 | 8.5 | 6,850 | 10.4 | 10,500 |
| 4.8 | 590 | 6.7 | 3,430 | 8.6 | 7,040 | 10.5 | 10,700 |
| 4.9 | 670 | 6.8 | 3,620 | 8.7 | 7,230 | 10.6 | 10,900 |
| 5.0 | 750 | 6.9 | 3,810 | 8.8 | 7,420 | 10.7 | 11,100 |
| 5.1 | 860 | 7.0 | 4,000 | 8.9 | 7,610 | 10.8 | 11,300 |
| 5.2 | 970 | 7.1 | 4,190 | 9.0 | 7,800 | 10.9 | 11,500 |
| 5.3 | 1,080 | 7.2 | 4,380 | 9.1 | 7,990 | | |

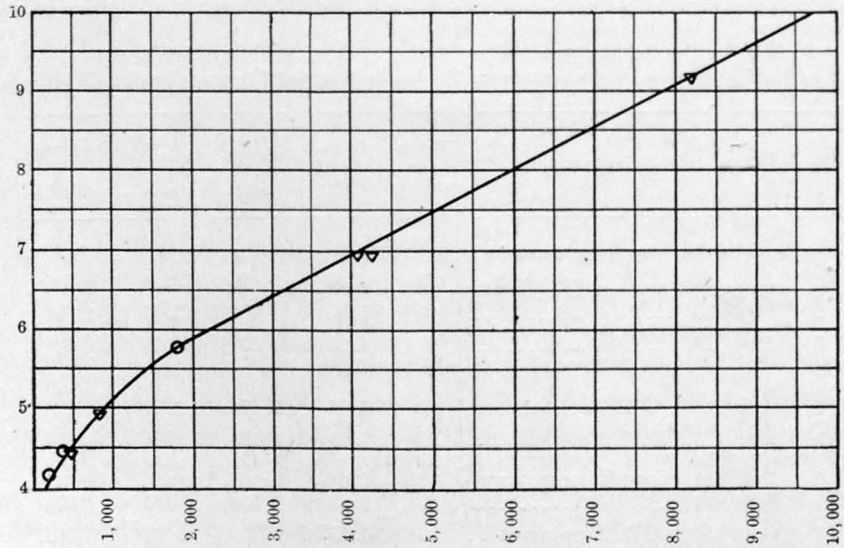



FIG. 66.—Rating curve for station at Lagrange bridge on Tuolumne River.

*Estimated discharge of Tuolumne River at Lagrange bridge, Lagrange, California.* (*a*)

[Drainage area, 1,501 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 7,610 | 350 | 2,312 | 142,159 | 1.78 | 1.54 |
| February | 1,780 | 1,080 | 1,164 | 66,954 | 0.84 | 0.78 |
| March *b* | 11,798 | 1,006 | 2,725 | 167,578 | 2.10 | 1.82 |
| April | 7,990 | 2,670 | 3,522 | 209,574 | 2.60 | 2.34 |
| May | 10,100 | 2,670 | 4,429 | 272,371 | 3.40 | 2.95 |
| June | 9,320 | 5,140 | 7,692 | 457,705 | 5.74 | 5.13 |
| July | 5,330 | 960 | 3,003 | 184,677 | 2.31 | 2.00 |
| August | 3,050 | 227 | 485 | 29,828 | 0.37 | 0.32 |
| September | 1,620 | 132 | 432 | 25,742 | 0.32 | 0.29 |
| October | 350 | 75 | 19 | 7,366 | 0.09 | 0.08 |
| November | 5,710 | 227 | 1,135 | 67,543 | 0.83 | 0.75 |
| December | 3,620 | 670 | 1,083 | 66,603 | 0.83 | 0.72 |
| Per annum | 11,798 | 75 | 2,342 | 1,698,100 | 21.21 | 1.56 |

*a* The discharge of the mining canal at Lagrange is not considered in this table.

*b* From March 1 to April 14, inclusive, no observations were taken at the Lagrange bridge. The Modesto station is on the same river, 35 miles below, and as no intermediate diversion occurs and but a small amount of water enters the river between these points, the volumes measured at Modesto are substituted for Lagrange between these dates.

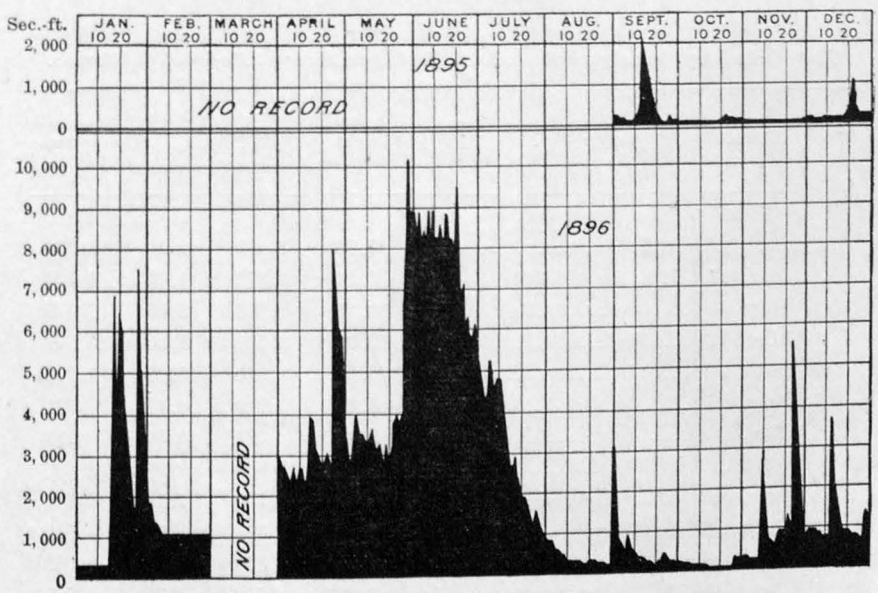



FIG. 67.—Discharge of Tuolumne River at Lagrange bridge, California, 1895–96.

## MODESTO STATION ON TUOLUMNE RIVER.

This station, described in the Twelfth Annual Report of the United States Geological Survey, Part II, page 322, also in Bulletin No. 131, page 83, and in Bulletin No. 140, page 289, is situated one-half mile south of the depot and at the wagon-road bridge. It was originally established by the Southern Pacific Railroad in 1879, and continuous observations have been kept on the river since then. The observer, Mr. J. T. Reed, is the Southern Pacific bridge watchman. Observations are taken daily at 6 a. m. and at 3 p. m.; the mean of the two observations are used in the table of daily rod readings. These observations have been made at this station without interruption during 1896, and are given in Water-Supply and Irrigation Paper No. 11, page 91. The gagings are made from the wagon bridge, 100 feet west of the railroad bridge. The gage is a vertical rod 2 by 6 inches, painted white, reading down to 3 feet only. The rod is fastened on the south side of the central railroad pier. The top of the rail at the central pier is 46.05 feet above the datum of the gage. The initial point for sounding is at the pier on the right bank. The channel above and below the station is straight, but in the summer stages of the stream the current is very sluggish. The right bank shows indication of overflow. The bed of the stream at Modesto maintains a section of considerable permanence, but the velocities are varied by the height of the water in the San Joaquin River, into which it flows at a point 12 miles below. While a rating curve can be plotted for this section, two of the eleven measurements show considerable divergence. The Modesto and Turlock irrigation districts have not yet completed their large canals, which are intended to divert the waters of the river 1 mile above Lagrange at the dam. The capacity of these canals will be in excess of the midsummer and autumn flow of the stream.

*List of discharge measurements made on Tuolumne River at Modesto, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Jan. 8 | A. P. Davis..... | ..... | 7.70 | 1,435 | 2.10 | 3,003 |
| 2 | Mar. 21 | J. B. Lippincott. | 24 | 6.90 | 1,378 | 1.76 | 2,429 |
| 3 | May 1 | .....do ..... | 24 | 10.25 | 2,395 | 2.55 | 6,078 |
| 4 | May 2 | .....do ..... | 24 | 12.90 | 3,148 | 4.37 | a13,546 |
| 5 | June 27 | .....do ..... | 24 | 13.00 | 3,090 | 3.01 | 9,308 |
| 6 | Aug. 27 | .....do ..... | 24 | 4.00 | 719 | 0.41 | 294 |
| 7 | Nov. 30 | .....do ..... | Floats. | 3.42 | 497 | 0.39 | 213 |
| | 1896. | | | | | | |
| 8 | Apr. 14 | J. A. Vogleson... | 63 | 7.90 | 1,719 | 2.18 | 3,745 |
| 9 | July 4 | C. C. Babb ..... | 63 | 9.60 | 2,091 | 1.78 | 3,719 |
| 10 | Sept. 5 | H. S. Crowe..... | 12 | 4.50 | 531 | 0.68 | 362 |
| 11 | Oct. 31 | J. B. Lippincott. | 67 | 3.92 | 642 | 0.58 | 375 |

a Local showers.

*Rating table for Tuolumne River at Modesto, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 3.0 | 180 | 8.0 | 3,560 | 12.5 | 8,735 | 17.0 | 14,040 |
| 3.5 | 220 | 8.5 | 4,080 | 13.0 | 9,320 | 17.5 | 14,635 |
| 4.0 | 390 | 9.0 | 4,600 | 13.5 | 9,910 | 18.0 | 15,230 |
| 4.5 | 600 | 9.5 | 5,200 | 14.0 | 10,500 | 18.5 | 15,825 |
| 5.0 | 950 | 10.0 | 5,800 | 14.5 | 11,090 | 19.0 | 16,420 |
| 5.5 | 1,230 | 10.5 | 6,395 | 15.0 | 11,680 | 19.5 | 17,020 |
| 6.0 | 1,610 | 11.0 | 6,990 | 15.5 | 12,270 | 20.0 | 17,620 |
| 6.5 | 2,060 | 11.5 | 7,570 | 16.0 | 12,860 | 20.5 | 18,220 |
| 7.0 | 2,550 | 12.0 | 8,150 | 16.5 | 13,450 | 21.0 | 18,820 |
| 7.5 | 3,010 | | | | | | |

*Estimated discharge of Tuolumne River at Modesto, California.*

[Drainage area, 1,501 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 13,686 | 246 | 3,080 | 189,370 | 2.37 | 2.05 |
| February | 1,880 | 950 | 1,182 | 68,007 | 0.86 | 0.79 |
| March | 11,798 | 1,006 | 2,725 | 167,578 | 2.10 | 1.82 |
| April | 14,873 | 1,970 | 3,577 | 212,828 | 2.66 | 2.38 |
| May | 14,754 | 2,550 | 5,180 | 318,500 | 3.98 | 3.45 |
| June | 14,754 | 6,990 | 11,648 | 693,104 | 7.87 | 7.09 |
| July | 8,735 | 1,306 | 4,121 | 253,408 | 3.17 | 2.75 |
| August | 1,118 | 300 | 575 | 35,392 | 0.44 | 0.38 |
| September | 2,918 | 220 | 574 | 34,191 | 0.43 | 0.38 |
| October | 474 | 180 | 224 | 13,797 | 0.17 | 0.15 |
| November | 7,802 | 273 | 1,210 | 72,012 | 0.90 | 0.81 |
| December | 3,560 | 516 | 1,028 | 63,247 | 0.79 | 0.69 |
| Per annum | 14,754 | 180 | 2,927 | 2,121,434 | 25.74 | 1.90 |

## HERNDON STATION ON SAN JOAQUIN RIVER.

This station, described in the United States Geological Survey's Twelfth Annual Report, Part II, page 321, also in Bulletin No. 131, page 81, and in Bulletin No. 140, pages 288 and 311, is at the wagon bridge, half a mile north of Herndon and 12 miles north of Fresno, on the Southern Pacific Railroad. The station was established by the

Southern Pacific Railway Company in 1879, and continuous observations of river heights have been maintained. Ten measurements have since been made by this Survey. The observer, Mr. G. G. Nelson, is employed as bridge watchman by the Southern Pacific Railroad for the bridge 930 feet below the wagon bridge. He reads the gage daily at 9.30 a. m. and at 3 p. m. It consists of a vertical rod fastened to the lower side of the south central railroad bridge pier. The space between the marks is 1 inch, to agree with the usage of the railroad. The bench mark is at the south end of the wagon bridge trestle on the west side, on a nail in a post 0.2 of a foot above the ground and marked by a

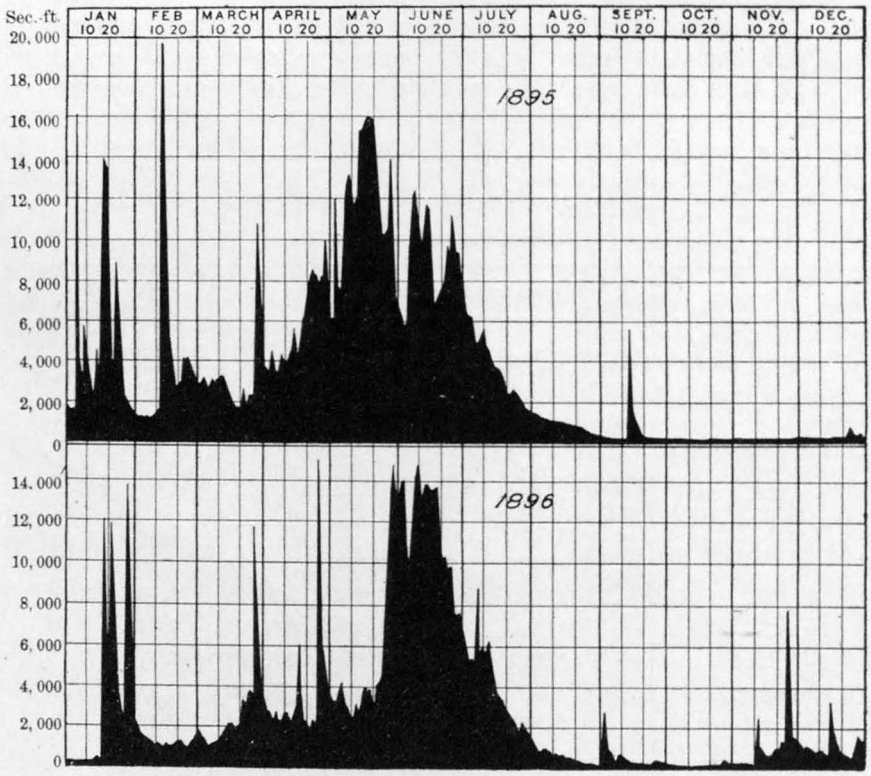



FIG. 68.—Discharge of Tuolumne River at Modesto, California, 1895–96.

"B. M." cut in the post. The elevation above rod datum is 24.12 feet. A gage on the same datum is also painted on the southwest cylinder. The initial point of the sounding is on the left bank at the south cylinder. The channel for 900 feet above and 3,000 feet below the bridge is straight and the water has a uniform and moderate velocity. There are no piers in the bed of the stream to disturb the current and the section is a satisfactory one. The right bank is high, rocky, and steep.

The bed of the stream is in part sandy and in part of small gravel. With the river standing at 9.5 feet on the gage rod, the bed is washed out from 3 to 7 feet as compared to its elevation when the river stands

at 2.5 feet. The intermediate stages of the river during the past year have so adjusted the bed of the stream that discharge measurements indicate a uniform rating curve similar to the one of the previous year. Since April 19, 1896, Mr. Nelson has made weekly soundings at the gaging station. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 91.

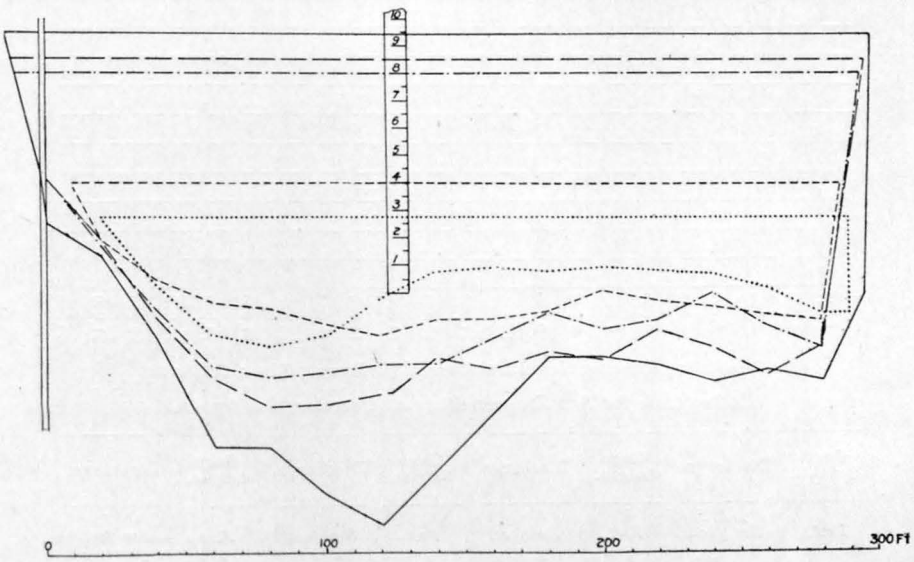



FIG. 69.—Sections of San Joaquin River at Herndon, California, showing changes in the bed.

*List of discharge measurements made on San Joaquin River at Herndon, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Jan. 9 | A. P. Davis..... | 24 | 4.00 | 1,198 | 1.67 | 1,995 |
| 2 | Mar. 22 | J. B. Lippincott. | 24 | 3.85 | 1,273 | 1.52 | 1,937 |
| 3 | May 5 | .....do ..... | 24 | 6.65 | 2,262 | 3.28 | 7,419 |
| 4 | June 23 | .....do ..... | 24 | 8.00 | 2,769 | 4.05 | 11,225 |
| 5 | Aug. 31 | .....do ..... | 24 | 3.00 | 1,005 | 0.68 | 677 |
| 6 | Oct. 11 | .....do ..... | 24 | 2.60 | 730 | 0.45 | 332 |
| 7 | Nov. 25 | .....do ..... | Floats. | 2.55 | 703 | 0.38 | 270 |
| | 1896. | | | | | | |
| 8 | Apr. 13 | J. A. Vogleson... | 63 | 4.10 | 1,350 | 1.78 | 2,406 |
| 9 | June 11 | J. B. Lippincott. | 63 | 9.33 | 3,839 | 4.15 | 15,942 |
| 10 | Nov. 2 | .....do ..... | 67 | 2.75 | 722 | 0.59 | 424 |

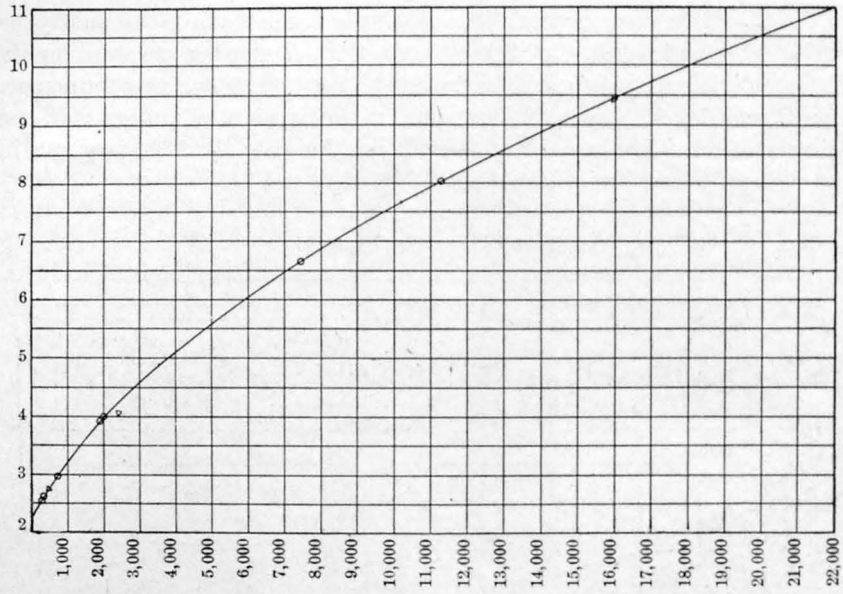



FIG. 70.—Rating curve for Herndon station on San Joaquin River, California.

*Rating table for San Joaquin River at Herndon, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 2.3 | 80 | 4.5 | 2,900 | 6.7 | 7,540 | 8.9 | 14,080 |
| 2.4 | 165 | 4.6 | 3,080 | 6.8 | 7,810 | 9.0 | 14,400 |
| 2.5 | 250 | 4.7 | 3,260 | 6.9 | 8,080 | 9.1 | 14,760 |
| 2.6 | 340 | 4.8 | 3,440 | 7.0 | 8,350 | 9.2 | 15,120 |
| 2.7 | 430 | 4.9 | 3,620 | 7.1 | 8,620 | 9.3 | 15,480 |
| 2.8 | 520 | 5.0 | 3,800 | 7.2 | 8,890 | 9.4 | 15,840 |
| 2.9 | 610 | 5.1 | 4,000 | 7.3 | 9,160 | 9.5 | 16,200 |
| 3.0 | 700 | 5.2 | 4,200 | 7.4 | 9,430 | 9.6 | 16,560 |
| 3.1 | 820 | 5.3 | 4,400 | 7.5 | 9,700 | 9.7 | 16,920 |
| 3.2 | 940 | 5.4 | 4,600 | 7.6 | 10,008 | 9.8 | 17,280 |
| 3.3 | 1,060 | 5.5 | 4,800 | 7.7 | 10,316 | 9.9 | 17,640 |
| 3.4 | 1,180 | 5.6 | 5,012 | 7.8 | 10,624 | 10.0 | 18,000 |
| 3.5 | 1,300 | 5.7 | 5,224 | 7.9 | 10,932 | 10.1 | 18,400 |
| 3.6 | 1,450 | 5.8 | 5,436 | 8.0 | 11,240 | 10.2 | 18,800 |
| 3.7 | 1,600 | 5.9 | 5,648 | 8.1 | 11,552 | 10.3 | 19,200 |
| 3.8 | 1,750 | 6.0 | 5,860 | 8.2 | 11,864 | 10.4 | 19,600 |
| 3.9 | 1,900 | 6.1 | 6,088 | 8.3 | 12,176 | 10.5 | 20,000 |
| 4.0 | 2,050 | 6.2 | 6,316 | 8.4 | 12,488 | 10.6 | 20,400 |
| 4.1 | 2,220 | 6.3 | 6,544 | 8.5 | 12,800 | 10.7 | 20,800 |
| 4.2 | 2,390 | 6.4 | 6,772 | 8.6 | 13,120 | 10.8 | 21,200 |
| 4.3 | 2,560 | 6.5 | 7,000 | 8.7 | 13,440 | 10.9 | 21,600 |
| 4.4 | 2,730 | 6.6 | 7,270 | 8.8 | 13,760 | 11.0 | 22,000 |

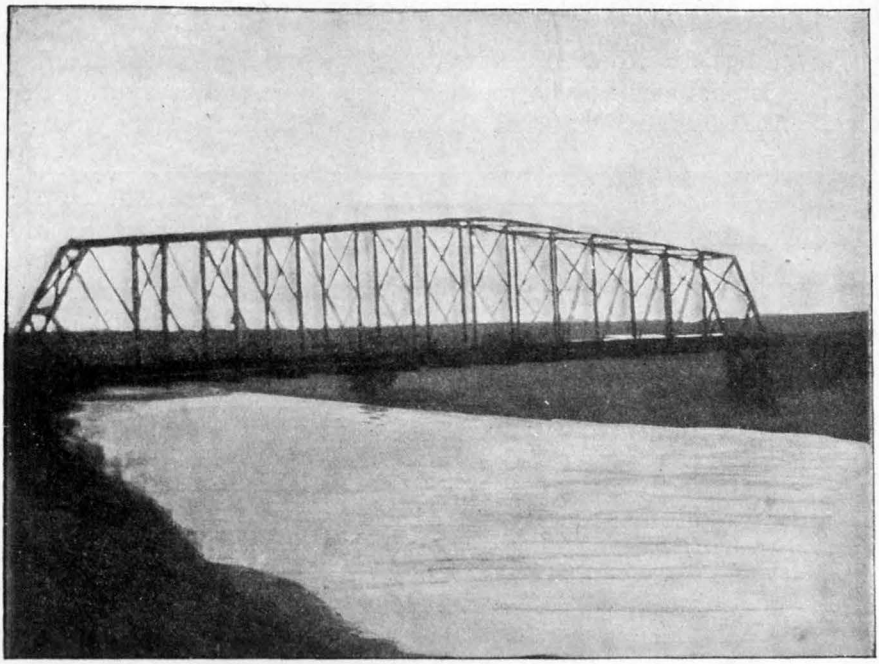


FIG. 71—Gaging station on San Joaquin River at Herndon, California.

*Discharge of San Joaquin River at Herndon, California.*

[Drainage area, 1,637 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 12,800 | 250 | 2,119 | 130,335 | 1.49 | 1.29 |
| February | 1,750 | 950 | 1,177 | 67,696 | 0.77 | 0.72 |
| March | 12,176 | 1,180 | 2,612 | 160,649 | 1.84 | 1.60 |
| April | 5,648 | 1,920 | 2,675 | 159,192 | 1.83 | 1.64 |
| May | 18,800 | 2,560 | 5,394 | 331,700 | 3.81 | 3.30 |
| June | 16,920 | 6,544 | 11,799 | 702,106 | 8.00 | 7.21 |
| July | 8,080 | 1,600 | 4,177 | 256,865 | 3.04 | 2.55 |
| August | 1,300 | 700 | 1,048 | 64,463 | 0.74 | 0.64 |
| September | 1,180 | 80 | 534 | 31,817 | 0.37 | 0.33 |
| October | 700 | 80 | 167 | 10,275 | 0.12 | 0.10 |
| November | 2,390 | 430 | 697 | 41,492 | 0.48 | 0.43 |
| December | 1,750 | 430 | 666 | 40,957 | 0.47 | 0.41 |
| Per annum | 18,800 | 80 | 2,756 | 1,997,547 | 22.96 | 1.69 |

## RED MOUNTAIN STATION ON KINGS RIVER.

This station, described in Bulletin No. 140, page 287, is located 15 miles east of Sanger, and may be reached by roads on either side of the river. The observer, Mr. C. W. Stalder, is a "herder" on the lumber

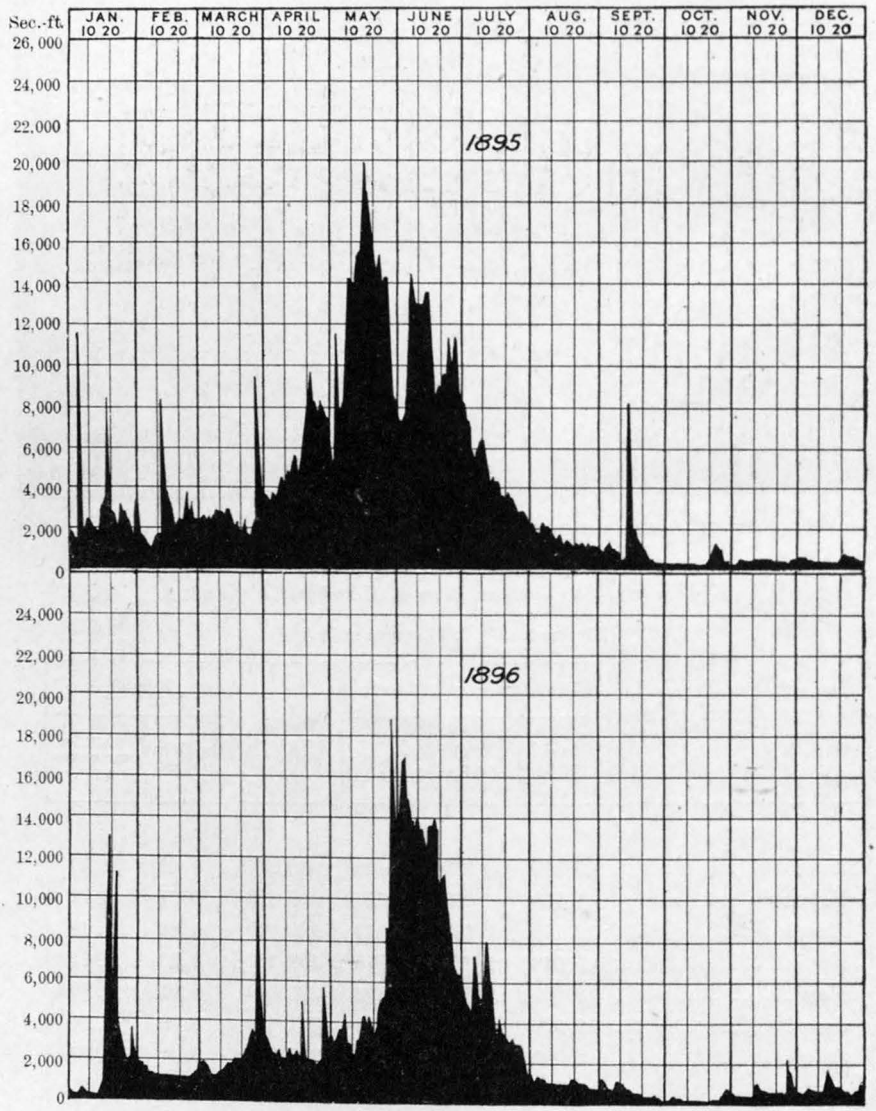



FIG. 72.—Discharge of San Joaquin River at Herndon, California, 1895–96.

flume, and observes twice a week, or oftener in the time of high water. The gage is made of two 4-inch by 8-inch timbers 14 and 20 feet long, respectively, laid on the ground under a rock and bolted to a tree. The division of the rod is for vertical intervals of one-tenth of a foot.

The station is on what is called "Lower Section of No. 9" of the lumber flume, and is southwest of Red Mountain and 3 miles below Jarrett's place. The bench mark is a + cut in the top of a granite bowlder 11 feet northwest of a blazed sycamore tree at top of rod and 18.045 above the zero of the rod. The initial point of measurement is on the left bank, the "deadman" being at station + 50.

The channel for 300 feet above and for an equal distance below is quite straight. The velocity of the water in high stages is swift. In low stages of the river the current near the right bank is sluggish, and the highest velocity is found on the left bank. The right bank is high

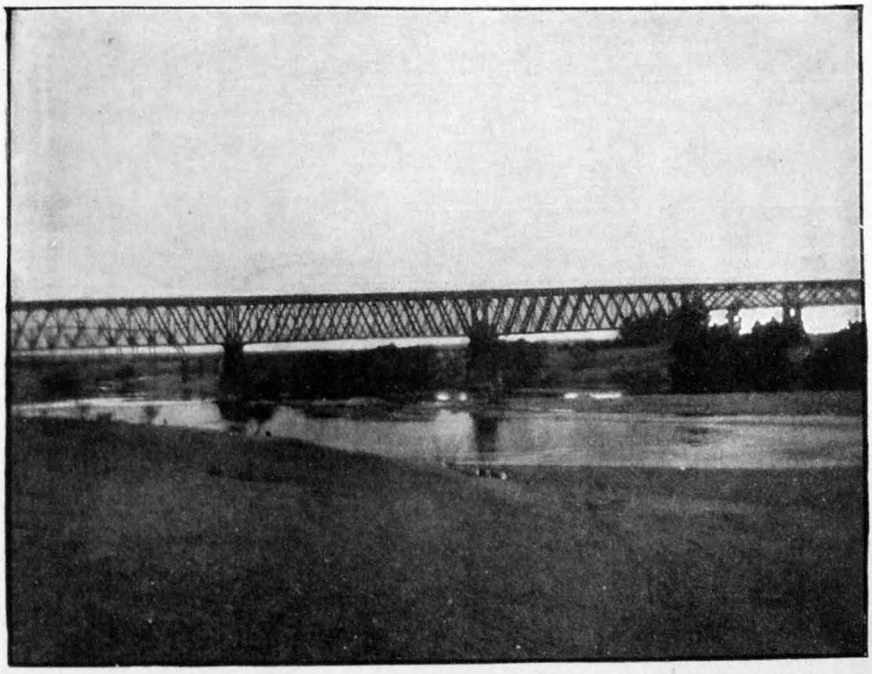


FIG. 73.—Railroad and wagon bridges across the San Joaquin River at the Herndon gaging station.

and rocky, the left, in cases of high water, is subject to overflow, but the river has not left its present channel at this point for the last three years. The bed of the stream is of large gravel and bowlders. On the left bank is a rocky ledge with a face 5 feet high toward the center of the channel. The ledge is at an angle of approximately 15° from the direction of the flow of the stream. The face of the ledge is between station 170 and 175. The soundings show that this gaging station has preserved its section well during the past year. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 92.

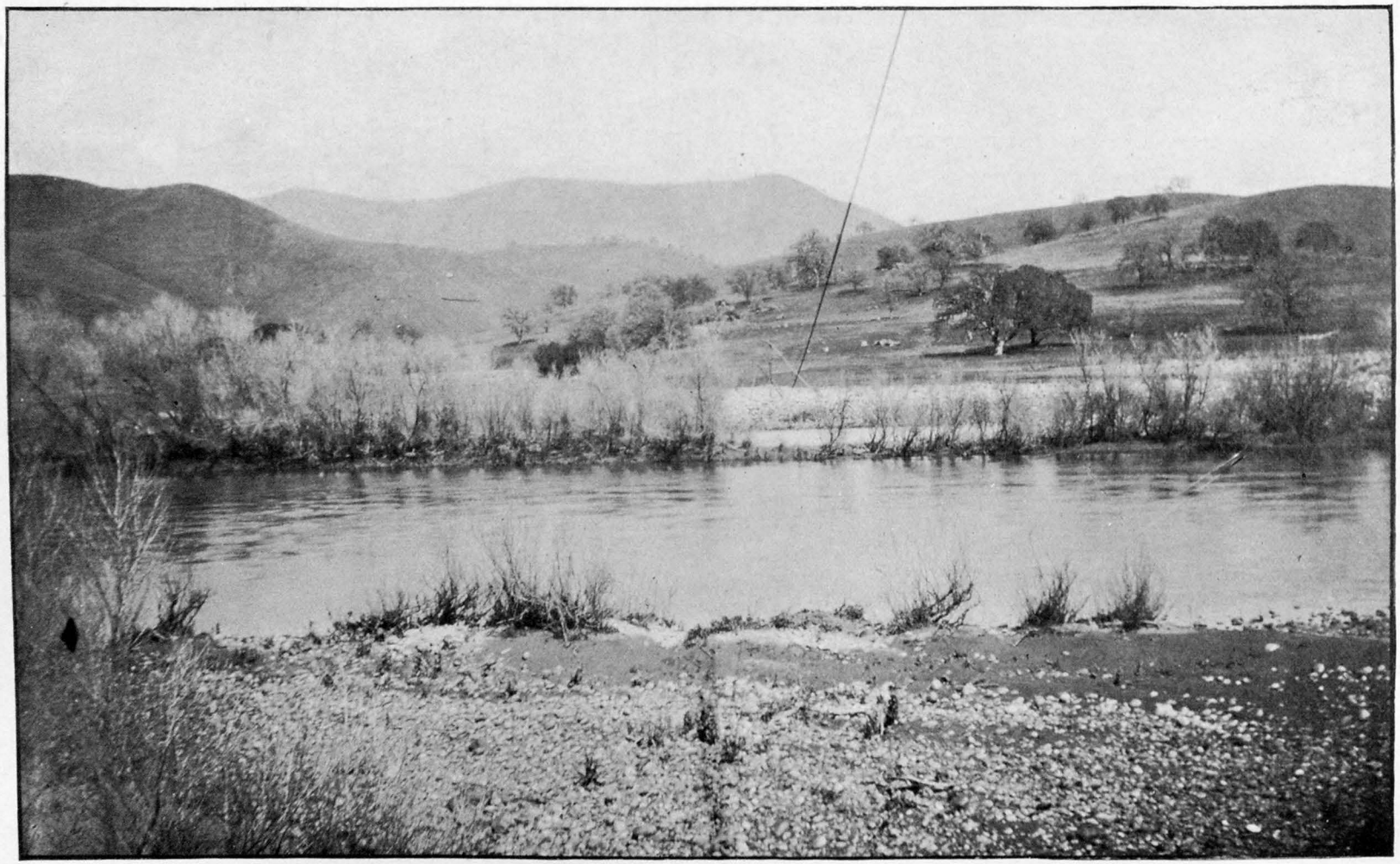
*List of discharge measurements made on Kings River at Red Mountain, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second) | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Sept. 3 | J. B. Lippincott... | ..... | 4.32 | ..... | ..... | *a* 524 |
| 2 | Nov. 24 | .....do ..... | 24 | 3.80 | 351 | 0.71 | 248 |
| | 1896. | | | | | | |
| 3 | Apr. 12 | J. A. Vogleson .... | 63 | 6.35 | 840 | 2.08 | 1,745 |
| 4 | June 12 | J. B. Lippincott... | 63 | 10.85 | 2,409 | 6.62 | *b* 15,941 |
| 5 | Nov. 1 | .....do ..... | 67 | 4.20 | 473 | 0.85 | 404 |

*a* Measured at Suspension bridge. *b* Section partly estimated from previous soundings.

*Rating table for Kings River at Red Mountain, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet* | *Sec feet.* |
| 3.5 | 220 | 5.7 | 1,284 | 7.9 | 4,368 | 10.1 | 12,380 |
| 3.6 | 250 | 5.8 | 1,356 | 8.0 | 4,600 | 10.2 | 12,860 |
| 3.7 | 280 | 5.9 | 1,428 | 8.1 | 4,880 | 10.3 | 13,340 |
| 3.8 | 310 | 6.0 | 1,500 | 8.2 | 5,160 | 10.4 | 13,820 |
| 3.9 | 350 | 6.1 | 1,586 | 8.3 | 5,440 | 10.5 | 14,300 |
| 4.0 | 390 | 6.2 | 1,672 | 8.4 | 5,720 | 10.6 | 14,800 |
| 4.1 | 430 | 6.3 | 1,758 | 8.5 | 6,000 | 10.7 | 15,300 |
| 4.2 | 470 | 6.4 | 1,844 | 8.6 | 6,340 | 10.8 | 15,800 |
| 4.3 | 510 | 6.5 | 1,930 | 8.7 | 6,680 | 10.9 | 16,300 |
| 4.4 | 550 | 6.6 | 2,064 | 8.8 | 7,020 | 11.0 | 16,800 |
| 4.5 | 590 | 6.7 | 2,198 | 8.9 | 7,360 | 11.1 | 17,330 |
| 4.6 | 636 | 6.8 | 2,332 | 9.0 | 7,700 | 11.2 | 17,860 |
| 4.7 | 682 | 6.9 | 2,466 | 9.1 | 8,100 | 11.3 | 18,390 |
| 4.8 | 728 | 7.0 | 2,600 | 9.2 | 8,500 | 11.4 | 18,920 |
| 4.9 | 774 | 7.1 | 2,768 | 9.3 | 8,900 | 11.5 | 19,450 |
| 5.0 | 820 | 7.2 | 2,936 | 9.4 | 9,300 | 11.6 | 19,980 |
| 5.1 | 884 | 7.3 | 3,104 | 9.5 | 9,700 | 11.7 | 20,510 |
| 5.2 | 948 | 7.4 | 3,272 | 9.6 | 10,140 | 11.8 | 21,040 |
| 5.3 | 1,012 | 7.5 | 3,440 | 9.7 | 10,580 | 11.9 | 21,570 |
| 5.4 | 1,076 | 7.6 | 3,672 | 9.8 | 11,020 | 12.0 | 22,100 |
| 5.5 | 1,140 | 7.7 | 3,904 | 9.9 | 11,460 | | |
| 5.6 | 1,212 | 7.8 | 4,136 | 10.0 | 11,900 | | |



RED MOUNTAIN STATION ON KINGS RIVER, CALIFORNIA.

*Estimated discharge of Kings River at Red Mountain, California.*

[Drainage area, 1,742 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | 11,020 | 390 | 1,474 | 90,682 | 0.98 | 0.85 |
| February | 1,140 | 728 | 825 | 47,477 | 0.51 | 0.47 |
| March | 7,020 | 820 | 1,710 | 105,181 | 1.13 | 0.98 |
| April | 4,600 | 820 | 1,938 | 115,349 | 1.24 | 1.11 |
| May | 22,100 | 1,140 | 5,918 | 363,890 | 3.90 | 3.40 |
| June | 18,920 | 5,160 | 12,737 | 757,922 | 8.15 | 7.31 |
| July | 6,680 | 1,212 | 3,742 | 230,110 | 2.48 | 2.15 |
| August | 1,212 | 590 | 795 | 48,938 | 0.52 | 0.45 |
| September | 590 | 390 | 491 | 29,234 | 0.31 | 0.28 |
| October | 510 | 310 | 350 | 21,520 | 0.23 | 0.20 |
| November | 1,076 | 390 | 538 | 32,043 | 0 35 | 0.31 |
| December | 550 | 470 | 466 | 28,659 | 0.31 | 0.27 |
| Per annum | 22,100 | 310 | 2,582 | 1,871,005 | 20.11 | 1.48 |

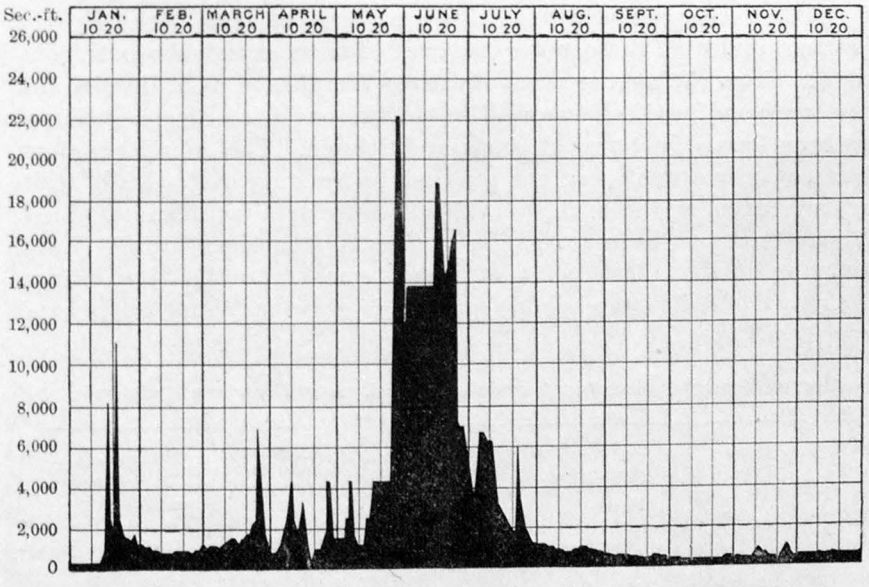



FIG. 74.—Discharge of Kings River at Red Mountain, California, 1896.

## KINGSBURG STATION ON KINGS RIVER.

This station, described in Bulletin No. 131, page 80, and in Bulletin No. 140, pages 284 and 310, also in the Twelfth Annual Report of the United States Geological Survey, Part II, page 320, is at the wagon bridge, 200

feet below the Southern Pacific Railway bridge and approximately 1 mile south of Kingsburg. It was established as early as 1879 by the Southern Pacific Railway Company, which has maintained daily observations of river height ever since. Mr. Alf. Thompson is the observer, and makes two observations daily, one at 9 a. m. and one at 3 p. m. Since April 18, 1896, he has been employed to make weekly soundings of river depths. The gagings are made from the lower side of the wagon bridge, a boat being sometimes used. The velocity is so slow at this station that the meter first used is not adapted to the work, and the results are therefore not as accurate as desired. The gage is the property of the Southern Pacific Railway Company. It is nailed to the south central railroad pier, is a vertical timber spaced to inches, and the zero of the rod is 31.66 feet below the top of the rail of the bridge. The initial point of sounding is on the right bank. The stations are cut in the lower foot rail of the bridge.

The channel of the stream at this station is badly broken by the piers of both bridges. The railroad bridge has two piers, and the highway crossing is a pile bridge. The direction of the flow is oblique to both, and the channel contains shifting sand bars. The right bank is not subject to overflow except in very high water, but the left bank is low. The soundings show the bed of the stream is shifting. The capacity of the canals above this point is far in excess of the normal summer flow, but the lowest discharge measured was 366 second-feet. Since April 18, 1896, weekly soundings of this section have been made by the observer, and from these notes the area of each section has been computed. From the gaging notes the areas are plotted as ordinates and the corresponding discharge as abscissæ, from which a discharge curve has been formed in terms of areas and volume. The soundings show the areas once a week and are referred to the gage rod. Daily readings are taken, and from them a table of daily area will be determined. This method has been used with success by the Kern County Land Company at the "first point of measurement" on the Kern River. The record of daily gage heights for 1896 is given in Water-Supply and Irrigation Paper No. 11, page 92.

*List of discharge measurements made on Kings River at Kingsburg, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Jan. 10 | A. P. Davis ..... | 24 | 6.00 | 1,985 | 0.92 | 1,830 |
| 2 | Mar. 23 | J. B. Lippincott . | 24 | 4.10 | 1,273 | 0.39 | 500 |
| 3 | Dec. 2 | .....do ..... | Floats. | 3.25 | 529 | 0.69 | 356 |
| | 1896. | | | | | | |
| 4 | Apr. 11 | J. A. Vogleson .. | 63 | 5.70 | 2,047 | 0.92 | 1,883 |

*Soundings of Kings River at Kingsburg, California.*

| Date. | Gage height. | Total width. | Area of section. | Date. | Gage height. | Total width. | Area of section. |
|---|---|---|---|---|---|---|---|
| 1896. | *Ft. In.* | *Feet.* | *Sq. ft.* | 1896. | *Ft. In.* | *Feet.* | *Sq. ft.* |
| Apr. 18 | 3 0 | 335 | 1,064 | Aug. 29 | 3 10 | 343 | 1,273 |
| Apr. 25 | 4 9 | 350 | 1,735 | Sept. 5 | 3 8 | 342 | 1,178 |
| May 2 | 4 3 | 343 | 1,287 | Sept. 12 | 3 9 | 334 | 1,295 |
| May 9 | 4 6 | 349 | 1,417 | Sept. 19 | 3 6 | 340 | 1,219 |
| May 16 | 6 5 | 413 | 2,152 | Sept. 26 | 3 6 | 350 | 1,159 |
| May 23 | 6 1 | 408 | 2,001 | Oct. 3 | 4 6 | 361 | 1,574 |
| May 30 | 10 1 | 511 | 3,959 | Oct. 10 | 4 6 | 365 | 1,611 |
| June 6 | 9 6 | 462 | 3,794 | Oct. 17 | 4 4 | 356 | 1,512 |
| June 13 | 10 6 | 465 | 4,094 | Oct. 24 | 3 1 | 317 | 1,086 |
| June 20 | 8 8 | 447 | 3,323 | Oct. 31 | 4 5 | 358 | 1,539 |
| June 27 | 6 8 | 442 | 2,513 | Nov. 7 | 3 9 | 344 | 1,311 |
| July 4 | 6 0 | 434 | 2,002 | Nov. 14 | 4 3 | 357 | 1,490 |
| July 11 | 6 8 | 442 | 2,412 | Nov. 21 | 3 8 | 363 | 1,179 |
| July 18 | 5 7 | 418 | 1,945 | Nov. 28 | 4 7 | 357 | 1,666 |
| July 25 | 5 7 | 398 | 1,922 | Dec. 5 | 4 6 | 358 | 1,643 |
| Aug. 1 | 3 6 | 341 | 1,180 | Dec. 12 | 4 5 | 360 | 1,567 |
| Aug. 8 | 3 2 | 338 | 1,154 | Dec. 19 | 4 0 | 343 | 1,359 |
| Aug. 15 | 3 10 | 343 | 1,309 | Dec. 26 | 3 10 | 346 | 1,366 |
| Aug. 22 | 3 10 | 343 | 1,288 | | | | |

## KERN RIVER.

This river is described in the Twelfth Annual Report of the United States Geological Survey, Part II, Irrigation, page 319, and Plate XIII; in Bulletin No. 131, page 79, and in Bulletin No. 140, pages 267 and 311. The gaging station is 7 miles northeast of the town of Bakersfield and about 12 miles below the mouth of the canyon at a place called the "first point of measurement." It was originally established in 1893 by the Kern County Land Company, Walter James being chief engineer and A. K. Warren hydrographer. The observations are maintained by the land company and the results are furnished to this Survey. During the past year this station has been watched with even greater care than during the preceding year. An automatic gage designed by Mr. A. K. Warren has been established, and the heights recorded by it are corrected from daily observations taken from five gage rods on the two sides and in the middle of the stream. There is at times as much as 0.25 of a foot difference in the height of the surface of the water on the different gages.

The measurement of discharge is from a foot walk crossing the stream, as described in Bulletin No. 140, on page 269. From numerous measurements the relation of velocity to hydraulic mean-radius is

determined. As the stream is approximately 325 feet wide and but a few feet deep the hydraulic radius and depth are practically the same. From the gage heights the daily hydraulic mean radii are obtained, and from the rating curves or tables the velocities are determined. Areas are determined as previously described, and from known areas and velocities quantities are found. The right bank of the stream is subject to infrequent overflow, but the left bank is not. The bed of the stream is sandy and shifting and it is also gradually rising.

During the past year the power and development company has constructed 2 miles of flume in the canyon of the Kern River. Their diversion is 2 miles above the mouth of the canyon. The flume has a capacity of 240 second-feet and reaches the mouth of the canyon 200 feet above the high-water mark. The water is then dropped through a 62-inch steel pipe and delivered through nozzles to a battery of Girard wheels. By continuing the pipe a quarter of a mile farther down the stream an additional head of 75 feet may be obtained. The water wheels are directly coupled to general electric triphase dynamos. The current is stepped up to a pressure of 10,000 volts delivered 13 miles distant in Bakersfield, where it is stepped down to 500 volts. It is proposed to use this power in Bakersfield for general commercial purposes.

*Rainfall in 1896 at Daunt and Kernville, (a) Kern County, California.*

| Month. | Kernville. | Daunt. |
|---|---|---|
| January | 3.52 | 11.91 |
| February | 0.00 | 0.83 |
| March | 1.54 | 5.13 |
| April | 0.86 | 11.01 |
| May | 0.00 | 1.30 |
| June | 0.20 | 2.76 |
| July | 2.25 | 0.65 |
| August | 0.05 | 0.50 |
| September | 0.00 | 0.00 |
| October | 1.15 | 0.60 |
| November | 0.41 | 0.40 |
| December | 0.85 | 1.95 |
| Year | 10.83 | 36.98 |

*a* Kernville is located at an elevation of 2,600 feet above sea near the junction of the two main forks of the Kern River. The rain gage at Daunt is at the Mountain Home sawmill, near the divide between the Kern and the Kawea rivers, at an elevation of 6,600 feet. Another rain gage is located on Mount Breckenridge, in the basin of the Kern.

*Estimated discharge of Kern River at first point of measurement.*

[Drainage area, 2,345 square miles. Authority, Kern County Land and Water Company.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 1,616 | 473 | 809 | 49,762 | 0.40 | 0.34 |
| February | 4,762 | 675 | 1,252 | 69,536 | 0.55 | 0.53 |
| March | 3,004 | 987 | 1,374 | 84,437 | 0.67 | 0.59 |
| April | 3,897 | 1,911 | 2,724 | 162,076 | 1.29 | 1.16 |
| May | 5,384 | 3,100 | 4,369 | 268,608 | 2.14 | 1.86 |
| June | 3,721 | 2,174 | 2,906 | 172,919 | 1.37 | 1.24 |
| July | 2,063 | 867 | 1,482 | 91,113 | 0.73 | 0.63 |
| August | 1,073 | 354 | 629 | 38,665 | 0.31 | 0.27 |
| September | 676 | 290 | 344 | 20,469 | 0.17 | 0.15 |
| October | 612 | 276 | 327 | 20,106 | 0.16 | 0.14 |
| November | 436 | 308 | 346 | 20,588 | 0.17 | 0.15 |
| December | 447 | 368 | 403 | 24,779 | 0.20 | 0.17 |
| Per annum | 5,384 | 276 | 1,413 | 1,023,058 | 8.16 | 0.60 |
| 1896. | | | | | | |
| January | 3,101 | 377 | 747 | 45,931 | 0.37 | 0.32 |
| February | 798 | 559 | 617 | 35,489 | 0.28 | 0.26 |
| March | 2,089 | 652 | 951 | 58,475 | 0.47 | 0.41 |
| April | 1,262 | 766 | 972 | 57,838 | 0.47 | 0.42 |
| May | 3,370 | 934 | 1,401 | 86,144 | 0.69 | 0.60 |
| June | 3,611 | 1,244 | 2,456 | 146,142 | 1.18 | 1.06 |
| July | 2,210 | 741 | 1,346 | 82,762 | 0.66 | 0.57 |
| August | 741 | 353 | 486 | 29,883 | 0.24 | 0.21 |

## SMALL LOST CREEKS IN SOUTHERN CALIFORNIA.

### SAN EMIDIO RANCH HOUSE STATION ON SAN EMIDIO CREEK.

This gaging station is referred to in United States Geological Survey Bulletin No. 140, page 258. The measurements are made at the San Emidio ranch house, which is approximately 30 miles southwest from Bakersfield. It is at the northeast foot of the McGill Mountain, whose elevation is 9,214 feet. The station is visited from Bakersfield. It was established September 1, 1894, by the Kern County Land Company, Mr. Walter James chief engineer and Mr. A. K. Warren hydrographer. The stream is of the small and spasmodic class. The normal flow is but a few second-feet, but floods carrying bowlders and mud may occur at any period of the year. The fact that there is such a range in volume

and that so much silt and sediment are carried renders weir measurements difficult. A rectangular flume, 25 feet long, on a level grade, was placed in the bed of the creek and this was rated. The tendency of the stream was to fill this flume with silt. The grade of the stream was then determined, and the flume was replaced on the stream grade, and in this condition it has scoured itself. A vertical rod in the flume serves as a gage.

The drainage basin rises from an elevation at the ranch house of approximately 1,000 feet to 9,214 at the summit of the McGill peak. The mean elevation of the basin is probably between 3,500 and 4,000 feet and its area is 54 square miles as indicated by the map of Lieut. George M. Wheeler, Corps of United States Engineers. It lies on the northwest side of the Coast Range, but probably, like the Tejon Creek,

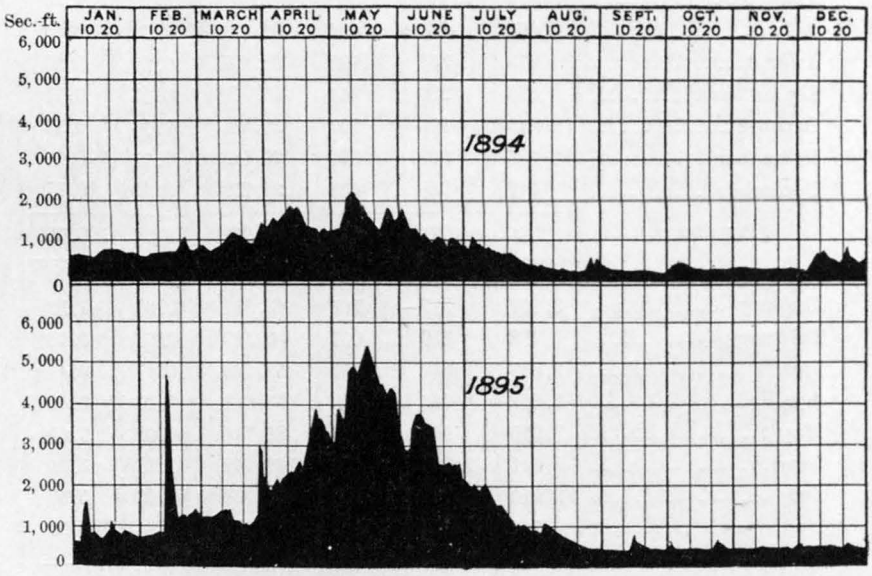



FIG. 75.—Discharge of Kern River, California, at "first point of measurement" of Kern County Land Company, 1894–95.

receives many of its rain storms from the northwest. The storms from the southwest, however, would have to pass over the crest of the range before reaching this basin. The stream is locally considered as having proportionally a high rate of run-off. San Emidio ranch house (Rose Station), and the Tejon ranch house are approximately at the same elevation and location.

The rainfall at the Tejon ranch house is 11.5 inches, at Rose Station approximately 10 inches, and at the San Emidio ranch house will probably average 11 inches. Fort Tejon lies but 8 miles east of the center of the San Emidio Basin, has an elevation of 3,245 feet, and has much the same topographic location. With the Fort Tejon record in view, the mean rainfall of the San Emidio Basin is estimated at 20

inches. The rainfall at Fort Tejon since February, 1895, has been as follows:

| 1895. | Inches. | 1896. | Inches |
|---|---|---|---|
| February | 3.08 | January | 3.07 |
| March | 2.14 | February | 0.40 |
| April | 1.44 | March | 4.01 |
| May | 1.31 | April | 3.33 |
| June | 0.00 | May | 2.05 |
| July | 0.00 | June | 0.22 |
| August | 0.00 | July | 0.26 |
| September | 0.00 | August | 0.30 |
| October | 1.42 | September | 0.53 |
| November | 1.42 | October | 1.63 |
| December | 1.25 | November | 1.74 |
| | | December | 1.14 |

*Estimated discharge of San Emidio Creek at San Emidio ranch house, California.*

[Drainage area, 54 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1894. | | | | | | |
| September | 2.0 | 1.6 | 1.8 | 107 | 0.035 | 0.033 |
| October | 2.3 | 1.5 | 1.7 | 105 | 0.036 | 0.031 |
| November | 1.5 | 1.5 | 1.5 | 89 | 0.031 | 0.028 |
| December | 38.2 | 1.5 | 4.7 | 289 | 0.100 | 0.087 |
| 1895. | | | | | | |
| January | 97.0 | 1.8 | 8.4 | 516 | 0.170 | 0.155 |
| February | 60.0 | 2.0 | 4.6 | 255 | 0.090 | 0.085 |
| March | 20.3 | 2.4 | 3.7 | 228 | 0.080 | 0.070 |
| April | 60.0 | 1.8 | 3.9 | 232 | 0.080 | 0.072 |
| May | 3.7 | 1.8 | 2 4 | 148 | 0.050 | 0.044 |
| June | 3.6 | 1.8 | 2.4 | 143 | 0.050 | 0.044 |
| July | 2.6 | 1.8 | 2.2 | 135 | 0.040 | 0.041 |
| August | 2.6 | 2.0 | 2.2 | 135 | 0.040 | 0.041 |
| September | 2.2 | 2.0 | 2.1 | 125 | 0.040 | 0.039 |
| October | 9.7 | 2.0 | 2.3 | 141 | 0.040 | 0.042 |
| November | 7.0 | 2.2 | 3.0 | 179 | 0.060 | 0.055 |
| December | 4.7 | 2.8 | 3.3 | 203 | 0.070 | 0.061 |
| Year | 97.0 | 1.8 | 3.4 | 2,440 | 0.810 | 0.063 |

TEJON RANCH HOUSE STATION ON TEJON HOUSE CREEK.

This creek and gaging station are described in United States Geological Survey Bulletin No. 140, page 260. The station is 30 miles southeast from Bakersfield, California, and can be best reached from that town. It was established January 1, 1895, by Mr. J. B. Lippincott. Mr. R. M. Pogson, voluntary observer at this station, is the agent for the Beale estate, and resides at the ranch house. Observations are taken at least once a week and upon each radical change of volume of the creek. The results of readings for the year 1896 are on file up to the month of June. Mr. Pogson states that during the months of October, November, and December the creek maintained a constant flow, that it has not been in flood, and that the record for that period will not materially differ from the discharge of December 19, 1896, when the stream was last visited.

As the bed of the creek rises and falls with each freshet and its following low-water stage, instead of placing a permanent rod in the creek, a hand rod is used, and the depth of the water is measured at the 5-foot mark on the bridge, the record reading "From bridge to bed" and "From bridge to water surface." During 1896 the measurements have been made with Price acoustic meter No. 12. While the channel of this stream is not subject to violent change, yet the fact that the area of the stream section is so small makes these changes in section relatively large and destroys the accuracy of the rating curves. The observations during the past year are thus disturbed, and the rating curve which applies from November 1, 1895, to July 1, 1896, does not apply to December, 1896. The discharge given for October, November, and December, 1896, is estimated from the measurement of December 19, 1896, and the statement of Mr. Pogson that during that period the stream has maintained a constant flow.

The rainfall at the Tejon ranch house (elevation 1,350 feet) from September 1, 1895, to January 1, 1897, is as follows: *a*

| 1895. | Inches. |
|---|---|
| September | 0.00 |
| October | 2.13 |
| November | 1.41 |
| December | 1.06 |
| 1896. | |
| January | 1.90 |
| February | 0.37 |
| March | 4.22 |
| April | 1.62 |
| May | 0.48 |
| June | 0.00 |
| July | 0.00 |
| August | 0.00 |
| September | 0.00 |
| October | 1.34 |
| November | 2.12 |
| December | 2.32 |

The past season's rainfall at Fort Tejon is given under the description of the San Emidio Station.

*a* For record from September, 1879, to September, 1895, see U. S. G. S. Bulletin No. 140, p. 257.

*List of discharge measurements made on the Tejon House Creek, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Nov. 19 | J. B. Lippincott. | H. 24 | 0.45 | 1.86 | 1.86 | 3.46 |
| | 1896. | | | | | | |
| 2 | Feb. 1 | J. B. Lippincott. | H. 24 | 0.70 | 3.75 | 2.09 | 7.82 |
| 3 | Feb. 2 | .....do ..... | H. 24 | 1.10 | 7.10 | 2.57 | 18.30 |
| 4 | June 4 | .....do ..... | 12 | 0.50 | 2.90 | 2.11 | *a* 6.09 |
| 5 | June 5 | .....do ..... | 12 | 0.60 | 3.62 | 2.29 | *b* 8.31 |
| 6 | Dec. 19 | .....do ..... | 12 | 0.54 | 2.08 | 1.28 | 2.70 |

*a* 6 p. m. *b* 5 a. m.

*Rating table for Tejon House Creek at ranch house, California.*

[To apply from November 1, 1895, to July 1, 1896.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.0 | 0.0 | 0.6 | 6.9 | 1.1 | 18.3 | 1.6 | 33.0 |
| 0.1 | 0.4 | 0.7 | 8.8 | 1.2 | 21.0 | 1.7 | 36.6 |
| 0.2 | 1.2 | 0.8 | 10.9 | 1.3 | 24.0 | 1.8 | 39.9 |
| 0.3 | 2.3 | 0.9 | 13.1 | 1.4 | 27.0 | 1.9 | 43.5 |
| 0.4 | 3.5 | 1.0 | 15.6 | 1.5 | 30.0 | 2.0 | 47.0 |
| 0.5 | 5.0 | | | | | | |

*Estimated discharge of Tejon House Creek at Tejon ranch house, Kern County, California.*

[Drainage area, 17 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| January | 93.0 | 5.0 | 13.6 | 835 | 0.77 | 0.80 |
| February | 44.0 | 7.0 | 26.1 | 1,453 | 1.33 | 1.53 |
| March | 33.0 | 11.0 | 19.0 | 1,169 | 1.07 | 1.11 |
| April | 49.0 | 16.3 | 24.7 | 1,473 | 1.35 | 1.45 |
| May | 34.0 | 9.0 | 18.3 | 1,127 | 1.04 | 1.08 |
| June | 8.0 | 3.1 | 5.2 | 312 | 0.29 | 0.30 |
| July | 3.0 | 1.2 | 2.0 | 126 | 0.11 | 0.12 |
| August | 1.5 | 1.2 | 1.3 | 77 | 0.07 | 0.08 |
| September | 1.6 | 1.6 | 1.6 | 95 | 0.09 | 0.09 |

*Estimated discharge of Tejon House Creek at Tejon ranch house, Kern County, California*—Continued.

[Drainage area, 17 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1895. | | | | | | |
| October | 4.0 | 2.0 | 2.7 | 163 | 0.15 | 0.16 |
| November | 5.0 | 3.5 | 3.9 | 232 | 0.26 | 0.23 |
| December | 6.9 | 5.0 | 5.5 | 338 | 0.37 | 0.32 |
| Per annum | 93.0 | 1.2 | 10.3 | 7,400 | 6.90 | 0.61 |
| 1896. | | | | | | |
| January | 13.1 | 5.0 | 5.6 | 344 | 0.37 | 0.32 |
| February | 12.0 | 3.5 | 6.4 | 368 | 0.40 | 0.38 |
| March | 13.1 | 6.0 | 10.8 | 664 | 0.75 | 0.65 |
| April | 18.3 | 6.0 | 11.3 | 672 | 0.73 | 0.66 |
| May | 15.6 | 7.0 | 11.9 | 732 | 0.79 | 0.69 |
| June | 6.9 | 5.0 | 5.4 | 321 | 0.36 | 0.32 |
| July | ..... | ..... | ..... | ..... | ..... | ..... |
| August | ..... | ..... | ..... | ..... | ..... | ..... |
| September | ..... | ..... | ..... | ..... | ..... | ..... |
| October | 2.7 | 2.7 | 2.7 | 166 | 0.18 | 0.16 |
| November | 2.7 | 2.7 | 2.7 | 161 | 0.18 | 0.16 |
| December | ..... | ..... | ..... | ..... | ..... | ..... |

Rod observations by Mr. R. M. Pogson were made about once a week or when a large change occurred in the volume of water. The discharge for intermediate dates is estimated. There is no record from July 1 to September 30, 1896. Change in channel prevents application of old rating curve to December, 1896.

## PALMDALE STATION ON LITTLE ROCK CREEK.

This station is located about 8 miles southeast of West Palmdale, a railway station on the Southern Pacific, at the headworks of the South Antelope Valley Canal, at an elevation of approximately 3,000 feet. It was established by Mr. J. B. Lippincott, April 20, 1896. The observer, Mr. Burt Cole, the engineer for the canal company, lives at Palmdale, but is at the head works frequently, and takes observations when there. From June 1 to November 1 the creek varies but little, and occasional observations give all the information that is essential during that period. During the flood stages of the creek a zanjero will take daily observations. The creek is diverted through a tunnel into a flume at the head works, and this flume at the normal stage of the stream will carry all of the water. A gage has been placed in this flume, and it has been rated as nearly as the conditions of a dry year will permit.

At high flood stage a second gaging will be made from the bridge where the flume crosses the creek, one-half mile below the head works, and a gage rod will be placed there for that station. The datum of the canal is used as a reference for the rods.

The channel of the stream is crooked and the bed is full of bowlders. The flume is straight. The banks of the stream are high, and it will not leave its present channel at the bridge. The drainage basin contains 78 square miles, as indicated by the Wheeler maps. This point is well up in the mountains, and there are no diversions above it. The purpose of the canal is to divert the winter storm-waters into a dry lake bed where they will be held for the following summer. The spring and summer waters are now all appropriated and used.

It will be of interest to compare the record of this stream with that of the San Gabriel, which is directly on the opposite side of the Sierra Madre range of mountains. The rainfall and run-off is markedly less, possibly not more than one-half of the mean for the San Gabriel Basin, while the catchment areas of both streams have approximately the same altitude.

On August 16, 1896, there was a cloud burst at Harold Station, in the basin of the Santa Clara, which is the next west of the Little Rock Basin, in which 5 inches of rain fell in 2 hours; and on August 17, at the same place, it is stated that 7 inches fell in 1½ hours. The figures for January, February, and March are estimated from personal observation and from notes kept by Mr. Cole. When observations have not been taken during other months, Mr. Cole has estimated the discharge, the creek being low.

A short distance below the gaging station the stream bed, during the summer, is entirely dry. This was the condition June 2, 1896, when the following measurements were made, notwithstanding the fact that the South Antelope Valley Canal was returning all water to the original channel to satisfy appropriations below. This dry condition is maintained until the channel reaches a bed of clay about 5 miles down the stream. This clay, which is found where an earthquake fault crosses the creek, is blue and of tough, tenacious nature. The fault extends nearly 100 miles, from the Tejon toward the Cajon Pass, and the same clay is repeatedly in evidence along the line of it, which is very straight and accompanied usually by peculiar springs and cienegas. The clay bank crosses the canyon almost at right angles. The small channel in which the water of the creek flows crosses the canyon above and almost parallel with the clay bank.

On the left bank there is a projecting rocky point; on the right bank there is a red clay and gravel formation. In the channel, at depths below the surface ranging from 4 feet at the left bank to 8 feet at the right bank, the blue clay is found. Over this clay is a deposit of coarse sand, gravel, and bowlders, such as are found in mountain canyons in this region. A flume that is 2 feet by 2 feet is laid on the top of this clay bed. Every 8 inches on the upstream face and on the top a longitudinal opening is left 2 inches in width. The bottom and downstream sides are tight. The bottom of the box is at a depth of 6 feet

below the surface of the gravel. At a point 5 miles above, on June 2, 1896, there was flowing 1.04 second-feet. For nearly all of the intervening distance the stream bed was dry. One hundred yards above the clay bank the water began to rise. The water surface in its channel near the bank is somewhat below the general surface of the gravel over the box flume, so that, all things being considered, the bottom of the box is taken as 4.5 feet below the plane of saturation. The length of the box is 360 feet, and the exposed face is taken as 1,600 square feet. The surface flow is diverted, and on this date measured 1.05 second-feet; below the box the stream bed was dry and remained so. The flume box was measured and found to be flowing 0.95 second-foot. This is the amount of developed water. It will be noted that the plane of saturation is above the top of the box flume, or that there is a head over the box. With the area of 1,600 square feet and a discharge of 0.95 second-foot a velocity of percolation of 0.0006 foot per second or of 3.58 miles per year is found.

*List of discharge measurements made on Little Rock Creek near Palmdale, California.*

| Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|
| 1896. | | | | | | |
| April 20 | J. A. Vogelson..... | 63 | 0.40 | 2.83 | 1.98 | *a* 5.61 |
| April 20 | .....do ..... | 63 | 10.33 | 11.2 | 0.639 | *b* 7.16 |
| June 2 | J. B. Lippincott..... | 12 | 0.17 | 1.18 | 0.87 | *a* 1.03 |
| June 2 | .....do ..... | 12 | 10.10 | 1.18 | 0 87 | *b* 1.03 |
| July 7 | Burt Cole ..... | Floats | ..... | ..... | ..... | .26 |

*a* In flume. *b* In creek above head works.

*Rating table for Little Rock Creek flume near West Palmdale, California.*

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.0 | 0.0 | 1.3 | 40.1 | 2.6 | 108.9 | 3.9 | 187.8 |
| 0.1 | 0.5 | 1.4 | 44.5 | 2.7 | 114.8 | 4.0 | 193.8 |
| 0.2 | 1.9 | 1.5 | 49.0 | 2.8 | 120.7 | 4.1 | 200.0 |
| 0.3 | 3.9 | 1.6 | 54.2 | 2.9 | 126.7 | 4.2 | 206.2 |
| 0.4 | 6.1 | 1.7 | 59.4 | 3.0 | 132.7 | 4.3 | 212.3 |
| 0.5 | 8.8 | 1.8 | 64.6 | 3.1 | 138.8 | 4.4 | 218.5 |
| 0.6 | 12.1 | 1.9 | 69.8 | 3.2 | 144.9 | 4.5 | 223.6 |
| 0.7 | 15.3 | 2.0 | 74.9 | 3.3 | 151.0 | 4.6 | 230.2 |
| 0.8 | 18.6 | 2.1 | 80.5 | 3.4 | 157.2 | 4.7 | 236.8 |
| 0.9 | 22.8 | 2.2 | 86.1 | 3.5 | 163.4 | 4.8 | 243.3 |
| 1.0 | 26.7 | 2.3 | 81.7 | 3.6 | 169.5 | 4.9 | 249.9 |
| 1.1 | 31.2 | 2.4 | 87.3 | 3.7 | 175.6 | 5.0 | 256.5 |
| 1.2 | 35.6 | 2.5 | 103.0 | 3.8 | 181.7 | | |

*Estimated discharge of Little Rock Creek near West Palmdale, California.*

[Drainage area, 78 square miles.]

| Month. | Discharge in second-feet. | | | Total in acre-feet. | Run-off. | |
|---|---|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | | Depth in inches. | Second-feet per square mile. |
| 1896. | | | | | | |
| January | ..... | ..... | 18.6 | 1,144 | 0.274 | 0.238 |
| February | ..... | ..... | 18.6 | 1,070 | 0.257 | 0.238 |
| March | ..... | ..... | 54.2 | 3,332 | 0.810 | 0.700 |
| April | ..... | ..... | 7.9 | 470 | 0.113 | 0.101 |
| May | ..... | ..... | 1.8 | 110 | 0.026 | 0.023 |
| June | 1.0 | 0.2 | 5.4 | 321 | 0.077 | 0.069 |
| July | 0.3 | 0.2 | 0.2 | 12 | 0.002 | 0.002 |
| August | 0.2 | 0 2 | 0.2 | 12 | 0.002 | 0.002 |
| September | 0.5 | 0.5 | 0.5 | 30 | 0.008 | 0 007 |
| October | 10.4 | 0.3 | 1 0 | 61 | 0.015 | 0.013 |
| November | 3.9 | 0.5 | 1.5 | 89 | 0.022 | 0.020 |
| December | 11.5 | 1.9 | 3.8 | 234 | 0.054 | 0.047 |
| Per annum | 11.5 | 0.2 | 9.6 | 6,885 | 1.660 | 0.122 |

## SOUTH PACIFIC COAST WATERSHED.

### AZUSA STATION ON SAN GABRIEL RIVER.

This station is described in United States Geological Survey Bulletin No. 140, page 317. Owing to the numerous divisions of the water and the various "developments" in the stream bed it is difficult to obtain a complete record of the San Gabriel River. Unfortunately for the hydrographer, this condition is general with the streams of southern California. Because of the scarcity of water supply as compared with irrigable land areas, and the consequent value of the water, great care has been exercised to prevent loss in its delivery.

The Azusa and Duarte irrigators, in order to prevent loss by percolation and evaporation in the sands and bowlders of the canyon, have constructed a series of tunnels and pipe lines from the mouth of the main canyon, which is 2 miles from Azusa, to a point 3 miles up the stream. The head of the last tunnel is on bedrock about 30 feet below the bed of the stream. The water of the stream is dropped through a shaft into this tunnel and thence carried through various conduits to a division box consisting of weirs, where it is distributed. Seven-tenths of the water goes to Azusa and the remaining three-tenths to Duarte. The Azusa water is carried from this place in a lined canal a distance of approximately 3 miles to a second division box, known as the "Ice House Weir."

The Vinland irrigation district claims the right to develop water in the mouth of the San Gabriel Canyon. In the prosecution of this

work they have run approximately 4,000 feet of tunnel, mostly in the sand and bowlder wash of the canyon, one spur of the tunnel extending within 175 feet of the river. The heading of the Vinland tunnel is about 2 miles below the heading of the upper tunnel of the Azusa-Duarte people, and the portal of the Vinland tunnel is near the first division box above referred to. When the Azusa-Duarte people turn their water down the shaft into the head of their upper tunnel the Vinland "developed" water at once begins to diminish. Thus on July 15, 1896, water was turned into the upper tunnel. On this date the Vinland "development" tunnel was discharging 1.15 second-feet. On August 7, 1896, the Vinland tunnel was entirely dry and remained so during the season. On October 27, 1896, a storm and a small flood that carried considerable silt occurred. This silt was in part deposited in the channel of the river. Water no longer being scarce, the Azusa-Duarte people turned the water back into its old channel, but in January, 1897, it had not begun to "develop" in the Vinland tunnel. Pending the final adjudication of the conflicting claims to the water of this river, the court ordered Azusa-Duarte to deliver to Vinland from the first division box above referred to an amount of water equal to the normal flow of the "development" tunnel. This was done by making a new gate in the division box. A decision was rendered in favor of the Azusa-Duarte people about August 15, 1897, and the Vinland people no longer use the tunnel nor receive water from the Azusa Duarte people.

The numerous weirs that have been placed in this stream have been subject to so many abnormal conditions that a comparison of amounts of flow at various points on the stream is not feasible. The "Ice House Weir," approximately 1 mile northeast of the town of Azusa, was the one chosen upon which to keep the record for the United States Geological Survey. Mr. H. F. Parkinson, the observer, has been appointed by those interested in the division of this water to allot it in accordance with contracts and the orders of the court. While the measurements have been made at the "Ice House Weir," all other waters previously diverted into other canals have been considered by him, and the total amount diverted given in the table of canal discharge. It is known that the "Ice House Weir" is not perfect. The head on the weir ranges from 0.5 foot to 1.5 feet, while the iron knife edge is set in the center of the top of a square concrete wall and projects above the wall only 3 inches. The side contractions are also incomplete. This weir was selected because it was the most feasible and accurate point of measurement. Mr. Parkinson's connection with the division of the water is discontinued at the opening of the rainy season. From these weir measurements the flume above the division box has been rated, and during the remainder of the year rod observations have been made on this flume by Mr. R. M. Follows, who passes up and down the canyon two or three times a week on his work.

During the greater portion of the year all the water of the San Gabriel River is diverted into canals, but there are times during the winter sea-

son when there is water flowing past the diversion points. To measure this water a gage rod has been placed in the bed of the river at a point near the first division box. A few hundred feet above is a car cable and tag wire for measuring floods. Mr. R. M. Follows observes also on this rod. The bench mark to which both rods are referenced is an X in the wooden sill at the head of the lowest Azusa tunnel. It is 7.97 feet above the zero of the new rod. The new datum of the river rod is 0.1 foot above its old datum. In consequence two rating curves are given for the river during the year 1896. The zero of the rod in the first division box is on the bottom of the flume. Both gages are vertical sticks, painted white, with divisions of one-tenth of a foot. The channel of the river for 200 feet above and below the cable is straight. The banks are not liable to overflow. The bed of the stream is full of bowlders that are embedded in sand. During the past year there has not been any radical change in the bed of the stream. On October 10, 1896, the gage rod, which had been set in the left bank of the stream, was moved to the right bank to avoid a sand bar that had formed in the front of it. The bed of the stream in the flume is somewhat shifting, as sand is deposited and flushed out.

The drainage basin of this stream has been described in Bulletin No. 140. It is 222 square miles in area and varies in elevation from 800 feet at the mouth of the canyon to 9,931 feet at the summit of San Antonio and 6,232 feet on the San Gabriel peak. The basin is rough and well covered with brush and timber. A rain gage was established at Follows Camp at an elevation of 1,800 feet and 2 miles east of the junction of the two forks of the river.

The record at this point and at Los Angeles is shown in the following table, and also the mean monthly precipitation at Los Angeles from July, 1877, to March, 1895:

*Monthly rainfall at Follows Camp and at Los Angeles.*

| Month. | Follows Camp (1896). *a* | Los Angeles. | |
|---|---|---|---|
| | | 1896. | Monthly mean. |
| January | 2.77 | 3.23 | 2.88 |
| February | Trace. | Trace. | 3.27 |
| March | 6.55 | 2.97 | 2.98 |
| April | 0.70 | 0.19 | 1.42 |
| May | 0.36 | 0.30 | 0.45 |
| June | 0.00 | Trace. | 0.11 |
| July | 0.00 | 0.02 | 0.02 |
| August | 1.10 | 0.01 | 0.05 |
| September | Trace. | Trace. | 0.06 |
| October | 2.95 | 1.30 | 0.76 |
| November | 1.03 | 1.66 | 1.40 |
| December | 1.61 | 2.12 | 4.15 |
| Year | 16.77 | 11.80 | 17.56 |

*a* The precipitation at Follows Camp for December, 1895, was 1.02 inches.

*List of discharge measurements made on San Gabriel River, near Azusa, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1895. | | | | | | |
| 1 | Nov. 5 | J. B. Lippincott. | H. 24 | 1.50 | ..... | ..... | 10.65 |
| | 1896. | | | | | | |
| 2 | Feb. 19 | J. B. Lippincott. | H. 24 | 1.35 | 4.60 | 1.06 | 4.86 |
| 3 | Feb. 19 | .....do ..... | H. 24 | 0.65 | ..... | ..... | 0.00 |
| 4 | Mar. 22 | .....do ..... | 63 | 2.27 | 29.82 | 2.34 | 69.91 |
| 5 | Jan. 10 | .....do ..... | ..... | 0.85 | ..... | ..... | 0.10 |
| 6 | Jan. 10 | .....do ..... | ..... | 1.28 | ..... | ..... | 4.50 |
| 7 | Oct. 27 | .....do ..... | ..... | 2.80 | 41.4 | ..... | ..... |

*Rating table for San Gabriel River, California.*

[November 5, 1895, to October 10, 1896 ]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 0.7 | 0.0 | 1.2 | 2.3 | 1.7 | 16.0 | 2.2 | 59.0 |
| 0.8 | 0.1 | 1.3 | 4.0 | 1.8 | 21.2 | 2.3 | 75.0 |
| 0.9 | 0.3 | 1.4 | 6.0 | 1.9 | 27.5 | 2.4 | 94.0 |
| 1.0 | 0.5 | 1.5 | 8.8 | 2.0 | 36.0 | 2.5 | 109.0 |
| 1.1 | 1.3 | 1.6 | 12.0 | 2.1 | 46.0 | 2.6 | 134.0 |

[October 10, 1896, to January 1, 1897.]

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.6 | 0.0 | 1.2 | 4.0 | 1.8 | 27.5 | 2.4 | 104.0 |
| 0.7 | 0.1 | 1.3 | 6.0 | 1.9 | 36.0 | 2.5 | 126.0 |
| 0.8 | 0.3 | 1.4 | 8.8 | 2.0 | 46.0 | 2.6 | 142.0 |
| 0.9 | 0.5 | 1.5 | 12.0 | 2.1 | 59.0 | 2.7 | 159.0 |
| 1.0 | 1.3 | 1.6 | 16.0 | 2.2 | 75.0 | 2.8 | 177.0 |
| 1.1 | 2.3 | 1.7 | 21.2 | 2.3 | 94.0 | | |

*Rating table for flume above division box, San Gabriel River.*

[To apply subsequent to Vineland opening in box.]

| Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* | *Feet.* | *Sec. feet.* |
| 1.5 | 1.9 | 1.9 | 13.3 | 2.3 | 27.0 | 2.7 | 42.0 |
| 1.6 | 4.6 | 2.0 | 16.5 | 2.4 | 30.6 | 2.8 | 46.0 |
| 1.7 | 7.4 | 2.1 | 20.0 | 2. | 34.3 | 2.9 | 50.0 |
| 1.8 | 10.3 | 2.2 | 23.5 | 2.6 | 38.1 | 3.0 | 54.0 |

*Estimated daily discharge of the San Gabriel River, near Azusa, California, for 1896, in second-feet.*

| Day. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10.3 | *26.2* | *2.7* | 46.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | *0.5* |
| 2 | *9.8* | 27.5 | 2.3 | 35.8 | .0 | .0 | .0 | .0 | .0 | .0 | 4.0 | *.5* |
| 3 | *9.3* | *26.0* | 36.0 | 27.5 | .0 | .0 | .0 | .0 | .0 | .0 | *2.6* | *.2* |
| 4 | 8.8 | *24.4* | 109.0 | 21.5 | .0 | .0 | .0 | .0 | .0 | .0 | 1.3 | *.2* |
| 5 | 2.3 | *22.8* | 94.0 | *24.5* | .0 | .0 | .0 | .0 | .0 | .0 | 2.0 | *.1* |
| 6 | *1.5* | 21.2 | 59.0 | 27.5 | .0 | .0 | .0 | .0 | .0 | .0 | 1.3 | *.2* |
| 7 | *.8* | *20.0* | *61.7* | *23.2* | .0 | .0 | .0 | .0 | .0 | .0 | *1.7* | *.3* |
| 8 | .0 | 18.6 | *64.4* | 19.0 | .0 | .0 | .0 | .0 | .0 | .0 | 2.0 | *.4* |
| 9 | .0 | *17.0* | 67.0 | 16.0 | .0 | .0 | .0 | .0 | .0 | .0 | .5 | .4 |
| 10 | .0 | *15.5* | 134.0 | 16.0 | .0 | .0 | .0 | .0 | .0 | .0 | .3 | *.3* |
| 11 | .0 | 14.0 | *127.2* | 14.0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *.2* |
| 12 | .0 | 14.0 | *120.3* | 10.4 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | .0 |
| 13 | .0 | *12.7* | *113.4* | *9.6* | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *1.6* |
| 14 | .0 | *11.4* | *106.5* | 8.8 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *3.3* |
| 15 | .0 | *10.2* | *99.7* | 8.8 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *5.0* |
| 16 | .0 | *8.9* | *92.8* | 8.8 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | 6.6 |
| 17 | 12.0 | *7.6* | 86.0 | 8.8 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *4.5* |
| 18 | 8.8 | *6.3* | 86.0 | 6.0 | .0 | .0 | .0 | 0 | .0 | .0 | *.3* | 2.3 |
| 19 | *15.0* | 5.0 | *82.0* | .0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *2.3* |
| 20 | 21.2 | 3.1 | *78.0* | 0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | 2.3 |
| 21 | *21.2* | *3.1* | *74.0* | .0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | .5 |
| 22 | *21.2* | *3.1* | 70.0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | .5 |
| 23 | *21.2* | *3.1* | *68.5* | .0 | .0 | .0 | .0 | .0 | .0 | .0 | *.3* | *.5* |
| 24 | 21.2 | *3.1* | 67.0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | 16.0 | *.5* |
| 25 | *18.6* | *3.1* | *59.4* | .0 | .0 | .0 | .0 | .0 | .0 | .0 | 10.0 | .5 |
| 26 | 16.0 | *3.1* | *51.7* | .0 | .0 | .0 | .0 | .0 | .0 | 177.0 | *8.7* | .5 |
| 27 | *18.6* | *3.1* | 44.0 | .0 | .0 | .0 | .0 | .0 | .0 | 142.0 | *7.5* | .5 |
| 28 | 21.2 | *3.1* | *59.5* | .0 | .0 | .0 | .0 | .0 | .0 | 31.7 | *6.2* | *.5* |
| 29 | *22.4* | 3.1 | 75.0 | .0 | .0 | .0 | .0 | .0 | .0 | 14.0 | 5.0 | *.5* |
| 30 | *23.7* | ..... | 67.0 | .0 | .0 | .0 | .0 | .0 | .0 | 7.5 | 4.0 | *.5* |
| 31 | *25.0* | ..... | 56.0 | .0 | .0 | .0 | .0 | .0 | ..... | 8.8 | ..... | 12.0 |

Figures in italics are estimated by J. B. Lippincott and H. F. Parkinson from other observations and from personal knowledge of the rainfall and of the stream.

Note table of discharge of San Gabriel canals, which quantities are not included in this table.

*Estimated discharge of San Gabriel Canals, near Azusa, California, for 1896, in second-feet.*

| Day. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *26* | *26* | 35 | *45* | *40.0* | 26.0 | 13.0 | 10.5 | 13.0 | 11.5 | 14.8 | 21.5 |
| 2 | *26* | *26* | *35* | *45* | *40.0* | 26.0 | 12.0 | 9.5 | 13.0 | 11.0 | 15.0 | *21.0* |
| 3 | *26* | *26* | *35* | *45* | *40.0* | 26.0 | 13.5 | 9.5 | 12.8 | 11.0 | 15.0 | *21.0* |
| 4 | *26* | *26* | *35* | *45* | 39.2 | 26.5 | 14.5 | 9.5 | 12.7 | 11.2 | 16.5 | *21.0* |
| 5 | *26* | *26* | *35* | *45* | 38.0 | 26.0 | 15.0 | 10.5 | 11.7 | 11.2 | 15.1 | 21.0 |
| 6 | *26* | *26* | *35* | *45* | 38.0 | 26.0 | 15.0 | 11.0 | 18.5 | 10.2 | 16.5 | 20.0 |
| 7 | *26* | *26* | *35* | *45* | 38.0 | 25.0 | 14.2 | 10.7 | 15.8 | 10.0 | 15.0 | 20.0 |
| 8 | *26* | *26* | *35* | *45* | 42.0 | 23.5 | 14.0 | 9.5 | 14.4 | 10.0 | 15.1 | 20.0 |
| 9 | *26* | *26* | *35* | *45* | 41.2 | 22.5 | 14.0 | 8.5 | 13.0 | 10.0 | 15.0 | 20.0 |
| 10 | *26* | *26* | 35 | *44* | 40.0 | 21.7 | 11.6 | 9.3 | 13.2 | 10.0 | 15.1 | 16.5 |
| 11 | *26* | *26* | *35* | *44* | 40.0 | 20.8 | 11.0 | 9.5 | 13.0 | 10.0 | *15.0* | 17.5 |
| 12 | *26* | *26* | *35* | *44* | 38.0 | 19.0 | 11.0 | 9.5 | 12.8 | 10.0 | *15.0* | 20.0 |
| 13 | *26* | *27* | *35* | *44* | 38.0 | 18.0 | 10.0 | 9.9 | 12.7 | 10.0 | *15.0* | 18.6 |
| 14 | *26* | *27* | *35* | *44* | 38.0 | 18.0 | 10.0 | 9.7 | 12.0 | 10.0 | *15.0* | 21.3 |
| 15 | *26* | *28* | *35* | *43* | 38.0 | 18.0 | 9.0 | 9.4 | 11.5 | 11.0 | *15.0* | 22.5 |
| 16 | *26* | *29* | *35* | *43* | 38.0 | 17.0 | 12.0 | 13.8 | 11.0 | 11.0 | *15.0* | 20.0 |
| 17 | *26* | *30* | *35* | *43* | 37.0 | 16.0 | 12.0 | 36.0 | 11.0 | 11.0 | *15.0* | 20.0 |
| 18 | *26* | *31* | *35* | *43* | 37.0 | 16.0 | 11.5 | 26.1 | 12.0 | 10.0 | *15.0* | 18.0 |
| 19 | *26* | 33 | *35* | *43* | 37.0 | 16.0 | 11.2 | 22.2 | 13.2 | 10.0 | *15.0* | 18.6 |
| 20 | *26* | *33* | *35* | *42* | 36.0 | 16.0 | 11.0 | 19.8 | 13.2 | 10.0 | *15.0* | 22.0 |
| 21 | *26* | *33* | *35* | *42* | 36.0 | 15.0 | 12.2 | 19.0 | 13.5 | 10.0 | *17.0* | 20.0 |
| 22 | *26* | *33* | 35 | *42* | 36.0 | 15.0 | 13.6 | 17.0 | 13.3 | 10.0 | *19.0* | 20.0 |
| 23 | *26* | *33* | *35* | *42* | 36.0 | 15.0 | 12.7 | 16.5 | 13.5 | 10.0 | *19.0* | 20.0 |
| 24 | *26* | *33* | *36* | *42* | 33.7 | 16.0 | 12.0 | 16.7 | 13.5 | 10.0 | *24.0* | 20.0 |
| 25 | *26* | *33* | *37* | *41* | 32.0 | 16.0 | 12.8 | 14.6 | 12.2 | 11.0 | 20.0 | 20.0 |
| 26 | *26* | *33* | *38* | *41* | 29.5 | 14.5 | 11.5 | 14.3 | 11.7 | 11.0 | *19.0* | 20.0 |
| 27 | *26* | *33* | *39* | *41* | 28.5 | 14.0 | 11.0 | 13.2 | 11.2 | 16.5 | *19.0* | 18.3 |
| 28 | *26* | 34 | *40* | *41* | 29.5 | 13.5 | 11.0 | 12.7 | 11.3 | 15.2 | 18.0 | 20.0 |
| 29 | *26* | *34* | *41* | *41* | 29.0 | 13.5 | 11.3 | 12.6 | 11.5 | 15.1 | 18.0 | 23.5 |
| 30 | *26* | ..... | *42* | *40* | 30.3 | 13.0 | 10.0 | 13.2 | 11.7 | 15.1 | *18.0* | 23.5 |
| 31 | *26* | ..... | *43* | ..... | 29.0 | ..... | 10.1 | 13.0 | ..... | 15.1 | ..... | 25.2 |

Figures in italics are estimated, from personal observation of the canals and knowledge of their flow, by H. F. Parkinson, water superintendent.

The Arrowhead Irrigation Company has been compiling information in reference to the rainfall, temperature, and run-off near the crest of the Sierra Madre Mountains, between the Cajon Pass and the Bear Valley Reservoir, north of San Bernardino, California. Observations are being made in the following basins: Dry Creek, Crab Creek (approximate area, 5 square miles), Deep Creek (approximate area, 15.3 square miles), Houston Flat, Holcomb Valley (approximate area, 30 square miles), Grass Valley (approximate area, 2.7 square miles), Little Bear Valley (approximate area, 7 square miles).

This data will probably be available at some future date. The observations have now been maintained for five years and will be of considerable hydrographic value when they are published. The observed rainfall has varied from 15 to 73 inches in depth, and the run-off, changing with the rainfall and general character of the basin, from 11 to 40.6 inches in depth. The run-off has been generally measured in weirs which are located at elevations ranging from 4,900 feet to 5,300 feet, while the rain gages have been located at points from 5,000 to 7,000 feet above the sea.

### WARM SPRINGS STATION ON SANTA ANA RIVER.

The mountainous portion of the Santa Ana River and its run-off is referred to in the United States Geological Survey Bulletin No. 140, page 318. The selected gaging station is approximately 3 miles above the mouth of the Santa Ana River, slightly above the junction of the Warm Springs Canyon with Santa Ana Canyon, and approximately three-fourths of a mile below the headworks of the Santa Ana Canal and opposite the Warm Springs, which is on the south side of the Santa Ana Canyon. The station was originally established in June, 1896, by Mr. J. B. Lippincott. The observer is Mr. A. Laird, ditch watchman and water divider on the Bear Valley system. He lives at the mouth of the Warm Springs Canyon, about 300 yards south of the gage rod. The gage is an inclined timber, the lower end of which has been set under the projecting edge of a large bowlder and fastened to upright posts at its upper end. It is intended to change the present graduations, which, though uniform, do not give vertical intervals of one-tenth of a foot, so that they will have this desired interval. The record for the last six months of 1896 is given in Water-Supply and Irrigation Paper No. 11, page 93.

Records of the catchment of water in the Bear Valley Reservoir have been kept since 1883, but the company, in view of pending litigation, does not desire to publish these records. At some future time this information will probably be available. The channel above and below the station for 100 feet is practically straight. The initial point of sounding is on the left bank. The right bank is not subject to overflow, but the left bank overflows at periods of very unusual floods. The bed of the river is quite broken with granite bowlders which disturb the uniformity of flow. It was impossible to avoid this in the canyon. The bed of the stream at this gaging station is quite constant in its section. It is proposed to stretch a cable across the river at this point.

From Beesley's official map of San Bernardino County, published in 1892, the following areas of the Santa Ana drainage basin are obtained:

| | Sq. miles. |
|---|---|
| Santa Ana, above mouth of Bear Creek | 86 |
| Tributary to reservoir | 56 |
| Tributary to Bear Lake | 16 |
| Bear Creek, between dam and Santa Ana | 14 |
| Santa Ana, between mouth of Bear Creek and mouth of canyon | 28 |
| Total | 200 |

During the rainy season the reservoir impounds the run-off from the 56 square miles tributary to it, and during the irrigation season this water is released into Bear Creek and thence flows into the Santa Ana. The 16 miles tributary to Bear Lake now drains into the desert to the east, but can be made tributary to the reservoir by damming its eastern outlet. The monthly flow of the Santa Ana is largely influenced by this reservoir, though the total flow for the season will be normal, provided there is no surplus water held over from one year to the next. With the present height of dam this holdover will be small. The present dam is 64 feet above the base. A contour 60 feet above will inclose an area of 2,250 acres; at 50 feet the area is 1,691 acres, and at 40 feet, 1,060 acres. If the mean water area for the season is taken as 1,500 acres, and it is assumed that during the time the water is held the loss by evaporation is 3 feet, this would represent a loss of 6.3 second-feet that would pass the point of measurement if it were not retained. The water supply in the reservoir was drawn on during the summer of 1896 until October 27, when the first heavy rains of the season occurred. On this date the gates were closed and the reservoir is said to have been practically empty at that time.

The following measurements have been made by the United States Geological Survey during the past year on the Santa Ana. Rating tables have not yet been constructed.

*List of discharge measurements made on Santa Ana River and its tributaries, California.*

| No. | Date. | Hydrographer. | Meter number. | Gage height (inches). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| | 1896. | | | | | | |
| 1 | April 27 | J. A. Vogleson... | 63 | ..... | 32.80 | 1.56 | *a* 51.1 |
| 2 | June 20 | J. B. Lippincott. | 12 | 15.3 | 47.70 | 1.29 | *b* 61.8 |
| 3 | June 20 | .....do ..... | 12 | ..... | 9.00 | 2.02 | *c* 18.3 |
| 4 | July 25 | J. H. Quinton.... | 12 | 15.5 | ..... | ..... | *d* 75.5 |
| 5 | July 28 | .....do ..... | 12 | 15.5 | 41.36 | 1.44 | *e* 59.7 |
| 6 | July 28 | .....do ..... | 12 | ..... | 4.50 | 3.33 | *f* 15.0 |
| 7 | July 27 | .....do ..... | 12 | ..... | ..... | ..... | *g* 70.6 |
| 8 | July 27 | .....do ..... | 12 | ..... | ..... | ..... | *h* 14.2 |
| 9 | July 29 | .....do ..... | 12 | ..... | ..... | ..... | *i* 14.2 |
| 10 | July 29 | .....do ..... | 12 | ..... | ..... | ..... | *j* 40.6 |
| 11 | Nov. 21 | J. B. Lippincott. | 67 | 11.75 | 33.30 | 0.95 | *k* 31.7 |
| 12 | Nov. 21 | .....do ..... | Weir. | ..... | ..... | ..... | *l* 3.5 |

*a* Two hundred yards above the headworks of the Santa Ana Canal.
*b* At Warm Springs Canyon and not including Santa Ana Canal.
*c* Alessandro water in Santa Ana Canal not included in river water.
*d* One-fourth of a mile above the head of the Santa Ana Canal and including all water.
*e* Twenty feet below Warm Springs gage rod, Santa Ana Canal not included.
*f* In Santa Ana Canal.
*g* On Bear Creek, one-fourth of a mile above the mouth.
*h* Santa Ana River, 300 feet above junction with Bear Creek.
*i* Mill Creek Canal, at crossing of the Santa Ana Canal, and carrying all the water of the stream.
*j* In Redlands Canal.
*k* At Warm Springs gage, not including Santa Ana Canal.
*l* In Santa Ana Canal, 1.5 second-feet returned to river.

## LOS ANGELES RIVER.

Los Angeles River rises in the mountains surrounding San Fernando Valley, and its various tributaries flow across or under this valley to the main stream, uniting with it 10 to 15 miles north of the city of Los Angeles. The city undertook in the summer of 1896 to measure the flow of the stream after it leaves the San Fernando Valley, this work being placed in charge of Mr. A. Q. Campbell. A number of measuring weirs were constructed, five of them being upon the river and the others either upon the flow of developed water or upon diversions from the river. The smaller weirs are reported to have caused little trouble, but those constructed in the river require considerable attention to keep them in working order, owing chiefly to the filling of the bays with sand. The readings of these weirs were at first taken upon graduated scales, but on September 24 automatic recording hook gages were put in operation.

The weirs upon the river were numbered 11, 1, 4, 5, and 8. The condition of the bays of Nos. 11 and 1 was continually the same, as the water had no silt, and the only irregularities occurring were those caused by the slight settlement of the weir and the inaccuracies of measuring the head. Between Weirs No. 11 and No. 1 the river received what is known as the Pomeroy and Hooker development and the Big Tahunga wash, carrying about 3.2 second-feet. Weir No. 4, the next below No. 1, was affected by the varying amount of water taken out at the diversion gate of the city main supply ditch and the waters of the West Los Angeles Water Company, which were wasted into the river irregularly. Weir No. 5, which is the next below No. 4, was affected by the city zanjero turning in water at irregular periods from the city main supply ditch below Weir No. 4, and also by the West Los Angeles Water Company turning in water from their pipe line. Below Weir No. 5 and above Weir No. 8, which is the next in order, the Los Angeles Water Company diverts its supply from the river.

Few floods pass from the mountain canyons to the narrows. The San Fernando Valley, filled with sand and bowlders, acts as a regulator to the flow of this river, the stream remaining constant and the water plane, or plane of saturation, rising and falling as the mountain rains are large or small. The following tables of discharge are compiled from the detailed report submitted by Mr. A. Q. Campbell, the engineer in charge:

*Discharge of Los Angeles River at Weir No. 11, 9.88 miles above the city limits of Los Angeles, California.*

| Month. | Discharge in second-feet. | | | Total in acre-feet. |
|---|---|---|---|---|
| | Maximum. | Minimum. | Mean | |
| 1896. | | | | |
| August | 16 | 13 | 14 | 861 |
| September | 16 | 14 | 15 | 893 |
| October | 22 | 14 | 16 | 984 |
| November | 18 | 15 | 16 | 952 |
| December | 19 | 15 | 16 | 984 |

*Discharge of Los Angeles River at Weir No. 1, 9.79 miles above city limits of Los Angeles, California.*

| Month. | Discharge in second-feet. | | | Total in acre-feet. |
|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | |
| 1896. | | | | |
| August | 21 | 19 | 20 | 1,230 |
| September | 21 | 19 | 20 | 1,190 |
| October | 26 | 19 | 20 | 1,230 |
| November | 24 | 19 | 21 | 1,250 |
| December | 23 | 19 | 20 | 1,230 |

*Discharge of Los Angeles River at Weir No. 4, 7.27 miles above city limits of Los Angeles, California.*

| Month. | Discharge in second-feet. | | | Total in acre-feet. |
|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | |
| 1896. | | | | |
| August | 46 | 41 | 44 | 2,705 |
| September | 44 | 41 | 43 | 2,559 |
| October | 56 | 41 | 44 | 2,705 |
| November | 52 | 43 | 46 | 2,737 |
| December | 55 | 43 | 47 | 2,828 |
| 1897. | | | | |
| January | 47 | 44 | 46 | 2,828 |

*Discharge of Los Angeles River at Weir No. 5, 4.87 miles above city limits of Los Angeles, California.*

| Month. | Discharge in second-feet. | | | Total in acre-feet. |
|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | |
| 1896. | | | | |
| August | 77 | 67 | 71 | 4,366 |
| September | 76 | 63 | 71 | 4,225 |
| October | 82 | 65 | 69 | 4,243 |
| November | 76 | 68 | 70 | 4,165 |
| December | 96 | 67 | 72 | 4,427 |
| 1897. | | | | |
| January | 96 | 67 | 73 | 4,489 |
| February | 96 | 71 | 77 | 4,276 |

*Discharge of Los Angeles River at weir No. 8, 3.65 miles above city limits of Los Angeles, California.*

| Month. | Discharge in second-feet. | | | Total in acre-feet. |
|---|---|---|---|---|
| | Maximum. | Minimum. | Mean. | |
| 1896. | | | | |
| August | 73 | 67 | 70 | 4,304 |
| September | 73 | 65 | 69 | 4,106 |
| October | 83 | 65 | 69 | 4,243 |
| November | 74 | 67 | 71 | 4,225 |
| December | 93 | 68 | 73 | 4,489 |
| 1897. | | | | |
| January | 79 | 71 | 73 | 4,489 |

## SWEETWATER RIVER.

### SWEETWATER DAM ON SWEETWATER RIVER.

Sweetwater dam is 12 miles southeast of the city of San Diego. It may be reached from San Diego directly by railroad. Mr. H. N. Savage, chief engineer of the San Diego Land and Town Company, is maintaining this gaging station, and is rendering a valuable service to the engineers of western America by the thoroughness of his investigations, which have been freely furnished to this Survey. At the present time Mr. Savage is having surveys made to determine the amount of

silt that has been deposited in the reservoir during the past nine years. The rainfall in this basin during the past year has been as follows:

| Month. | Sweetwater dam (250 feet). | Descanso (3,500 feet). | Julian (4,500 feet) | Cuyamaca (4,800 feet). |
|---|---|---|---|---|
| January | 1.70 | 2.93 | 4.55 | 28.43 |
| February | 0.00 | 0.10 | 0.40 | 6.05 |
| March | 2.52 | 8.04 | 6.10 | 5.52 |
| April | 0.65 | 1.14 | 1.40 | 1.20 |
| May | 0.05 | 0.17 | 0.10 | 0.16 |
| June | 0.00 | 0.00 | 0.00 | 0.00 |
| July | 0.05 | 0.30 | 2.00 | ..... |
| August | 0.11 | 1.38 | ..... | ..... |
| September | 0.04 | 0.03 | ..... | ..... |
| October | 0.21 | 2.71 | ..... | ..... |
| November | 1.62 | 2.12 | ..... | ..... |
| December | 0.81 | 2.43 | ..... | ..... |
| Year | 7.76 | 21.35 | ..... | ..... |

The discharge of Sweetwater River into the reservoir from its drainage area of 186 square miles is estimated to have been from July, 1895, to June 30, 1896, on an average of 1.39 second-feet or a total of 1,007 acre-feet. This is equivalent to a run-off of 0.101 inch, or 0.0074 second-foot per square mile. The mean rainfall was 15 inches, as is determined according to the method explained on page 324 of Bulletin No. 140. The rainfall at Sweetwater was 7.22 inches, and at Descanso (approximately) 18.88 inches, the record for July, August, and September, 1895, being lost. The evaporation at the reservoir is estimated to have been 45.18 inches or 0.7 per cent of the run-off.

## MISCELLANEOUS MEASUREMENTS.

*Miscellaneous discharge measurements made by J. B. Lippincott.*

| Date. | Stream. | Locality. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| 1896. | | | | | | | |
| Feb. 3 | Fort Tejon Creek. | Near Rose Station, Cal. | Floats. | ..... | 1.80 | 1.92 | 3.46 |
| Mar. 22 | San Gabriel Canal. | Azusa, Cal .... | Price. | 2.27 | 8.81 | 2.80 | 24.63 |
| June 4 | Tunis Creek... | Road Crossing, Cal. | 12 | ..... | 1.28 | 1.55 | 1.98 |
| Aug. 22 | Merced..... | Yosemite, Cal.. | 12 | ..... | 1.09 | 0.82 | 0.89 |

*Miscellaneous discharge measurements made by J. B. Lippincott*—Continued.

| Date. | Stream. | Locality. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| 1896. | | | | | | | |
| Sept. 9 | South Fork of Stanislaus. | Sugar Pine, Cal. | 12 | ..... | 5.48 | 11.04 | 60.48 |
| Oct. 17 | Little Walker. | Junction House, Cal. | 12 | ..... | 20.15 | 1.95 | 39.36 |
| Oct. 18 | Big Walker ... | Leavitts Station, Cal. | 12 | ..... | 26.5 | 1.65 | 44.8 |
| Oct. 20 | Main Fork of Stanislaus. | Eureka Valley, Cal. | Floats. | ..... | 93.4 | 1.69 | 158. |
| Oct. 30 | Stanislaus and San Joaquin Canal. | Knights Ferry, Cal. | Floats. | ..... | 5.01 | 7.5 | 37.6 |
| Nov. 18 | Los Angeles River. | Headworks Los Angeles, Water Co. | 12 | 0.51 | ..... | ..... | ..... |
| Nov. 19 | .....do ..... | .....do ..... | 12 | ..... | 9.66 | 0.79 | 7.60 |
| Nov. 19 | .....do ..... | .....do ..... | 67 | 0.51 | 9.66 | 0.76 | 7.29 |
| Nov. 22 | San Gabriel Canal. | Azusa, Cal .... | 67 | 2.10 | 15.60 | 1.35 | 21.10 |
| Dec. 22 | Tejon Creek... | Foot of Hill.. | ..... | ..... | ..... | ..... | 1.5 |

*Miscellaneous discharge measurements.*

| Date. | Stream. | Locality. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| 1896. | | | | | | | |
| Apr. 15 | Mining Canal *a* | Lagrange Dam, Cal. | 63 | ..... | 12.96 | 2.47 | 32.11 |
| Apr. 30 | Azusa Canal *a* . | Azusa, Cal .... | 63 | 2.70 | 18.85 | 2.93 | 55.20 |
| June 20 | Santa Ana *b* ... | Warm Springs, Cal. | 12 | ..... | 46.0 | 1.33 | 61.2 |
| June 20 | Santa Ana Flume *b*. | .....do ..... | 12 | ..... | 10.0 | 2.13 | 21.3 |
| July 22 | San Gabriel *c* .. | Azusa, Cal .... | 12 | ..... | 24.02 | 1.11 | 26.75 |
| July 23 | San Antonio *c*.. | 300 feet above division box. | 12 | ..... | 5.74 | 1.30 | 7.48 |
| July 24 | Lytle Creek *c*.. | Near San Bernardino, Cal. | 12 | ..... | 4.44 | 3.53 | 15.69 |

*a* Measurement made by J. A. Vogleson.
*b* Measurement made by C. C. Babb.
*c* Measurement made by J. H. Quinton.

*Miscellaneous discharge measurements*—Continued.

| Date. | Stream. | Locality. | Meter number. | Gage height (feet). | Area of section (square feet). | Mean velocity (feet per second). | Discharge (second-feet). |
|---|---|---|---|---|---|---|---|
| 1896. | | | | | | | |
| July 27 | Bear Creek *a*... | ¼ mile above mouth. | 12 | ..... | ..... | ..... | 70.64 |
| July 29 | Redlands Canal *a*. | Mill Creek Crossing. | 12 | ..... | ..... | ..... | 40.62 |
| July 29 | Mill Creek *a*... | Head of Alessandro pipe line. | 12 | ..... | ..... | ..... | 14.21 |
| Sept. 8 | Stanislaus Flume *b*. | Knights Ferry. | 12 | ..... | 5.6 | 11.85 | 66.35 |

*a* Measurement made by J. H. Quinton.
*b* Measurement made by H. S. Crowe.

## CALIFORNIA RAINFALL DATA.

The following figures, with the exception of those for Redbluff and Sissons, were obtained by this Survey, and are given as not being previously published. In the table a precipitation of 10 inches in depth of snow is considered as being equal to 1 inch of rain.

*Rainfall data in California in 1896.*

| Station. | Elevation. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. | Mean annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Redbluff | ..... | 7.30 | 0.27 | 3.06 | 3.67 | 2.42 | T. | 0.00 | 0.54 | 0.63 | 0.66 | 3.41 | 6.20 | 28.16 | 23.79 |
| Sissons | 3,555 | 21.09 | 0.21 | 4.16 | 3.55 | 3.02 | 0.00 | ..... | 0.00 | 0.00 | 1.29 | 6.68 | ..... | ..... | ..... |
| Senora | 1,900 | 10.80 | 0.49 | 5.00 | 8.65 | 1.14 | 0.00 | 0.40 | 0.61 | 0.25 | 2.85 | 6.74 | 3.97 | 40.90 | 37.13 |
| Second Garotte (Sequoia post-office) | 2,900 | 12.00 | 0.00 | 5.50 | 7.25 | 0.25 | 0.00 | 0.00 | 2.50 | 0.00 | 3.00 | 6.00 | 4.50 | 41.00 | 38.98 |
| Crockers | 4,453 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.10 | 0.14 | 2.30 | 9.18 | 5.41 | ..... | ..... |
| Yosemite | 4,063 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.85 | 1.36 | 6.19 | 3.83 | ..... | ..... |
| Daunt | 6,600 | 11.91 | 0.83 | 5.13 | 11.01 | 1.30 | 2.70 | 0.65 | 0.50 | 0.00 | 0.60 | 0.40 | 1.95 | 36.98 | ..... |
| Mount Breckenridge | 6,750 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.20 | 4.30 | ..... | ..... |
| Kernville | 2,600 | 3.02 | 0.00 | 1.54 | 0.86 | ..... | 0.40 | 2.25 | 0.05 | 0.00 | 1.15 | 0.41 | 0.85 | 10.83 | ..... |
| Tejon Ranch | 1,300 | 1.90 | 0.37 | 4.22 | 1.62 | 0.48 | 0.00 | 0.00 | 0.00 | 0.00 | 1.34 | 2.12 | 2.32 | 14.37 | 11.62 |
| Palmdale | ..... | ..... | ..... | ..... | ..... | ..... | 0.00 | 0.25 | 1.35 | 0.32 | 1.42 | 0.43 | 0.98 | ..... | ..... |
| Fort Tejon | 3,245 | 3.07 | 0.40 | 4.01 | 3.38 | 2.05 | 0.22 | 0.26 | 0.30 | 0.53 | 1.63 | 1.74 | 1.14+ | 18.73 | ..... |
| Follows Camp | 1,800 | 2.77 | T. | 6.55 | 0.70 | 0.36 | 0.00 | 0.07 | 1.10 | T. | 2.95 | 1.03 | 1.61 | 17.14 | ..... |
| Sweetwater | 250 | 1.70 | 0.00 | 2.52 | 0.65 | 0.05 | 0.00 | 0.05 | 0.11 | 0.04 | 0.21 | 1.62 | 0.81 | 7.76 | ..... |
| Descanso | 3,500 | 2.93 | 0.10 | 8.04 | 1.14 | 0.17 | 0.00 | 0.30 | 1.38 | 0.03 | 2.71 | 2.12 | 2.43 | 21.35 | ..... |
| Mount Lowe | 3,200 | 2.85 | 0.10 | 4.10 | 0.60 | 0.30 | 0.00 | 0.00 | 0.10 | 0.00 | 2.38 | 1.51 | 2.11 | 14.05 | ..... |

# THE WATER RESOURCES OF INDIANA AND OHIO.

BY

FRANK LEVERETT.

# CONTENTS.


| | Page. |
|---|---|
| General statement | 425 |
| Physical features | 426 |
| Altitude | 426 |
| Reliefs | 427 |
| Glacial ridges | 434 |
| The drainage systems | 438 |
| The Ohio River system | 441 |
| The Ohio River | 441 |
| Lesser tributaries of the Ohio | 444 |
| The Wabash River system | 446 |
| Wabash River | 446 |
| Salamonie River | 449 |
| Mississinewa River | 449 |
| Eel River | 449 |
| Tippecanoe River | 450 |
| Small tributaries of the Wabash between Tippecanoe and White rivers | 451 |
| West White River | 451 |
| East White River | 453 |
| Patoka River | 456 |
| Whitewater River system | 456 |
| Great Miami River system | 457 |
| Little Miami River system | 458 |
| The Scioto River system | 458 |
| Hocking River system | 460 |
| Muskingum River system | 460 |
| Beaver River system | 463 |
| Tributaries of Lake Erie | 464 |
| Conneaut Creek | 465 |
| Grand River | 465 |
| Chagrin River | 466 |
| Cuyahoga River | 466 |
| Rocky River | 467 |
| Black River | 467 |
| Vermilion River | 468 |
| Huron River | 468 |
| Sandusky River | 468 |
| Maumee River | 468 |
| The Lake Michigan system | 470 |
| St. Joseph River | 470 |
| Calumet River | 471 |
| Illinois River system | 471 |
| Kankakee River | 471 |
| Lakes | 472 |

Page.
Underground waters ..... 474
General statement ..... 474
Ground-water wells ..... 475
Shallow wells in valleys ..... 478
Drift wells with wide or remote absorption areas ..... 478
Drift wells with strong hydrostatic pressure ..... 480
Subterranean drainage lines ..... 483
Rock wells with slight hydrostatic pressure ..... 484
Rock wells with strong hydrostatic pressure ..... 485
Wells in Indiana ..... 487
Mineral springs ..... 493
Water analyses ..... 495
Water supplies for cities and villages ..... 502
Surface water ..... 503
Shallow wells in valleys ..... 511
Wells in glacial drift ..... 517
Wells in rock ..... 527
Detailed observations ..... 537
*Indiana towns:* Anderson, Bloomington, Bluffton, Brookville, Columbia City, Covington, Danville, Elkhart, Evansville, Fort Wayne, Frankfort, Garrett, Greensburg, Greenwood, Hammond, Huntington, Indianapolis, Knox, Kokomo, Lafayette, Lodi, Logansport, Marion, Martinsville, Michigan City, Mitchell, Montezuma, New Albany, New Castle, New Haven, Plymouth, Richmond, Rochester, Rockville, Shoals, South Bend, Spencer, Sullivan, Terre Haute, Union City, Valparaiso, Wabash, Warsaw, Whiting, Williamsport, Worthington ..... 537
*Ohio towns:* Akron, Ashland, Ashtabula, Athens, Attica, Bellaire, Bellefontaine, Bellevue, Berea, Bucyrus, Canton, Celina, Cincinnati and suburbs, Cleveland, Clyde, Columbus, Conneaut, Coshocton, Dayton, Defiance, Delaware, Dennison, Eaton, Elyria, Findlay, Franklin, Fremont, Gallipolis, Greenfield, Hamilton, Hillsboro, Hudson, Ironton, Jackson, Kenton, Lancaster, Lima, London, Lynchburg, Mansfield, Marietta, Marion, Massillon, Mechanicsburg, Mount Vernon, Napoleon, Nelsonville, Newark, New Lisbon, New Philadelphia, New Straitsville, Niles, Oberlin, Ottawa, Plain City, Piqua, Pomeroy, Portsmouth, Ravenna, Ripley, St. Marys, Sandusky, Sidney, Springfield, Steubenville, Tiffin, Toledo, Troy, Urbana, Van Wert, Wapakoneta, Wellington, Wellsville, West Union, Wilmington, Wooster, Xenia, Youngstown, Zanesville ..... 544
Rainfall ..... 555

# ILLUSTRATIONS.


| | | Page. |
|---|---|---|
| PLATE XXXIII. | Topographic map of Indiana and Ohio | 426 |
| XXXIV. | Geologic formations of Indiana and Ohio | 428 |
| XXXV. | Geologic sections in Indiana and Ohio | 430 |
| XXXVI. | Map of the Pleistocene deposits of Indiana and Ohio | 434 |
| XXXVII. | Relation of the drift to the ordinary wells | 480 |
| FIG. 76. | Rock ledges exposed in bed of Ohio River opposite Ravenswood | 442 |
| 77. | Diagram of average yearly fluctuations of Ohio and Mississippi rivers | 443 |

# WATER RESOURCES OF INDIANA AND OHIO.

By FRANK LEVERETT.

## GENERAL STATEMENT.

The gathering of material concerning water resources contained in this paper has been carried on largely in connection with glacial studies which the writer has pursued under the direction of Prof. T. C. Chamberlin. These studies were begun in Indiana in 1887 and in Ohio in 1888, and have embraced about six field seasons. As a result of this connection with glacial studies the data are much fuller in the glaciated than in the unglaciated portions of these States.

The data collected on the underground waters are much more full in the Indiana than in the Ohio portion, and embrace not only the waters from wells obtained from glacial deposits, but also those from the rock formations. The underground waters of Ohio are to be discussed by Prof. Edward Orton in a paper for this Survey, hence only brief reference is made to them in the present discussion.

Since arrangements are being made by this Survey for a special investigation of water power in Indiana, and since the water power of Ohio has been discussed quite fully by Prof. Dwight Porter in the Tenth Census Report,[1] the subject receives but little attention in this paper.

A special circular letter making inquiries concerning city water supply was mailed to town officials, or others qualified to give information, in all towns of Indiana and Ohio having a population of 1,000 or more and to smaller towns which were known to have a waterworks system. The generous response to that letter makes it possible to present a somewhat full report upon this subject. It is taken to be a measure of the general deep interest in the publication of such statistics, and the writer wishes here to acknowledge great indebtedness to the large number of persons who have supplied information. Advance sheets of the Manual of American Waterworks for 1897, published by the Engineering News, have been furnished through the kindness of the editor, Mr. M. N. Baker, from which statistics concerning waterworks are rounded out and brought down to date. Proper credit is given in the tables of city

[1] Report on the water power of the Ohio River Basin and the Ohio State Canals, by Dwight Porter: Tenth Census of United States, 1880, Vol. XVII, pp. 429–504.

water supply for statistics thus obtained. The pains taken by Mr. Baker and his associates in collecting this body of statistics can be appreciated only by those who attempt similar work, and his kindness in thus cooperating places us under a debt of gratitude to him.

## PHYSICAL FEATURES.

### ALTITUDE.

The accompanying topographic map (Pl. XXXIII) presents 100-foot contours, which are based principally upon railway-survey altitudes. A large part of these data, which include not only stations, but also natural summits and beds of streams crossed by the railway lines, were collected by Mr. Henry Gannett, of this Survey, and arranged for his forthcoming revised edition of the Dictionary of Altitudes in the United States. Through Mr. Gannett's kindness the writer has been given free access to all such unpublished material as pertains to Indiana and Ohio. Some of the elevations were obtained from Capt. H. M. Chittenden's map accompanying his report on the canal routes between Lake Erie and the Ohio River.[1] A considerable number of elevations have been obtained from Professor Orton's list of altitudes in Ohio, published in Volume VI of the Ohio Geological Survey. For the outlining of the 800-foot contour in Monroe and Lawrence counties, Indiana, Mr. C. E. Siebenthal, of the Indiana survey, should receive credit. Where precise elevations are wanting use has been made of aneroid readings taken by the writer.[2] A general acquaintance with the topography of the region has also been of service in drawing the contour lines. The minor sinuosities of the contour lines must necessarily be neglected on a map of this scale. It is thought, however, that the variations in altitude are presented with a sufficient degree of approximation to represent fairly the general features.

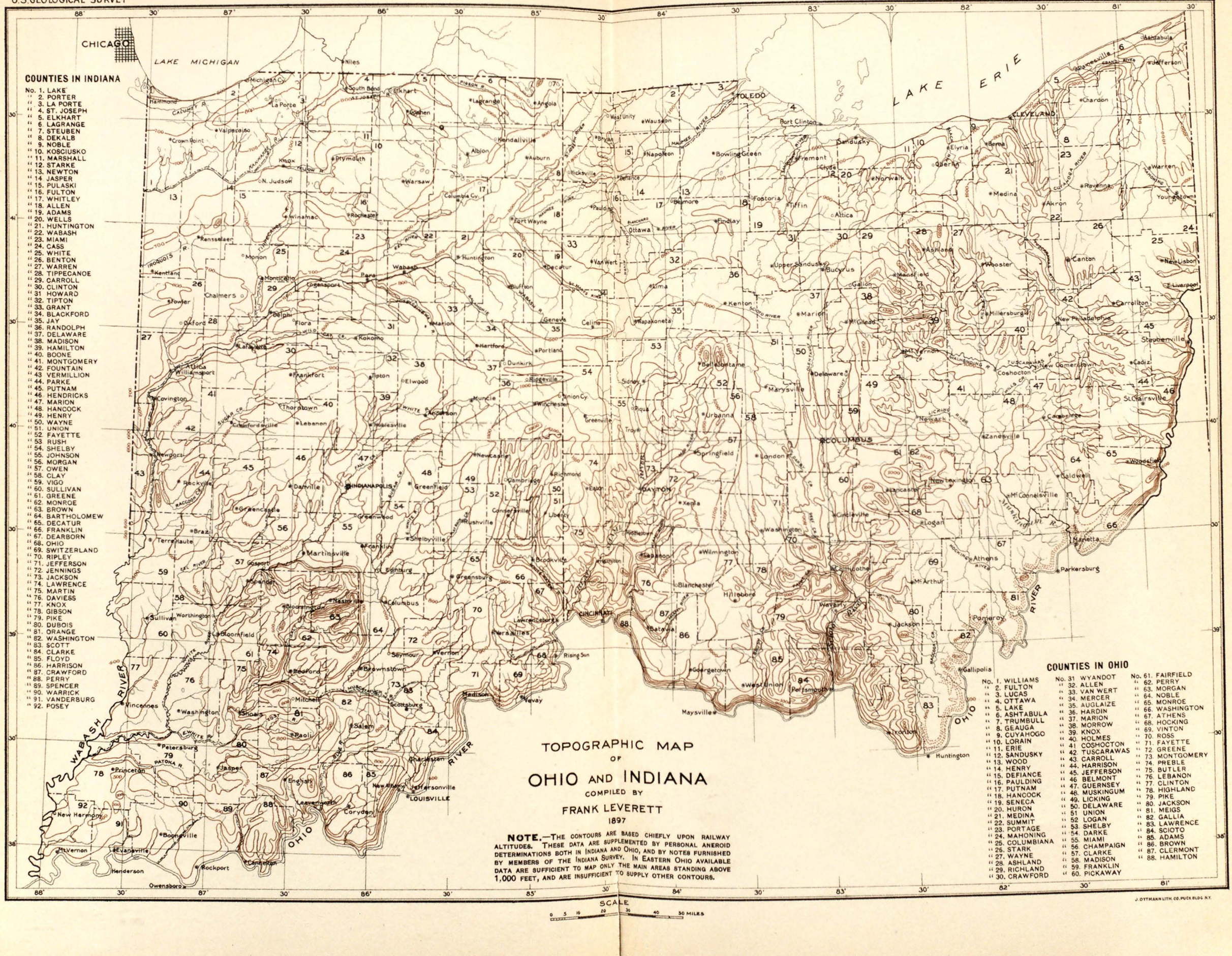
The mean elevation of Indiana is estimated by Mr. Gannett, through a study of railway elevations and other published data, to be 700 feet above tide.[3] Mr. S. S. Gorby, formerly State geologist, who has a somewhat intimate personal acquaintance with the features of the State, estimates the average altitude to be 800 feet.[4] Nearly three-fourths of the State stands between 500 and 1,000 feet. Of the 35,910 square miles there are, according to Mr. Gannett's estimate, but 2,850 square miles above the 1,000-foot contour and but 4,700 square miles below the 500-foot contour. The highest land is found near the eastern boundary of the State, in southern Randolph and northern Wayne counties, where the altitude reaches about 1,250 feet above tide; it is

[1] Ex. Doc. No. 278, House of Representatives, Fifty-fourth Congress, first session, 1896.

[2] It should be noted that in the unglaciated portion the contouring is restricted mainly to the 1,000-foot line. The available data are too meager to justify the full contouring attempted in the glaciated portion. A part of the glaciated upland in northeastern Ohio is also defective in this respect.

[3] Thirteenth Ann. Rept. U. S. Geol. Survey, Part II, 1893, p. 289.

[4] Sixteenth Ann. Rept. Indiana Geol. Survey, 1891, p. 217.




## COUNTIES IN INDIANA

No. 1. LAKE
" 2. PORTER
" 3. LA PORTE
" 4. ST. JOSEPH
" 5. ELKHART
" 6. LAGRANGE
" 7. STEUBEN
" 8. DEKALB
" 9. NOBLE
" 10. KOSCIUSKO
" 11. MARSHALL
" 12. STARKE
" 13. NEWTON
" 14. JASPER
" 15. PULASKI
" 16. FULTON
" 17. WHITLEY
" 18. ALLEN
" 19. ADAMS
" 20. WELLS
" 21. HUNTINGTON
" 22. WABASH
" 23. MIAMI
" 24. CASS
" 25. WHITE
" 26. BENTON
" 27. WARREN
" 28. TIPPECANOE
" 29. CARROLL
" 30. CLINTON
" 31 HOWARD
" 32. TIPTON
" 33. GRANT
" 34. BLACKFORD
" 35. JAY
" 36. RANDOLPH
" 37. DELAWARE
" 38. MADISON
" 39. HAMILTON
" 40. BOONE
" 41. MONTGOMERY
" 42. FOUNTAIN
" 43 VERMILLION
" 44. PARKE
" 45. PUTNAM
" 46. HENDRICKS
" 47. MARION
" 48. HANCOCK
" 49. HENRY
" 50. WAYNE
" 51. UNION
" 52. FAYETTE
" 53. RUSH
" 54. SHELBY
" 55. JOHNSON
" 56. MORGAN
" 57. OWEN
" 58. CLAY
" 59. VIGO
" 60. SULLIVAN
" 61. GREENE
" 62. MONROE
" 63. BROWN
" 64. BARTHOLOMEW
" 65. DECATUR
" 66. FRANKLIN
" 67. DEARBORN
" 68. OHIO
" 69. SWITZERLAND
" 70. RIPLEY
" 71. JEFFERSON
" 72. JENNINGS
" 73. JACKSON
" 74. LAWRENCE
" 75. MARTIN
" 76. DAVIESS
" 77. KNOX
" 78. GIBSON
" 79. PIKE
" 80. DUBOIS
" 81. ORANGE
" 82. WASHINGTON
" 83. SCOTT
" 84. CLARKE
" 85. FLOYD
" 86. HARRISON
" 87. CRAWFORD
" 88. PERRY
" 89. SPENCER
" 90. WARRICK
" 91. VANDERBURG
" 92. POSEY

## COUNTIES IN OHIO

No. 1. WILLIAMS
" 2. FULTON
" 3. LUCAS
" 4. OTTAWA
" 5. LAKE
" 6. ASHTABULA
" 7. TRUMBULL
" 8. GEAUGA
" 9. CUYAHOGO
" 10. LORAIN
" 11. ERIE
" 12. SANDUSKY
" 13. WOOD
" 14. HENRY
" 15. DEFIANCE
" 16. PAULDING
" 17. PUTNAM
" 18. HANCOCK
" 19. SENECA
" 20. HURON
" 21. MEDINA
" 22. SUMMIT
" 23. PORTAGE
" 24. MAHONING
" 25. COLUMBIANA
" 26. STARK
" 27. WAYNE
" 28. ASHLAND
" 29. RICHLAND
" 30. CRAWFORD
No. 31 WYANDOT
" 32. ALLEN
" 33. VAN WERT
" 34. MERCER
" 35. AUGLAIZE
" 36. HARDIN
" 37. MARION
" 38. MORROW
" 39. KNOX
" 40. HOLMES
" 41 COSHOCTON
" 42. TUSCARAWAS
" 43. CARROLL
" 44. HARRISON
" 45. JEFFERSON
" 46 BELMONT
" 47. GUERNSEY
" 48. MUSKINGUM
" 49. LICKING
" 50. DELAWARE
" 51 UNION
" 52 LOGAN
" 53. SHELBY
" 54. DARKE
" 55. MIAMI
" 56. CHAMPAIGN
" 57. CLARKE
" 58. MADISON
" 59. FRANKLIN
" 60. PICKAWAY
No. 61. FAIRFIELD
" 62. PERRY
" 63. MORGAN
" 64. NOBLE
" 65. MONROE
" 66. WASHINGTON
" 67. ATHENS
" 68. HOCKING
" 69. VINTON
" 70. ROSS
" 71. FAYETTE
" 72. GREENE
" 73. MONTGOMERY
" 74. PREBLE
" 75. BUTLER
" 76. LEBANON
" 77. CLINTON
" 78. HIGHLAND
" 79. PIKE
" 80. JACKSON
" 81. MEIGS
" 82. GALLIA
" 83. LAWRENCE
" 84. SCIOTO
" 85. ADAMS
" 86. BROWN
" 87. CLERMONT
" 88. HAMILTON

# TOPOGRAPHIC MAP
OF
# OHIO AND INDIANA
COMPILED BY
FRANK LEVERETT
1897

**NOTE.**—The contours are based chiefly upon railway altitudes. These data are supplemented by personal aneroid determinations both in Indiana and Ohio, and by notes furnished by members of the Indiana Survey. In Eastern Ohio available data are sufficient to map only the main areas standing above 1,000 feet, and are insufficient to supply other contours.

SCALE
0 5 10 20 30 40 50 MILES

J. OTTMANN LITH. CO. PUCK BLDG. N.Y.

in the midst of the main area that rises above the 1,000-foot contour, as may be seen by reference to the map (Pl. XXXIII). A small area in the northeast corner of the State rises above 1,000 feet, and still smaller areas in Hendricks, Brown, and Washington counties, too small to be indicated on the map, also exceed 1,000 feet. The portion falling below 500 feet is confined to the southwestern corner and to valleys in the southern half of the State. The lowest elevation (at the mouth of Wabash River) is 311 feet above tide at low water of the stream.

The mean elevation of Ohio is estimated by Mr. Gannett, in the paper above cited, to be 850 feet, or about 150 feet greater than that of Indiana.[1] Only 460 of the 40,760 square miles in the State are estimated to fall below 500 feet, and this low part is confined to the Ohio Valley and the lower course of its tributaries, the lowest point being about 425 feet above tide. Less than one square mile stands above 1,500 feet. This is near Bellefontaine, in Logan County, in the west-central part, where one hillock reaches 1,540 feet and another 1,525 feet above tide. At least one-fourth of the State stands above 1,000 feet. This elevated part is largely in the eastern half, though it is estimated by the writer that nearly 4,000 square miles in the western half stands above 1,000 feet. Two-thirds, or possibly a larger part, of the State is between 500 and 1,000 feet above tide. The western half is lower than the eastern, because it includes the two most extensive lowlands of the State, one bordering the western end of Lake Erie, the other occupying the Scioto basin. Furthermore, the great elevation attained in Logan County, in western Ohio, is confined to a few square miles, there being very little territory in western Ohio standing above 1,200 feet. But in eastern Ohio there are extensive areas rising not only above 1,200 feet, but even above 1,300 feet.

## RELIEFS.

Under this head the escarpments, ridges, or hills formed by variations in rate of disintegration of the rock strata are discussed. The broad arches due to uplift are also briefly considered. Morainic ridges, dunes, and other aggregations of Pleistocene age are not included.

Throughout the greater part of Indiana and in northwestern Ohio the glacial deposits are so heavy as to conceal the reliefs quite effectually and to reduce the surface to a somewhat smooth contour. Indeed, the morainic ridges constitute the principal features that would attract notice in the northern two-thirds of the region. The southern third of Indiana has largely escaped glaciation; the southern part of western Ohio has been less heavily covered than the northern, and much of the

[1] The great extent of elevated tracts in eastern Ohio is not shown by railway elevations, since the railways in that portion of the State are largely confined to valleys. This suggests the possibility that Mr Gannett's estimate of the mean elevation, which is based largely upon railway elevations, may be too low. It is scarcely probable, however, that it falls below more than 100 feet.

eastern half of Ohio is unglaciated. Hence the reliefs of the rock surface are well exhibited in these districts.

Since the reliefs of the region under discussion depend upon the geological formations, and these formations are definitely related to the Cincinnati arch, the discussion of this arch naturally precedes that of the other reliefs. Its relation to the geological history of Ohio and Indiana is clearly set forth by Dr. Edward Orton in an early report of this Survey, as follows:[1]

> All of the earlier geological history of these two States [Ohio and Indiana] as far back as it can be followed, is connected with an elevatory movement that, advancing from the southward, extended itself through most of the territory now under consideration [western Ohio and eastern Indiana]. This great uplift is most widely known in geology under the name of the Cincinnati axis, or Cincinnati anticline, a designation to which Newberry gave wide currency in his admirable account of the geological structure of Ohio.[2] The views that he sets forth as to the character of this uplift have been invalidated to some extent by the surprising discoveries of the last three years (1886–1889), but the account given by him still remains by far the best that has been published of the earlier stages of this important movement. He has shown beyond question its early origin in Tennessee and Kentucky and its gradual advance through these States. The term "axis," or "anticline," as applied to a structural feature of this character, is in some respects misleading. It is hard to qualify it so that it will not at once suggest to the ordinary reader a line or ridge, but this feature has been expressly excluded from all the statements that have been made in regard to it. Its extreme flatness and its great breadth have been insisted upon by all who have studied it. In the discussion of the physical geology of the Cincinnati group of southern Ohio it was shown that for 30 miles in an east and west direction there is scarcely any appreciable fall in the strata that compose the axis, and that all the determinable dip is a very slight and equable fall to the northward.[3] The term "axis" might well be replaced by a less confusing term, viz, the term "uplift."
>
> * * * * * * *
>
> The main axis of the Cincinnati uplift extends to the northwest, and not to the northeast. In the light of all that we have been accustomed to hold in regard to this great structural feature the statement here made is a surprising one, but no other interpretation of the facts is possible. The high levels of the Trenton limestone all advance to the west of north, and for this we ought to have been partially prepared by facts already in hand. The geological map of the United States has long shown a distinct westerly trend for the joint Silurian formations of the two States, Ohio and Indiana.
>
> From Wayne and Randolph counties, Indiana, a northeasterly prolongation of high-lying Trenton rock extends through Darke, Mercer, Shelby, Auglaize, Allen, and Hardin counties to the central part of Hancock County. This prolongation may be named the Lima axis. From Hancock County an important spur of high-lying Trenton extends northerly, with a very slight westerly element in its direction. On the western side this spur is bounded by one of the most marked disturbances yet discovered in Ohio geology, viz, a monoclinal fold, or perhaps a series of connected folds of this character. The downthrow is to the west, and its total amount is not less than 200 feet. The most of the descent is accomplished within a half or a quarter of a mile, and in some cases at the rate of 1 foot in 8. This field may be appropriately styled the Findlay monocline, the Findlay break, or the Find-

[1] Eighth Ann. Rept. U. S. Geol. Survey, 1889, pp. 573–574, 576.
[2] Report Geol. Survey Ohio, Vol. I, p. 93.
[3] Report Geol. Survey Ohio, Vol. I, p. 411.

CHICAGO

LAKE MICHIGAN

LAKE ERIE

## COUNTIES IN INDIANA

No. 1. LAKE
" 2. PORTER
" 3. LA PORTE
" 4. ST. JOSEPH
" 5. ELKHART
" 6. LAGRANGE
" 7. STEUBEN
" 8. DEKALB
" 9. NOBLE
" 10. KOSCIUSKO
" 11. MARSHALL
" 12. STARKE
" 13. NEWTON
" 14. JASPER
" 15. PULASKI
" 16. FULTON
" 17. WHITLEY
" 18. ALLEN
" 19. ADAMS
" 20. WELLS
" 21. HUNTINGTON
" 22. WABASH
" 23. MIAMI
" 24. CASS
" 25. WHITE
" 26. BENTON
" 27. WARREN
" 28. TIPPECANOE
" 29. CARROLL
" 30. CLINTON
" 31 HOWARD
" 32. TIPTON
" 33. GRANT
" 34. BLACKFORD
" 35. JAY
" 36. RANDOLPH
" 37. DELAWARE
" 38. MADISON
" 39. HAMILTON
" 40. BOONE
" 41. MONTGOMERY
" 42. FOUNTAIN
" 43 VERMILLION
" 44. PARKE
" 45. PUTNAM
" 46. HENDRICKS
" 47. MARION
" 48. HANCOCK
" 49. HENRY
" 50. WAYNE
" 51. UNION
" 52. FAYETTE
" 53 RUSH
" 54. SHELBY
" 55. JOHNSON
" 56. MORGAN
" 57. OWEN
" 58. CLAY
" 59. VIGO
" 60. SULLIVAN
" 61. GREENE
" 62. MONROE
" 63. BROWN
" 64. BARTHOLOMEW
" 65. DECATUR
" 66. FRANKLIN
" 67. DEARBORN
" 68. OHIO
" 69. SWITZERLAND
" 70. RIPLEY
" 71. JEFFERSON
" 72. JENNINGS
" 73. JACKSON
" 74. LAWRENCE
" 75. MARTIN
" 76. DAVIESS
" 77. KNOX
" 78. GIBSON
" 79. PIKE
" 80. DUBOIS
" 81. ORANGE
" 82. WASHINGTON
" 83 SCOTT
" 84. CLARKE
" 85. FLOYD
" 86. HARRISON
" 87. CRAWFORD
" 88. PERRY
" 89. SPENCER
" 90. WARRICK
" 91. VANDERBURG
" 92. POSEY

## COUNTIES IN OHIO

No. 1. WILLIAMS
" 2. FULTON
" 3. LUCAS
" 4. OTTAWA
" 5. LAKE
" 6. ASHTABULA
" 7. TRUMBULL
" 8. GEAUGA
" 9. CUYAHOGO
" 10. LORAIN
" 11. ERIE
" 12. SANDUSKY
" 13. WOOD
" 14. HENRY
" 15. DEFIANCE
" 16. PAULDING
" 17. PUTNAM
" 18. HANCOCK
" 19. SENECA
" 20. HURON
" 21. MEDINA
" 22. SUMMIT
" 23. PORTAGE
" 24. MAHONING
" 25. COLUMBIANA
" 26. STARK
" 27. WAYNE
" 28. ASHLAND
" 29. RICHLAND
" 30. CRAWFORD
No. 31 WYANDOT
" 32. ALLEN
" 33. VAN WERT
" 34. MERCER
" 35. AUGLAIZE
" 36. HARDIN
" 37. MARION
" 38. MORROW
" 39. KNOX
" 40. HOLMES
" 41 COSHOCTON
" 42. TUSCARAWAS
" 43. CARROLL
" 44. HARRISON
" 45. JEFFERSON
" 46 BELMONT
" 47. GUERNSEY
" 48. MUSKINGUM
" 49. LICKING
" 50. DELAWARE
" 51. UNION
" 52 LOGAN
" 53. SHELBY
" 54. DARKE
" 55. MIAMI
" 56. CHAMPAIGN
" 57. CLARKE
" 58. MADISON
" 59. FRANKLIN
" 60. PICKAWAY
No. 61. FAIRFIELD
" 62. PERRY
" 63. MORGAN
" 64. NOBLE
" 65. MONROE
" 66. WASHINGTON
" 67. ATHENS
" 68. HOCKING
" 69. VINTON
" 70. ROSS
" 71. FAYETTE
" 72 GREENE
" 73. MONTGOMERY
" 74. PREBLE
" 75. BUTLER
" 76. LEBANON
" 77. CLINTON
" 78. HIGHLAND
" 79. PIKE
" 80. JACKSON
" 81. MEIGS
" 82. GALLIA
" 83. LAWRENCE
" 84. SCIOTO
" 85. ADAMS
" 86. BROWN
" 87. CLERMONT
" 88. HAMILTON

# GEOLOGICAL FORMATIONS OF OHIO AND INDIANA

COMPILED FROM
ORTON'S MAP OF OHIO 1894 PHINNEY'S MAP OF INDIANA U.S.G.S. 1890
GORBY'S MAP OF INDIANA 1893 AND 1894.
BY FRANK LEVERETT
1897

**NOTE.**—THE CONTOURS ARE BASED CHIEFLY UPON RAILWAY ALTITUDES. THESE DATA ARE SUPPLEMENTED BY PERSONAL ANEROID DETERMINATIONS BOTH IN INDIANA AND OHIO, AND BY NOTES FURNISHED BY MEMBERS OF THE INDIANA SURVEY. IN EASTERN OHIO AVAILABLE DATA ARE SUFFICIENT TO MAP ONLY THE MAIN AREAS STANDING ABOVE 1,000 FEET, AND ARE INSUFFICIENT TO SUPPLY OTHER CONTOURS.

SCALE.
0 5 10 20 30 40 50 MILES

CARBONIFEROUS
- COAL MEASURES CONGLOMERATE GROUP
- EOCARBONIFEROUS LIMESTONE WAVERLY GROUP

DEVONIAN
- OHIO SHALE AND BLACK SHALE
- HAMILTON UPPER HELDERBERG

SILURIAN
- UPPER
  - LOWER HELDERBERG WATERLIME
  - NIAGARA, CLINTON, MEDINA
- LOWER
  - HUDSON RIVER GROUP UTICA SHALE, TRENTON LIMESTONE

J. OTTMANN LITH. CO. PUCK BLDG. N.Y.

lay arch. It can be followed northward to the Michigan border, which it reaches near Sylvania. It can also be traced to the south and east of Findlay, though in somewhat reduced proportions.

There is a dip toward the west and southwest across Indiana and toward the east across Ohio, while at the north, between the main axis and the Lima axis, the strata dip northward. The oldest rocks of the region are exposed along the arch, and consist at the south of the lower Silurian and at the north of the upper Silurian. In passing away from the arch either to the west, east, or north one encounters several formations of Devonian and Eocarboniferous age and enters the Coal Measures near the west and north and east borders of the region under discussion. (See geological map, Pl. XXXIV.)

The Cincinnati arch does not stand markedly higher than border tracts except in a small area of scarcely 1,000 square miles, the middle of which is near the line of Ohio and Indiana. This greatest elevation is attained where the arch is capped by the resistant Niagara limestone. The rock surface slightly exceeds 1,100 feet, while in border districts it is but 900 to 1,000 feet. The district is largely concealed by drift deposits, which blanket it to a depth of 100 to 250 feet or more, and the rise is mainly apparent through instrumental determinations and appears to be very gradual.

Throughout the region under discussion the principal reliefs, aside from the high elevation along the Cincinnati arch, appear to be entirely dependent upon rock structure. The ridges, or elevated tracts, occur where the strata are insoluble or are with difficulty broken down by weathering and stream action. The basins, or low tracts, occur where the strata are soluble or so weak as to yield readily to disintegrating agencies. Referring to the geological map (Pl. XXXIV), it will be seen that the rock formations southwest of the Cincinnati arch have each a narrow belt of outcrop trending from west of north to east of south across Indiana. These lines of outcrop indicate the trend of the ridges or reliefs of that region. In the southern portion of the State these reliefs are not concealed by the drift. In the northern portion they are more or less completely masked by it, but by means of wells they are known to occur. By means of well records it is also known that northeast from the western limb of this arch there is a low rock surface where the strata immediately below the drift are weak, and a higher rock surface where the strata are hard or insoluble. The large area of Devonian shale in northern Indiana, though generally filled now with drift to a height of 200 to 400 feet above Lake Michigan, has a rock surface about as low as the lake level. In the district east of the Cincinnati arch, also, the strata outcrop in narrow belts trending north to south across the State of Ohio, and here, as in Indiana, the lines of outcrop indicate the trend of the reliefs or escarpments.

The accompanying diagrammatic profile section (A—A, Pl. XXXV), leading west to east across southern Indiana, brings out the escarp-

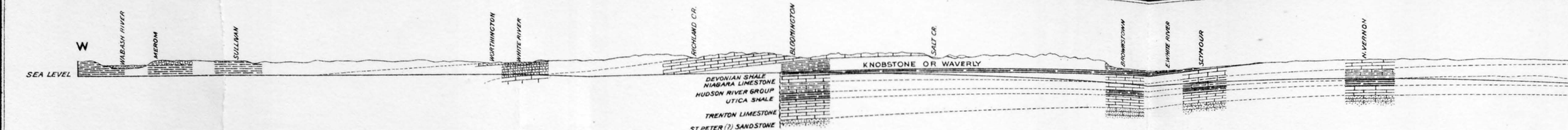
ments of that State in their average strength. A line following any one of the ridges or basins would have considerable oscillation, 100 feet or more in the weak strata and an even greater amount in the hard strata. The section aims to strike a mean between the highest and lowest points on such a line.

Taking the section somewhat in detail, it is found that the weak strata of the Hudson River group, along the southeast border of the State, are broken down sufficiently to give a perceptible relief to the tract immediately west, which is still capped by the more resistant Niagara strata. The relief, however, seldom exceeds 100 feet. From the Niagara there is a somewhat rapid descent westward, nearly as rapid as the dip of the strata, to a low tract or basin occupied by Devonian shale, a descent of about 400 feet in a distance of 25 to 30 miles. Along the west border of this shale area is a prominent rim formed by the resistant strata of the Eocarboniferous Knobstone or Waverly formation. This basin is conspicuous from the vicinity of Columbus, Indiana, southward some distance into Kentucky, and is crossed by the Ohio River near Louisville. Northwestward from Columbus it is greatly filled by glacial deposits, but can be traced readily by deep borings at least to the Wabash Valley, near Lafayette. In the unfilled southern portion of the basin there is a low rock divide separating the East White from the Ohio drainage area, a feature which shows that since the present drainage systems were inaugurated no large stream has flowed lengthwise of its course. Concerning the northern portion of this basin nothing definite can be determined as to the effect of drainage lines in preglacial times, on account of the great deposits of drift in that region.

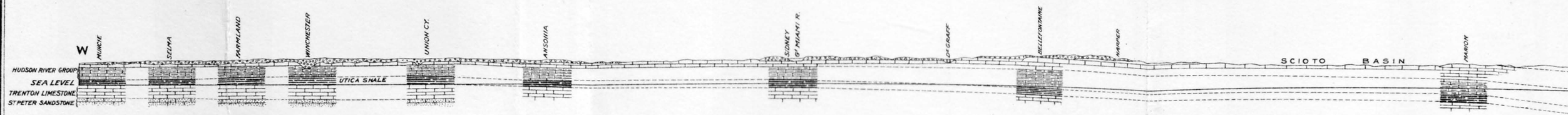
The Knobstone or Waverly formation, on the west border of the basin occupied by the Devonian shale, has an abrupt and nearly continuous relief of 300 to 400 feet, with occasional knobs 500 to 600 feet above the basin. One knob in Brown County, "Weedpatch Hill," stands about 1,150 feet above tide, but this is nearly 100 feet higher than any of the neighboring knobs and ridges. This escarpment is so abrupt in the unglaciated districts, from Brown County, in central Indiana, southward to the Ohio River, as to resemble a river bluff, and it is but natural that this feature, taken in connection with the rapid descent from the Niagara to the Devonian shale on the east border, should have led some of the earlier students to consider the low tract occupied by the Devonian shale to be due to the action of a large river.

The knobs and ridges of the Knobstone or Waverly formation form a belt that is scarcely 2 miles in width near the Ohio, but which becomes 25 or 30 miles wide in central Indiana. It stands in relief not only above the low basin on the east, but also above a limestone belt on the west. The relief above this limestone belt, however, is only 150 to 300 feet, or scarcely half so great as the relief above the Devonian shale. This belt of limestone is bordered on the west by the conglomerate sandstone. This formation has knobs and ridges which rise 100

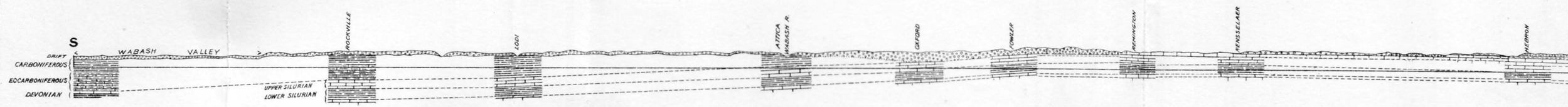
U.S. GEOLOGICAL SURVEY



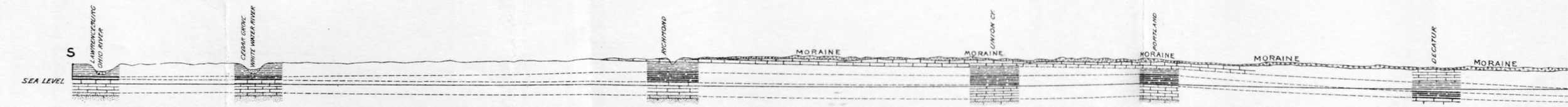

SECTION A-A. FROM MEROM EASTWARD ACROSS SOUTH CENTRAL INDIANA TO LAWRENCEBURG



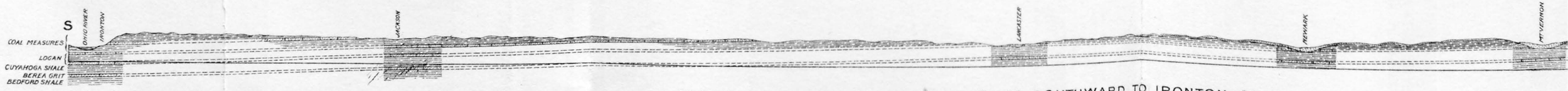

SECTION B-B. FROM MUNCIE INDIANA TO MANSFIELD OHIO




SECTION C-C. FROM TERRE-HAUTE NORTHWARD ACROSS WESTERN INDIANA TO MICHIGAN CITY



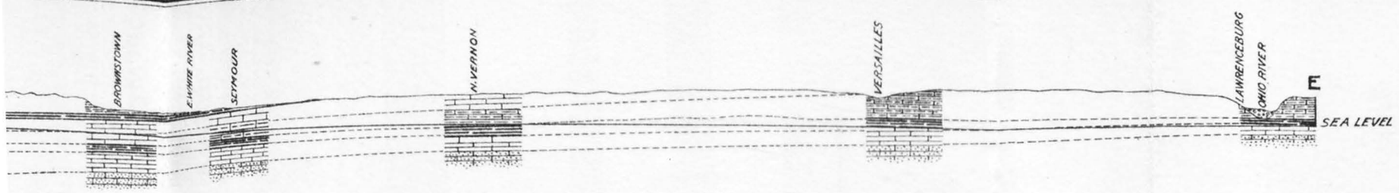

SECTION D-D. FROM LAWRENCEBURG NORTHWARD ACROSS EASTERN INDIANA TO BUTLER



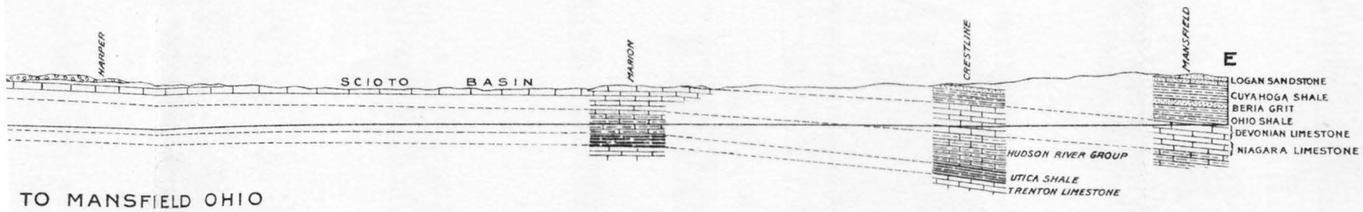

SECTION E-E. FROM BERLIN HEIGHTS SOUTHWARD TO IRONTON OHIO

# GEOLOGICAL SECTION IN INDIANA AND OHIO

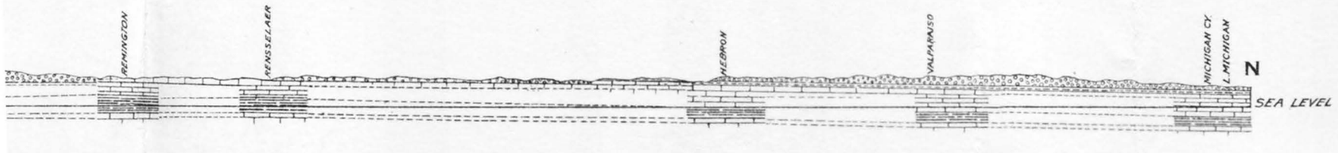
BY FRANK LEVERETT



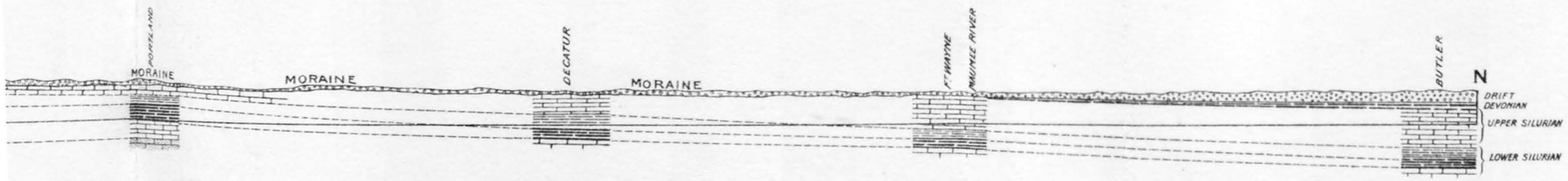

CENTRAL INDIANA TO LAWRENCEBURG



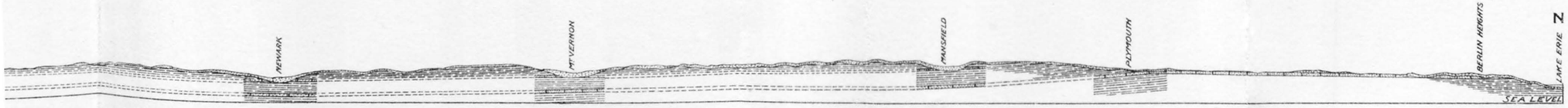

TO MANSFIELD OHIO



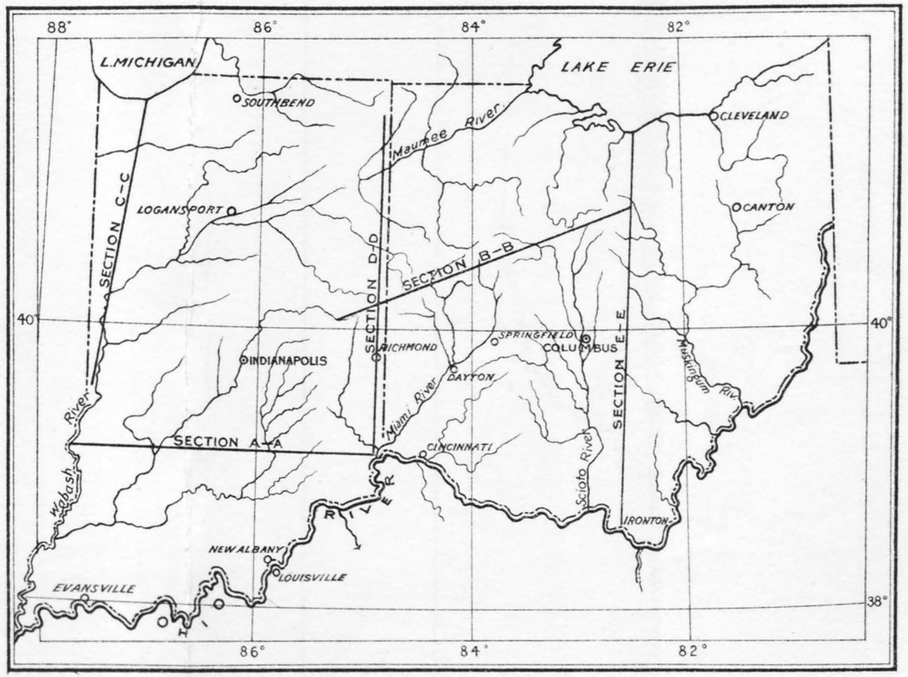

S WESTERN INDIANA TO MICHIGAN CITY




ROSS EASTERN INDIANA TO BUTLER




HWARD TO IRONTON OHIO




Scale

5 0 5 10 15 MILES

HORIZONTAL SCALE

2000 1000 0 2000 4000 6000 FEET

VERTICAL SCALE

Vertical exaggeration 10 times

# GEOLOGICAL SECTION IN INDIANA AND OHIO

BY FRANK LEVERETT

J.Ottmann Lith.Co.N.Y.

feet or more above the limestone, thus forming the western rim of a shallow trough or basin occupied by it. The occurrence of these reliefs on either side gave rise to the opinion advanced by Mr. Collett[1] that this limestone trough is the ancient valley of a stream. There seems, however, no necessity for assuming the presence of a large stream to effect the reduction of such a limestone tract to a lower level than the sandstone tracts which border it on the east and west. The sandstone being less easily acted upon by atmospheric solvents, naturally stands in relief above the more soluble limestone.

The belt occupied by the conglomerate sandstone has in southern Indiana a rather abrupt relief of 150 or 200 feet, or even more, above the Coal Measures basin which borders it on the west, the rise not infrequently being made within 4 or 5 miles. The relief is perhaps somewhat less in western Indiana, though still sufficient to be recognizable in the presence of a heavy coating of drift.

All these formations, from the Niagara westward to the Coal Measures basin, are crossed by drainage lines whose courses show little regard to the reliefs of the region. The general course of drainage is southwestward, or almost directly across the trend of the ridges and basins, and with but slight deflections where a stream passes from one formation to another. The drainage seems therefore largely inherited from a time when the basins and ridges did not exist in their present strength.

Turning to Ohio, we have in Pl. XXXV, section B—B, a diagrammatic section, based upon railway elevations, extending from Union City, on the Cincinnati arch, in a course north of east to Mansfield. It crosses the elevated tract near Bellefontaine and the northern end of the basin drained by the Scioto and rises to the escarpment forming the eastern border of that basin. In the nearly level portion from the State line eastward to Degraff the Niagara limestone is crossed. The rise eastward from Degraff to Harper is over the Waterlime, Lower Helderberg, and Upper Helderberg limestones. The highest points in Ohio are only a few miles south of Harper, and they carry remnants of the Devonian shale. The descent to the Scioto is made over the Waterlime and Lower Helderberg limestones. East from the Scioto the rise is made to the Upper Helderberg or Corniferous near Marion, to the Knobstone or Waverly near Galion, and to later Eocarboniferous formations on the brow of the escarpment near Mansfield. Eastward from this escarpment there is an eroded tract whose ridges and knobs rise 200 to 600 feet above the valleys and whose intricacy has not been reduced to system.

The Devonian shales have only a narrow belt of outcrop on the east border of the basin, though they probably extended west originally beyond the outcrops near Harper. Their extensive removal seems attributable to the weakness of the strata.

[1] Tenth Ann. Rept. Indiana Geol. Survey, 1878, pp. 298–301.

From this section it appears that there are two prominent escarpments separated by a lowland drained by the Scioto River. This section fairly illustrates the reliefs of western Ohio from the watershed between Lake Erie and the Ohio southward to the southern end of the Scioto basin near Chillicothe. In places the escarpment on the west border of the Scioto basin reaches 1,400 feet (independent of drift coating), but usually it is only 1,100 to 1,200 feet, above tide. The escarpment east of the Scioto basin stands higher in the vicinity of the watershed than farther south. The highest points, a few miles south of Mansfield, reach about 1,400 feet, while the escarpment generally is but 1,100 to 1,150 feet above tide. The Scioto basin, as well as the escarpments on its east and west borders, stands highest in the vicinity of the watershed, being about 950 to 1,000 feet, while in the southern portion it decreases in altitude to about 650 feet, above tide. The escarpments have therefore about as great relief on the borders of the basin in the southern part as in the northern. The southward dip of the strata in central Ohio is shown in section E—E, of Pl. XXXV, and the northward dip near the Ohio-Indiana line is shown in section D—D.

North from the watershed the escarpment which forms the western rim of the Scioto basin disappears, but the escarpment east of the basin is continued north to the shore of Lake Erie, though with a markedly diminished strength. From this point eastward Lake Erie is bordered more or less closely by elevated tracts rising abruptly 200 to 500 feet or more above its water surface.

In southern Ohio the escarpment which forms the western rim of the Scioto basin is continued southward to the Ohio River. The closing in and disappearance of the Scioto basin in southern Ohio leaves the country elevated from the western escarpment eastward beyond the Scioto River. A reference to the topographic and geologic maps (Pls. XXXIII and XXXIV) will aid in making clear the above statements.

In northeastern Ohio there is a basin formed in the Cuyahoga shales and bordered by escarpments of the Eocarboniferous conglomerates This low tract, known as the Grand River basin, has a width of 10 or 12 miles and extends fully 30 miles southward from the border of the Lake Erie basin and about 40 miles from the lake shore, there being a narrow plain bordering the lake in this region. The escarpments bordering the basin rise 200 to 400 feet above it. On the west the rise is abrupt like a bluff, but on the south and east it is more gradual. This basin, as indicated below, was the line of discharge for the preglacial Upper Ohio, and is filled with drift to a depth of over 200 feet along the line of the old valley.

The general upland surface of this region, though probably nearly plane at the close of the Cretaceous cycle of base leveling and possibly down to the middle Tertiary, does not readily suggest the restoration of the ancient surface. The irregularity in the altitude of the escarpments and ridges is such as to make it doubtful if a notable portion of any of them preserves the surface of an ancient peneplain.

A similar conclusion is reached from an examination of the high-level gravel deposits of southern Indiana. These gravel deposits, as long since noted by Prof. E. T. Cox[1] and more recently by Prof. R. D. Salisbury and the present writer, have been found only in small remnants at altitudes of 700 to 750 feet above tide on the crests of the most elevated ridges of the portions of southern Indiana and northern Kentucky where they occur. The gravel deposits appear to mark the shores or wave products of an ancient sea connected with a period of much less altitude than the present, and also probably with a period of base-leveling of the uplands.

They are referred to the Tertiary by Professor Cox, and because of the general resemblance in weathering, etc., are thought to be of similar age to the gravels of southern Illinois. The present writer concurs in the view that a striking resemblance exists between the gravels of the two districts, yet it seems scarcely safe to correlate definitely from the present fragmentary data. The gravels of southern Illinois and their continuation southwestward into Arkansas are found to rest upon clays and sands of Eocene age, thus making it certain that they are not older than the Tertiary.[2]

Professor Call finds evidence of an interval of erosion between the deposition of the sands and the overlying gravels, thus opening the question of a much later date than Eocene for the deposition of the gravels.[3] Should the correlations just suggested be sustained, the striking physiographic features of Indiana and Ohio here noted are confined to the later part of the Tertiary and the Pleistocene. In this connection it may be noted that recent studies by Dr. C. W. Hayes and others in Tennessee and western Kentucky point to a similar late Tertiary development of great lowland tracts in the western part of those States, comparable in size to those of the region under discussion.[4]

Much of the northwestern part of Ohio presents a surface so level as to suggest a base-leveled plain. The even surface covers limestone and shale areas alike, though the shale area is slightly lower than the limestone. Near the west end of Lake Erie this plain stands no higher than the surface of the lake. It rises gradually southward to an altitude about 300 feet above the lake in the vicinity of the continental watershed. South from the watershed it varies but little in elevation over wide areas in western Ohio and eastern Indiana, which are underlain by the Silurian limestones. In this region, however, the plain seems due to the level position of the underlying limestone strata rather than to base-leveling. Upon passing either east or west into districts in which the rate of dip becomes greater, reliefs or other variations in

[1] Third Ann. Rept Indiana Geol. Survey, 1872, p. 138.

[2] A. H. Worthen, Geology of Illinois, Vol. I, 1866, pp. 44–46, 411, 413, 417, 423, 444, 452; Vol. II, 1868, pp. 21, 22, 52. R. Ellsworth Call, Arkansas Geol. Survey, 1889, Vol. II, Crowleys Ridge.

[3] Loc. cit., pp. 125–131.

[4] Communicated to the writer.

altitude become correspondingly greater. The writer scarcely feels warranted, in view of this complexity, in passing judgment upon the cause of the extensive plains which the region presents.

## GLACIAL RIDGES.

The glacial history in this as well as in neighboring districts is very complex. Not only are there numerous moraines marking the successive positions of the ice front, but there are evidences of more than one ice invasion. An invasion which reached to the glacial boundary so long preceded a later invasion which came down nearly to the boundary that the deposits of the former have suffered much greater weathering and erosion than are presented by the latter, and they appear to have an age several times as great. In consequence of this difference in age the former deposits have come to be designated the older or earlier drift, while the latter are called the newer or later drift. In the later drift also there is a double invasion whose movements differ greatly in direction, the first movement being southward and the later movement southwestward. The earliest drift sheet found in this region is a continuation eastward of the earliest sheet of Illinois. The name *Illinoian* has come into use as the most suitable one for this sheet.[1] The later drift includes the early and late Wisconsin of Chamberlin.

The approximate glacial boundary has been traced in a westward and southward course across eastern Ohio by Prof. G. F. Wright[2] and found to come to the Ohio River near the southeast corner of Brown County, as may be seen by the glacial map (Pl. XXXVI). For about 200 miles below this point it appears to lie a few miles outside the line indicated by Professor Wright, extending south of the Ohio from 1 to perhaps 20 miles, the greatest extension being opposite Cincinnati. A short distance above Louisville, Kentucky, the boundary crosses into Indiana and has a pronounced reentrant angle that carries it about 75 miles north of the Ohio River near the meridian of Indianapolis. The boundary from here turns southwest, and where it passes into Illinois it nearly touches the Ohio River. The portion of the boundary east from Highland County, Ohio, is not far outside the limits of the Wisconsin or later ice invasion, and in places seems to be reached by that invasion. West from this county the earlier drift is usually exposed for a width of 20 or 30 miles, and in places for a much greater distance. On the line of Indiana and Illinois it extends nearly 100 miles beyond the later drift. Near the reentrant angle in south-central Indiana, however, it extends but 10 or 15 miles beyond the later drift.

The glacial boundary, except where touched by the later ice invasion, is seldom characterized by a definite morainic ridge, and in places is

[1] See Chamberlin, Jour. Geol., Vol. IV, 1896, pp. 872–876.

[2] The Glacial Boundary in Ohio, Indiana, and Kentucky, by G. F. Wright. Published by Western Reserve Historical Society, Cleveland, Ohio, 1884. Also Bull. U. S. Geol. Survey No. 58, 1890.

## COUNTIES IN INDIANA

No. 1. LAKE
" 2. PORTER
" 3. LA PORTE
" 4. ST. JOSEPH
" 5. ELKHART
" 6 LAGRANGE
" 7. STEUBEN
" 8. DEKALB
" 9. NOBLE
" 10. KOSCIUSKO
" 11. MARSHALL
" 12. STARKE
" 13. NEWTON
" 14 JASPER
" 15. PULASKI
" 16. FULTON
" 17. WHITLEY
" 18. ALLEN
" 19. ADAMS
" 20. WELLS
" 21. HUNTINGTON
" 22. WABASH
" 23. MIAMI
" 24. CASS
" 25. WHITE
" 26. BENTON
" 27. WARREN
" 28. TIPPECANOE
" 29. CARROLL
" 30. CLINTON
" 31 HOWARD
" 32. TIPTON
" 33. GRANT
" 34. BLACKFORD
" 35. JAY
" 36. RANDOLPH
" 37. DELAWARE
" 38. MADISON
" 39. HAMILTON
" 40. BOONE
" 41. MONTGOMERY
" 42. FOUNTAIN
" 43 VERMILLION
" 44. PARKE
" 45. PUTNAM
" 46 HENDRICKS
" 47. MARION
" 48. HANCOCK
" 49. HENRY
" 50. WAYNE
" 51. UNION
" 52. FAYETTE
" 53. RUSH
" 54. SHELBY
" 55. JOHNSON
" 56. MORGAN
" 57. OWEN
" 58. CLAY
" 59. VIGO
" 60. SULLIVAN
" 61. GREENE
" 62. MONROE
" 63. BROWN
" 64. BARTHOLOMEW
" 65. DECATUR
" 66. FRANKLIN
" 67. DEARBORN
" 68. OHIO
" 69. SWITZERLAND
" 70. RIPLEY
" 71. JEFFERSON
" 72. JENNINGS
" 73. JACKSON
" 74. LAWRENCE
" 75. MARTIN
" 76. DAVIESS
" 77. KNOX
" 78. GIBSON
" 79. PIKE
" 80. DUBOIS
" 81. ORANGE
" 82. WASHINGTON
" 83. SCOTT
" 84. CLARKE
" 85. FLOYD
" 86. HARRISON
" 87. CRAWFORD
" 88. PERRY
" 89. SPENCER
" 90. WARRICK
" 91. VANDERBURG
" 92. POSEY

# THE PLEISTOCENE DEPOSITS OF OHIO AND INDIANA

BY

FRANK LEVERETT

1897

**NOTE.**—THE CONTOURS ARE BASED CHIEFLY UPON RAILWAY ALTITUDES. THESE DATA ARE SUPPLEMENTED BY PERSONAL ANEROID DETERMINATIONS BOTH IN INDIANA AND OHIO, AND BY NOTES FURNISHED BY MEMBERS OF THE INDIANA SURVEY. IN EASTERN OHIO AVAILABLE DATA ARE SUFFICIENT TO MAP ONLY THE MAIN AREAS STANDING ABOVE 1,000 FEET, AND ARE INSUFFICIENT TO SUPPLY OTHER CONTOURS.

## COUNTIES IN OHIO

No. 1. WILLIAMS
" 2. FULTON
" 3. LUCAS
" 4. OTTAWA
" 5. LAKE
" 6. ASHTABULA
" 7. TRUMBULL
" 8. GEAUGA
" 9. CUYAHOGO
" 10. LORAIN
" 11. ERIE
" 12. SANDUSKY
" 13. WOOD
" 14. HENRY
" 15. DEFIANCE
" 16. PAULDING
" 17. PUTNAM
" 18. HANCOCK
" 19. SENECA
" 20. HURON
" 21. MEDINA
" 22. SUMMIT
" 23. PORTAGE
" 24. MAHONING
" 25. COLUMBIANA
" 26. STARK
" 27. WAYNE
" 28. ASHLAND
" 29. RICHLAND
" 30. CRAWFORD
No. 31 WYANDOT
" 32. ALLEN
" 33. VAN WERT
" 34. MERCER
" 35. AUGLAIZE
" 36. HARDIN
" 37. MARION
" 38. MORROW
" 39. KNOX
" 40. HOLMES
" 41 COSHOCTON
" 42 TUSCARAWAS
" 43. CARROLL
" 44. HARRISON
" 45. JEFFERSON
" 46 BELMONT
" 47. GUERNSEY
" 48. MUSKINGUM
" 49. LICKING
" 50. DELAWARE
" 51 UNION
" 52 LOGAN
" 53. SHELBY
" 54. DARKE
" 55. MIAMI
" 56. CHAMPAIGN
" 57. CLARKE
" 58. MADISON
" 59. FRANKLIN
" 60. PICKAWAY
No. 61. FAIRFIELD
" 62. PERRY
" 63. MORGAN
" 64. NOBLE
" 65. MONROE
" 66. WASHINGTON
" 67. ATHENS
" 68. HOCKING
" 69. VINTON
" 70. ROSS
" 71. FAYETTE
" 72 GREENE
" 73. MONTGOMERY
" 74. PREBLE
" 75. BUTLER
" 76. LEBANON
" 77. CLINTON
" 78. HIGHLAND
" 79. PIKE
" 80. JACKSON
" 81. MEIGS
" 82 GALLIA
" 83. LAWRENCE
" 84. SCIOTO
" 85. ADAMS
" 86. BROWN
" 87. CLERMONT
" 88. HAMILTON

GLACIAL RIDGES
TILL PLAINS
LOESS COVERED TILL
VALLEY DRIFT AND ALLUVIUM
EXTINCT LAKES
UNGLACIATED

J. OTTMANN LITH. CO. PUCK BLDG. N.Y.

very vague. Indeed, the earliest or Illinoian ice invasion, so far as its deposits are exposed to view, had not such a pronounced moraine-forming habit as the later invasions. There are, however, occasional definite ridgings of the drift of the Illinoian invasion. In some cases the ridges are very sharp. A conspicuous illustration is found in "Chestnut Ridge," in Jackson County, Indiana, which, though only a mile in width, in one place attains a height of 170 feet by surveyor's level, and it presents a general elevation of 75 or 100 feet above the bordering plains. A similar ridge leads southeast a few miles from Martinsville, Indiana. These are the only instances noted in Indiana. Ridges of this type are not rare in southwestern Illinois, but none have been observed in Ohio. Sharp knolls of drift appear in the valleys of several of the small tributaries of the Ohio in southeastern Indiana and southern Ohio, which, in some instances, reach a height of 75 or 100 feet. A few sharp knolls also occur just south of Hillsboro, Ohio, on the headwaters of Rocky Fork of Paint Creek.

The early Wisconsin invasion, which had its terminus at the Shelbyville moraine in Illinois, and which is represented in that State by a series of bulky moraines, is apparently represented in Indiana and Ohio by rather feeble moraines in a narrow district in which the ice sheet extended beyond the next succeeding invasion—the late Wisconsin. The moraines are to be seen in Vigo, Parke, Fountain, Warren, Benton, Montgomery, and Putnam counties in western Indiana, and in Bartholomew, Decatur, Rush, Fayette, Union, and Franklin counties in southeastern Indiana. In Ohio a single morainic belt is recognized as belonging to this invasion, viz, the outermost moraine represented on the glacial map, and which leads from the Indiana line eastward to Ross County, Ohio. This belt apparently passes beneath the later series and has not been recognized in central or northeastern Ohio. All the moraines of this invasion, so far as exposed in Indiana and Ohio, are of a single type, that of a gently undulating ridge. The relief is usually but 20 or 30 feet, and the swells and undulations on the crest and slopes are but 5 to 15 feet in usual height. In Benton and Warren counties, Indiana, however, the ridges present reliefs of 50 to 75 feet or more.

Before passing to the discussion of the moraines formed by the late Wisconsin ice movement, attention is called to an elevated tract of thick drift in Clinton, Boone, western Tipton, and western Hamilton counties, Indiana. By reference to the topographic map it will be seen that portions of these counties stand above 900 feet, or about 100 feet above the average altitude of that part of the State. Yet well sections show that the rock surface is much lower than in the counties west and south, it being the district underlain by Devonian shale. This elevated tract has generally a smooth surface, though occasional feeble drift ridges occur. It seems not improbable that this great drift accumulation was made largely in the early Wisconsin and has been overridden by

the late Wisconsin movement. Possibly it is the continuation of a bulky system of moraines which enters Indiana from Illinois in Benton and Warren counties. The same system may find an eastward continuation beyond White River in the elevated belt of thick drift south of the westward-flowing portion of that stream. In that district, however, a morainic system of the late Wisconsin follows nearly the south border and thus suggests a late Wisconsin age for the belt.

The late Wisconsin movement is represented in Indiana and western Ohio by a remarkably full series of moraines, there being a greater number than have been found associated with this movement in the neighboring States. The distribution and characteristics of the outer system or series were studied by Professor Chamberlin in the early days of his glacial investigations and discussed by him in a report of this Survey as the "Terminal Moraine of the Second Glacial Epoch."[1] As shown by Professor Chamberlin, it is disposed in a series of loops which encircle or extend into the larger basins of the district, while its reentrants are at the somewhat elevated escarpments. It is a pronounced topographic feature throughout much of its course in Indiana and Ohio, though for a few miles in central and western Indiana it is rather vague. In such places, however, the moraine carries a very large number of bowlders, which aid in mapping the position of the ice margin. It consists in places of two or more distinct members. Such differentiation is best displayed in the basins. At reentrant angles there is usually a single sharp belt. In strength of expression this morainic system is not surpassed by any other in Ohio, but in northern Indiana some of the later moraines have sharper features. It consists usually of a closely aggregated series of knolls, 10 to 40 feet or more in height, often elliptical, in line with the moraine, but in some cases nearly conical. These knolls sometimes rest upon a basement ridge with a relief of 25 to 50 feet, but in many places the ridge is not well defined. Its variations from place to place have been set forth by Professor Chamberlin in the paper referred to, and need not be entered into here. The position of this morainic system may be readily traced on the accompanying map, Pl. XXXVI. It will be observed that from the Scioto eastward it lies near the glacial boundary as traced by Professor Wright, while west from the Scioto it departs widely from that boundary. At the west it projects slightly into Illinois in crossing the Iroquois basin, but returns into Indiana on the north border of that basin, and is lost in the Kankakee marsh. Its correlation with moraines farther north and west is not fully established.

Of the later moraines of the late Wisconsin movement, the Valparaiso, which traverses northwestern Indiana, the Maxinkuckee in Marshall County, Indiana, and a strong interlobate belt in northeastern Indiana are conspicuous representatives.

The Valparaiso moraine, with a width of 5 to 10 miles or more, rises

[1] Third Ann. Rept. U. S. Geol. Survey, 1883.

50 to 150 feet above the low plain on its north border, but somewhat less above the Kankakee marsh on its south border. It has generally a swell-and-sag topography, with oscillations of 15 to 30 feet, but in places assumes a sharper topography and carries lakelets among its knolls and ridges.

The Maxinkuckee moraine is very similar in topography to the Valparaiso moraine, but is less bulky. The topography is of a very sharp type near Lake Maxinkuckee, and this lake is set in a deep depression almost completely surrounded by morainic knolls.

The interlobate belt of northeastern Indiana, formed at the junction of the Saginaw and Erie lobes, is very complex, there being in addition to the main moraine several belts leading off from it to the northwest and southeast. The northwest slope and the tract occupied by the Saginaw lobe north of the moraine is characterized by a greater number of sharp knolls and also by more numerous lake-filled basins than the southeast slope and the moraines of the Erie lobe. On the former it is not rare to find knolls and ridges rising abruptly 50 or 75 feet above border tracts, while lake basins are in some cases 50 feet or more in depth. The southeast slope, formed by the Erie lobe, has seldom such sharp features, the knolls being usually less than 25 feet in height. The crest of this interlobate moraine stands 100 to 200 feet above the neighboring plains on the northwest and southeast, as may be seen by reference to the glacial map (Pl. XXXVI).

In the remainder of the district, which includes much of central and northeastern Indiana and northern Ohio, the moraines are of a type best designated perhaps as a smooth ridge. They are commonly 1 or 2 miles but occasionally 5 miles' in width, and rise 25 to 75 feet above the bordering plains. The rise is more abrupt on the outer than on the inner or iceward border, the slope on the inner border being usually twice or thrice as long as on the outer. These moraines have a gently undulating surface, with oscillations of 10 to 25 feet, but portions are nearly smooth, with oscillations no greater than on the bordering till plains. In such portions, however, the relief of the ridge is usually sufficiently pronounced to make the belt conspicuous. The moraines of this type have greater continuity than some of the moraines with sharper expression. By reference to the glacial map (Pl. XXXVI) it will be observed that they are very influential in determining the courses of drainage lines. The course of each ridge being shown on this map, it is scarcely necessary to outline the distribution of the several ridges in detail. It will be observed that in the plains drained by the Miami and Scioto there are loops formed by these moraines, and reentrants at the higher tracts on their borders, thus rudely repeating the looping of the main or outer system of the late Wisconsin ice movement. It will also be observed that a somewhat complex series, consisting in places of three members, follows nearly the continental watershed from the bend of the Cuyahoga near Akron westward to the

plains of northwestern Ohio. The series there and in northeastern Indiana has its members more widely separated.

Note should be taken also of feeble moraines on the border of Lake Michigan, which rise only 30 to 50 feet above the lake plains and are a mile or less in width.

## THE DRAINAGE SYSTEMS.

The region under discussion is so situated as to discharge its waters to several great drainage systems. From the extreme northwest the discharge is into Lake Michigan; south of this is a small area which drains to the Illinois; from the northeast the drainage enters Lake Erie; the drainage of the greater part of Indiana is tributary to the Wabash, itself a tributary of the Ohio; the southern end of Indiana is directly tributary to the Ohio through small streams; much of Ohio drains southward through the Miami, Scioto, Muskingum, and smaller streams.

The boundaries between the several systems fall mainly within the glaciated portion and are largely determined by glacial accumulations. The only water partings within the glaciated portion which are to any marked degree coincident with an elevated rock surface are (1) in southern Randolph County between the headwaters of White River, a tributary of the Wabash, and Whitewater River, a more direct tributary of the Ohio, and (2) in west-central Ohio between tributaries of the Scioto and the Great Miami. But even here the water partings are only in a general way dependent upon the elevated rock surface, the parting itself being at a moraine.

The boundaries between some of the systems have suffered notable changes since the ice sheet withdrew from the basins of the Great Lakes and their present outlet, the St. Lawrence River.[1] It has long been known that the Wabash once received the drainage from the portion of northern Indiana now tributary to Lake Erie and from a glacial lake occupying the western end of the Lake Erie basin.[1] The channel connecting the Maumee, a tributary of Lake Erie, with the Wabash is still a plainly marked feature along the line of the Wabash Railway from Fort Wayne to Huntington. At the eastern end of this outlet, near Fort Wayne, there are beach lines opening into it which leave no doubt as to the presence of a lake at a level corresponding to the outlet (about 775 feet above tide). The present water parting in this old outlet is determined simply by a slight accumulation of silt in the old channel near the mouths of the St.-Joseph-of-the-Maumee and the St. Mary rivers. This delta-like deposit being at the summit in the outlet, the waters were easily turned eastward down the Maumee.

Another notable change in drainage is found at South Bend, Indiana.

[1] See Report on the surface geology of the Maumee Valley, by G. K. Gilbert: Geology of Ohio, Vol. I, 1873, pp. 535–556; also Am. Jour. Sci., May, 1871.

The St. Joseph River,[1] now tributary to Lake Michigan, formerly discharged southwestward from South Bend into the Kankakee. There is still a well-defined river channel connecting the St. Joseph with the Kankakee, whose surface at the point where it leaves the St. Joseph is but 45 or 50 feet above the present low-water surface of the river. The discharge to the Kankakee was the best line open to the St. Joseph River while the ice sheet was occupying the Lake Michigan basin, but upon the withdrawal of the ice sheet and the lowering of the lake formed by it at the south end of the Lake Michigan basin, a new line was opened which had the advantage of more rapid fall. Thus the Lake Michigan system became enlarged at the expense of the Illinois River system.

The present lines of drainage within the glaciated portion of this region seldom coincide for any great distance with preglacial lines. They are in many cases too shallow to reach the bottom of the glacial deposits. Those which have cut through these deposits often encounter the uneven rock surface of preglacial ridges and hills. Throughout the greater part of the glaciated area in Indiana and in much of northwestern Ohio the present drainage channels are flowing at an elevation nearly as high as that of the preglacial ridges. The rock floors of preglacial valleys encountered in wells show that the channeling had reached a low level. In western Ohio channels stand in places within 400 feet of sea level, and in western Indiana within 250 or 300 feet. The channeling is even lower in northeastern Ohio, the rock floor of the Cuyahoga at Cleveland being but 100 feet above tide. The southern portion of Indiana has too little drift filling to prevent the main drainage lines from following preglacial valleys. Thus the Ohio along the boundary of Indiana, the West Whitewater and main Whitewater, and the lower courses of the White and Wabash rivers occupy valleys of preglacial age. These valleys are usually filled, however, to such an extent that the present streams are flowing nearly 100 feet above the old rock floors, and occasionally, as on the West Whitewater, nearly 200 feet above the old floor.

The streams within the glaciated portion of southern Ohio are seldom strictly coincident with preglacial lines for any great distance except in the case of the Ohio River, though they may have general courses nearly coincident with the preglacial lines. Thus the Great Miami below Dayton and several of its tributaries in the same section of the stream traverse lowlands with only occasional short incursions into the edge of bordering uplands. The Scioto basin probably had a preglacial drainage line along its north-to-south axis, but it was not coincident with the present Scioto River. In the unglaciated portion of Ohio great changes of drainage have resulted from the blocking of northward outlets, but the streams are only rarely thrown into courses which had not been opened by preglacial drainage lines. It is proba-

[1] This river should be distinguished from the smaller St.-Joseph of-the-Maumee.

ble that in many instances they have a flow in the reverse direction from that of the preglacial lines, especially in the central and northern portions of the State. The subject of changes of drainage in that region is now under investigation by several physiographers, and it is probable that the leading preglacial lines will ere long be traced and their connections established.

The development of the drainage lines in the glaciated portion of the region is naturally in a far from mature stage. The best-developed lines show but partially graded beds, with rapids or falls where barriers are in process of removal. Some of the streams in the northern portion have scarcely begun the opening of a channel, but flow through a succession of ponds and marshes, their principal work being the removal of barriers between the ponds. In southern Ohio, in portions of Clermont, Brown, Clinton, and Highland counties, channels are poorly developed, owing to the extreme flatness of the surface. In southwestern Indiana extensive marshes border some of the tributaries of the White and Wabash rivers. In this latter district the sluggish drainage is due to low rate of fall. In the detailed discussion which follows, the rate of fall of the main streams is considered.

In the unglaciated portion of Indiana drainage systems are strikingly in contrast with the immature systems of the glaciated portion. Except in the "sink-hole region" along the outcrop of the St. Louis limestone (see p. 483), widely branching or dendritic systems are developed, which are cut down to comparatively low and regular gradients. In some cases, however, these valleys have been so obstructed by the glacial deposits which fill the main lines of discharge that deflections of some consequence occur. At such points the valleys have the appearance of an immature state of development. The most conspicuous illustration of such a deflection is found in the Ohio Valley at Louisville. The filling with gravel brought down by the river is so great as to overspread a shelf of rock on the border of the valley. The stream in reexcavating its valley has taken a course a little to the north of the deep part of the preglacial line, and thus encountered the rock shelf. Similar slight deflections occur on the East White at Shoals and at Rockford. The falls on East White at Hindostan, a few miles below Shoals, are only in part due to the gravel filling. At that point the stream has cut across the neck of an old oxbow, the gravel filling being sufficiently high to carry the stream over a low point in the ridge that was encircled by the oxbow. This ridge is now cut down nearly to the level of the stream bed below the falls, so that scarcely 5 feet of descent is made over the rock ledges at low water, and the falls are said to be scarcely perceptible at high-water stages.

The system of underground drainage in the limestone has been so complete that surface drainage lines are very poorly developed in several counties of southern Indiana, notably Harrison, Washington, Orange, and Lawrence counties.

## THE OHIO RIVER SYSTEM.

Under this system is included the Ohio, on the boundary of Ohio and Indiana, and the small streams directly tributary to it above the Wabash. The several large tributaries, the Wabash, Great and Little Miami, Scioto, Hocking, and Muskingum, are each discussed under a separate head.

*The Ohio River.*—A survey of the Ohio River made by the United States Army Engineers shows the length of the stream from Pittsburg to Cairo to be 967 miles, of which the southern boundary of Ohio occupies 446 miles, and that of Indiana 352 miles.[1]

The river presents an interesting series of shoals and riffles, separated by pools in which the water is deeper and the fall very low. The summary of the profile made by the Army engineers shows 187 pools with over 7 feet depth at low water, which occupy 632½ miles, an average length of 3.47 miles. Of these, 127 pools above Louisville, Kentucky, average 2.8 miles, with a total length of 363 miles; 60 pools below Louisville, with a total length of 266 miles, have an average length of 4.4 miles.

On the border of Ohio the riffles (103 in number) cover a combined length of 137 miles and have a total fall of 170 feet. The pools, with a combined length of 309 miles, have a fall of 64 feet, or but 2.5 inches per mile. The greatest fall noted for a single mile on the border of this State is at Letart Falls, Meigs County, where a descent of 3.2 feet is made. There are 11 riffles with a descent exceeding 2 feet per mile. The least fall reported is in a pool 8 to 15 miles below Cincinnati. This pool, with a length of 7 miles, has a fall of but 3.5 inches. Another pool with about as low fall is found 23 to 30 miles above Cincinnati. These are the most conspicuous pools in this section of the Ohio.

On the border of Indiana there are 55 riffles aside from the Louisville rapids. These show a total fall of 80.28 feet in a combined distance of 134.5 miles. At the Louisville rapids there is a fall of 23.09 feet in 2.25 miles. There is left but 18.13 feet for the fall of the stream in about 215 miles embraced in the pools, or only 1 inch per mile.

In general the rock floor of the valley is 30 to 50 feet below the level of the stream at low water. It rarely reaches a lower level than 75 feet below the stream. Its level is 65 or 75 feet below the stream between Evansville, Indiana, and Shawneetown, Illinois. It is thought that no place occurs in the whole length of the valley where a rock barrier crosses the entire width of the valley at a level so high as the present stream. In several places rock shelves extend out part way across the river bed, leaving a channel deep enough for the passage of boats along the opposite bank. At Letart Falls the rock is stated by

[1] Ex. Doc. No. 72, House of Representatives, Forty-first Congress, third session, January, 1871, pp. 139–153.

citizens to extend across the entire breadth of the stream, but it dips toward the east bank sufficiently to allow the passage of boats when the rock of the western part of the stream bed is above the water surface. It is thought from well data that this descent continues eastward beneath the bottom lands to a level as low as in neighboring parts of the channel. Near Ravenswood, West Virginia (see fig. 76), rocky reefs are exposed at low water fully half way across the stream bed, but wells on the bottom lands near the village show the rock floor to be at least 25 feet below the stream at low water. At Louisville it is found

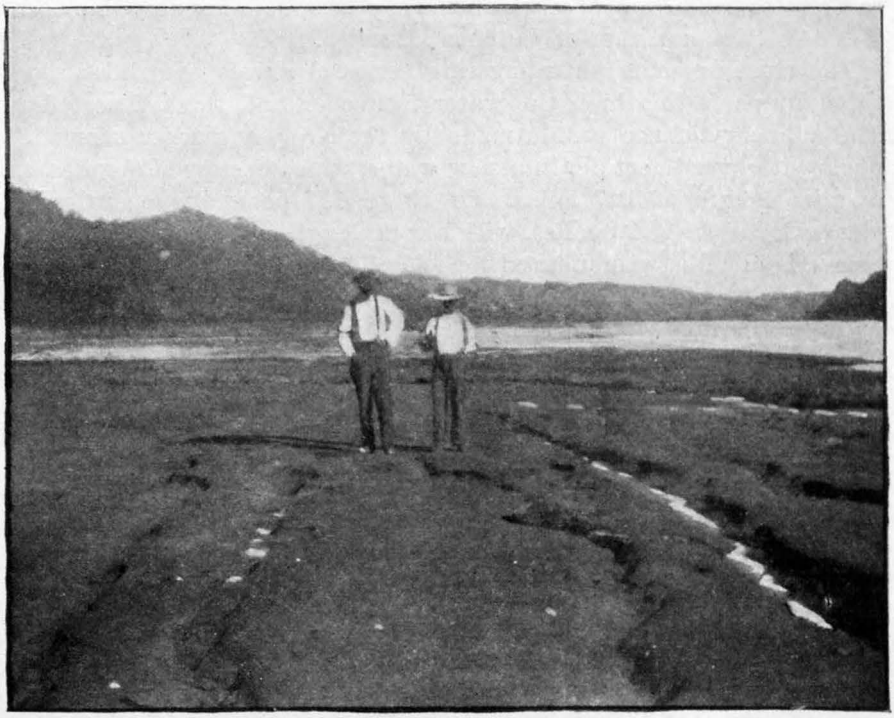


FIG. 76.—Rock ledges exposed in the bed of the Ohio River opposite Ravenswood, West Virginia. The most striking features are the channels and potholes formed by the stream with its burden of sediment. Striæ are also found on these ledges, which are apparently due to the scratching by floating masses of river ice, for the locality is outside the glacial boundary. The resemblance to glacial striæ is in places very striking.

by wells and bridge soundings that a channel 25 feet or more lower than the present surface at the head of the rapids leads southwestward from near the south end of the Jeffersonville bridge a short distance and then turns westward, passing through the midst of the city.[1] Thus at the side of each of the three most conspicuous rock reefs touched by the stream a buried channel apparently occurs.

Notwithstanding the great number of riffles and shoals, the Ohio River is generally navigable throughout the entire season for small

[1] Data on this subject were furnished by Maj. William J. Davis, of the Louisville school board, and by Messrs John Ryan and John C. Oestrich, of the Louisville Pump Works.

boats drawing less than 3 feet of water. It is navigable for vessels drawing 6 feet of water during a few months of the early part of the season, but there is usually little traffic with such boats after the month of July. The canal constructed at Louisville affords opportunity for passing around the rapids during low water. During high-water stages the boats are able to pass over the rapids. In fig. 77 the average range in the stage of the lower part of the Ohio throughout the year may be seen. The diagram is constructed from tables published by the United States Weather Bureau.[1]

The valley of the Ohio River along the south boundary of Ohio and Indiana is very narrow except for a few miles near Louisville, where it has expanded itself in the Devonian shales, and in the southwestern

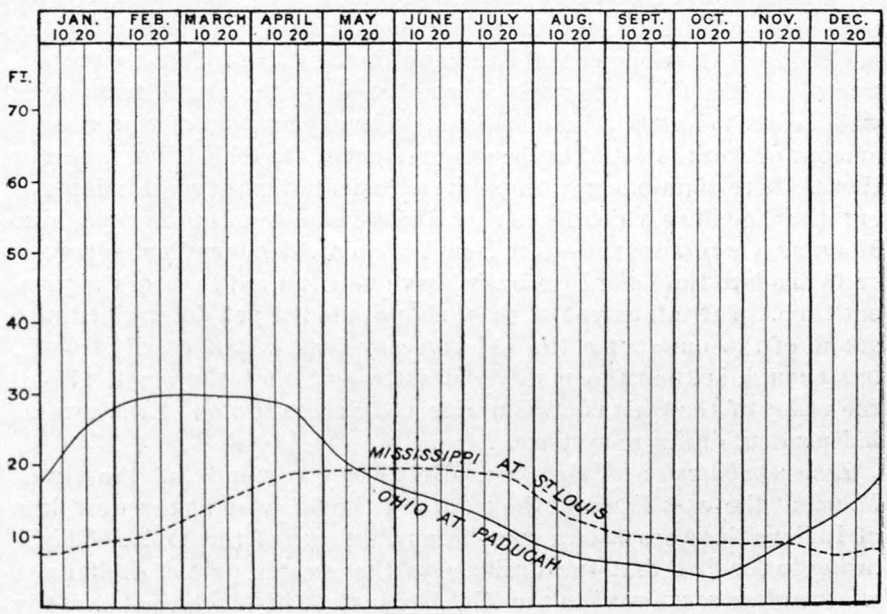



FIG. 77.—Diagram of average yearly fluctuations of Ohio and Mississippi rivers.

portion of Indiana in the Coal Measures. Its narrowness has been a subject of remark from the early days of settlement. There are very few places between Pittsburg and Louisville where its width exceeds 2 miles, and usually it is scarcely more than 1 mile wide. In the vicinity of Louisville where it crosses the low tract formed in the Devonian shales it has a width of perhaps 4 miles, but upon entering the Knobstone escarpment, below the mouth of Salt River, it narrows abruptly to a width of about 1 mile, and remains narrow for nearly 100 miles in its passage through the hard beds of Eocarboniferous age. It then enters the Coal Measures and soon attains a width of 6 or 8 miles, which it maintains for much of its course to Cairo. The only exception

[1]Report for 1891–92, pp. 495–498.

is found where it passes the elevated ridge below Shawneetown, at which place its width is reduced to about 2½ miles. The depth of the valley ranges from about 600 feet down to scarcely 100 feet, being greatest on the border of the "Pan Handle" of West Virginia and least in the lower portion of its course. Its depth seldom falls below 300 feet in the portion above Louisville, and probably averages 450 feet. The narrow portion below Louisville is about 300 feet in depth. The broad portions at Louisville and in the lower parts of its course are but 100 to 150 feet in depth. The work done by the river in excavating a narrow valley through the elevated districts is apparently commensurate with that accomplished where it has eroded a wide valley in low districts.

The entire work of the stream, however, is less than should have been accomplished by a drainage line of this size in the time since the beginning of development of drainage lines. It is far less in proportion to its size than the work accomplished by the small tributaries which enter it from southern Indiana. The explanation of this meager amount of work is found in the enlargement of the Ohio River in recent times. Investigations now in progress indicate that several independent drainage lines which formerly led northward from the Appalachian Mountains across southwestern New York, northwestern Pennsylvania, and Ohio into the Lake Erie basin, have been united to form the present Ohio. The full extent of these changes is not yet determined, nor are all of the outlets for the old river systems satisfactorily traced; but enough is known to justify the statement that the small size of the valley of the Ohio is attributable to the recent union of the several independent drainage systems.

*Lesser tributaries of the Ohio.*—Between the mouth of the Great Miami at the east line and the mouth of the Wabash at the west line of Indiana there are no large northern tributaries of the Ohio. This is owing to the fact that the drainage of the greater part of Indiana is westward or southward to the Wabash, instead of southward directly to the Ohio. At a point a few miles west of Madison, Indiana, a drainage line heads within 2 miles of the Ohio, and yet leads westward to the East White and thence across the State to the Wabash. Nearly all the tributaries of the Ohio in southern Indiana head within the limits of the counties that border the river, and consequently have a length of less than 30 miles. Only two, Blue River and Laughery Creek, have a length of 50 miles. In Ohio the four main northern tributaries, Great and Little Miami, Scioto, and Muskingum, absorb nearly all the drainage. A few short tributaries head between the trunks of these large systems and discharge direct to the Ohio.

In southwestern Indiana, where the altitude is low, the streams have very little fall, and are occupying broad, shallow valleys, which are not infrequently filled to depths of 50 feet or more with marshy alluvium. In the more elevated tracts, whose western border is between Rockport

and Cannelton, Indiana, the streams present valleys cut to a correspondingly greater depth. Their bottoms are narrow and well drained, the fall of the streams being adequate to give rapid escape for the surplus rainfall. The streams make a descent of 300 to 500 feet, in many cases within a distance of 10 to 20 miles. Notwithstanding this great descent there are very few waterfalls. The only notable ones occur in southeastern Indiana, where the drift deposits have obstructed the preglacial valleys and led to the development of new lines of drainage. In the unglaciated portion of southern Indiana and in southern and southeastern Ohio there are but few rock rapids, and, so far as the writer is aware, no waterfalls.

The gradients of streams, though steep, show a gradual lessening in rate of descent in passing from source to mouth and a general disregard for hardness of strata, such as results only from maturing of a drainage system. The rapid rate of descent is not favorable to the development of broad flood plains, yet there is usually a flood plain having several times the breadth of the stream bed. In this respect the tributaries, as noted above, have accomplished more work in proportion to their size than the Ohio. It is difficult to realize that the broad valleys of southwestern Indiana, 1 or 2 miles in width, were begun at no earlier date than the narrower valleys of the higher district, yet such is apparently the case in the Indiana portion and also in southwestern Ohio. In southeastern and southern Ohio changes of drainage, which have resulted in an enlargement of the Ohio and a deepening of its valley, have caused a deepening of the tributaries and the development of gorges. These gorges in the southeast part of Ohio have, at their mouths, depths of 150 to 300 feet below the old gradation plains which open out into the Ohio at these high levels.

With the exception of a few streams in southwestern Indiana, these small tributaries of the Ohio have water power of considerable value. Gristmills, as well as sawmills, utilized this power extensively in the early days of settlement, before steam mills were introduced. Blue River, in southern Indiana, still supplies several gristmills, but on the majority of the streams the water power is abandoned. In general these small tributaries maintain a good flow throughout the dry season, since the limestone and sandstone strata which they have channeled often furnish copious springs. In some cases a single spring furnishes enough water to run a mill. Harrison spring, a tributary of Blue River, near White Cloud, Indiana, furnishes enough water power to run both a gristmill and a sawmill.

In the report on water power of Ohio streams, in the Tenth Census, Prof. Dwight Porter furnishes a table showing that the minor tributaries of the Ohio in that State were at that time supplying 150 mills and other manufacturing establishments with a total of 3,266 horsepower.[1]

[1] Tenth Census of the United States, 1880, Vol. XVII, pp. 487, 488.

There are conditions unfavorable to the use of water power on portions of several streams in southern Indiana. The limestone belt of Harrison and Crawford counties has an extensive subterranean drainage, and it is not rare for a surface stream to lose a portion of its water through leakage into the subterranean channel. In this way Indian Creek, just below Corydon, becomes throughout much of the year entirely dry. There is also a disadvantage resulting from the backwater of the Ohio. This, however, affects the streams only for a short distance near the mouth, and for a few days, or at most a few weeks, of the year.

## THE WABASH RIVER SYSTEM.

The drainage basin of the Wabash embraces an area of about 33,000 square miles, distributed as follows: In Ohio, 400 square miles; in Indiana, 24,350 square miles; in Illinois, 8,250 square miles. It drains, therefore, slightly more than two-thirds of Indiana, the area of the State being 35,910 square miles. Of the portion in Indiana, about one-half is embraced in the drainage areas of the East and West White rivers. By including these drainage areas with the Wabash the entire watershed has a nearly symmetrical, broadly ovate form. Not including the White River system, the Wabash watershed is an unsymmetrical, elongated tract, curving around White River.

But a small part of the Wabash watershed lies outside the glacial boundary. The Wabash and West White rivers lie within that boundary for their entire length. The East White flows in a glaciated region to western Jackson County, but from that point to western Martin County is in an unglaciated tract. It enters a drift-covered district in its lower course near the corners of Martin, Davis, and Dubois counties, but apparently occupies its preglacial valley there, as in the unglaciated tract. The greater part of this system being within the limits of glaciation, and in a region where the drift coating is sufficiently thick to conceal more or less completely the preglacial valleys, it has been largely developed in interglacial and postglacial time.

*Wabash River.*—The valley occupied by the Wabash River has not had a uniform development from source to mouth. In its upper part, from the source to Huntington, Indiana, the valley has been entirely formed by the present stream and is a shallow and narrow trench. At Huntington the river enters the old westward outlet of a glacial lake that occupied part of the basin of Lake Erie, and which has a valley several times as large as that occupied by the Wabash above this point. This old lake outlet opened a new or postglacial line of drainage in its westward course across Indiana, except for a few miles in the vicinity of Lafayette, where it crosses or follows a preglacial valley for a few miles. It has been compelled to do considerable excavation in rock from Huntington down as far as Covington, and still carries rapids at

several points. Below Covington the stream follows very nearly the line of a partially filled preglacial valley, and its work has been largely the removal of a portion of the glacial deposits left in that valley. It makes, however, some deflections into the edge of the uplands, cutting off points of the bluffs. At such places the channel is occasionally in process of excavating rock. The cause for these deflections is not in all cases clear, but it is probable that in the majority of cases the filling was such that the stream was free to pass across these points, and thus take a more direct course than that of the old line around them. In some cases it is possible that the ice sheet may have had its eastern edge along the line of the Wabash sufficiently long to cause a stream flowing on its border to cut across projecting points.

The length of the valley occupied by the Wabash is about 450 miles; but the length of the stream is fully 500 miles, for the river in its lower course makes several oxbow curves within the valley. The source of the river is about 1,000 feet above tide, while its mouth at low water is but 311 feet. The average fall, if we estimate the stream to have a length of 500 miles, is therefore about 16½ inches per mile. The rate of descent is far from uniform, being much more rapid in the upper portion than in the lower. There are also many rapids, separated by pools or sluggish portions of the stream. The elevation of the stream is accurately determined at many points, but in the absence of a careful measurement of the length of the stream the rate of fall is only approximately known. The section above the point where the river enters the old lake outlet, estimated to have a length of 100 miles, has a fall of about 300 feet, or 3 feet per mile. Railway levels and canal surveys at the point where the river joins the old lake outlet show its elevation to be very nearly 700 feet above tide, the altitudes reported varying between 696 and 699 feet. The canal survey below Huntington shows a fall of 32 feet to the mouth of the Salamonie, a distance of about 15 miles, and a fall of 34 feet between the mouth of the Salamonie and the mouth of the Mississinewa, a distance of perhaps 20 miles. In the next 20 miles, to Logansport, there is a fall of 50 feet. From Logansport to Lafayette, a distance of about 50 miles, there is a fall of 77 feet. From Lafayette to Attica, a distance of 25 miles, the fall is but 19 feet, and from Attica to Covington, a distance of 20 miles, but 17 feet. From Covington to Terre Haute, a distance of about 55 miles, there is a fall of only 22 feet, this being the lowest gradient for so long a section found on the river. From Terre Haute to the mouth of White River an accurate survey by the United States Army engineers shows a fall of 71.18 feet in a distance of 122.55 miles, or about 7 inches per mile. In this distance there are 13 riffles, each but a fraction of a mile in length, which have a combined fall of 17.86 feet. These reduce the fall of the 120 miles not embraced in the riffles to 53.32 feet, or 5.33 inches per mile. The greatest fall at a riffle in this section of the

Wabash is at Grand Rapids, just above the mouth of White River, where it amounts to 4.5 feet.[1] The fall from the mouth of the White is 65 feet in a distance of perhaps 90 miles by the windings of the stream. The following table includes the data upon which the above statements are made:

*Table of altitudes and distances along Wabash River.*

| Location. | Estimated distance. | Altitude. | Fall per mile. |
|---|---|---|---|
| | *Miles.* | *Feet.* | *Inches.* |
| Source | 0.0 | 1,000.0 | 00.00 |
| Huntington | 100.0 | 699.0 | 36.00 |
| Mouth of Salamonie River | 15.0 | 667.0 | 25.56 |
| Mouth of Mississinewa River | 20.0 | 633.0 | 20.40 |
| Logansport | 20.0 | 583.0 | 30.00 |
| Lafayette | 50.0 | 506.0 | 18.48 |
| Attica | 25.0 | 487.0 | 9.12 |
| Covington | 20.0 | 470.0 | 10.20 |
| Terre Haute | 55.0 | 447.7 | 4.80 |
| State line | 14.6 | 440.6 | 5.80 |
| Hutsonville, Illinois | 29.0 | 424.6 | 6.60 |
| Vincennes | 46.4 | 398.8 | 6.60 |
| Mouth of White River | 32.5 | 376.5 | 8.30 |
| Grayville, Illinois | 28.0 | 365.0 | 5.00 |
| Mouth of Little Wabash | 46.0 | 323.0 | 11.00 |
| Mouth of river | 16.0 | 311.0 | 9.00 |

In the early days of settlement the Wabash River was made use of for the shipment of produce down the stream in barges; but upon the construction of the Wabash and Erie Canal, which leads from Terre Haute up the valley to Huntington and thence up the old lake outlet to Fort Wayne and down the Maumee to Toledo, the shipments of the upper portion of the valley changed to the eastern seaboard, and the shipments down the river were largely discontinued. The river has, therefore, been but little used for navigation. It would require a great amount of improvement to render it navigable at ordinary stages, and the demands of commerce seem at present scarcely to justify any outlay. Railways cross or follow the valley in such a manner as to offer the best of facilities for shipment of produce.

The canal, long used as a means of water transportation, has been supplanted by the railroad, but is still partially utilized as a hydraulic force. The cities along the Wabash from Huntington to Terre Haute may thus, at comparatively slight expense, avail themselves of an excellent water power.

[1] Geology of Indiana, Thirteenth Report, 1883, pp. 69, 70.

*Salamonie River.*—The Salamonie River, a southeastern tributary entering the Wabash a few miles above the city of Wabash, has a length of about 75 miles. Its source is on the northern slope of the elevated limestone district of eastern Indiana, at an altitude of about 1,000 feet above tide. Throughout the greater part of its course the river follows a plain on the south border of the Salamonie moraine. Its descent is measured by the descent of the plain, except in the lower 40 miles, where it has deepened its channel to enter the old lake outlet. Sufficient time has not elapsed since the river began flowing for it to form a regular gradient. It can scarcely be said to have developed any valley except in the lower 40 miles, the bed of the stream in its upper course being seldom more than 20 or 25 feet below the bordering plain. The descent from Portland to Montpelier is less than 3 feet per mile, but in the 40 miles from Montpelier to the mouth the average descent is about 4 feet per mile.

*The Mississinewa River.*—The Mississinewa River, a southeastern tributary entering the Wabash near Peru, has a length of about 100 miles. Its source is in western Ohio, 10 or 12 miles beyond the State line, on the north slope of the elevated limestone district which occupies eastern Indiana and western Ohio. At its source the altitude is probably 1,100 feet above tide. In the 25 miles from its source to Ridgeville, Indiana, the stream has a fall of about 5.5 feet per mile, descending with the plain, which it follows on the south border of the Mississinewa moraine, and cutting but 15 to 30 feet into the plain. From Ridgeville to Marion, a distance of 50 miles, the rate of fall is but little more than 3 feet per mile. The stream in this distance has deepened its channel slightly, but at Marion is scarcely 50 feet below the bordering plain. The most of the work accomplished by the stream is in the section between Marion and the mouth, a distance of only 30 miles. Its fall in this section is about 5.5 feet per mile, or fully as great as in the headwaters. The depth of the channel increases from about 50 feet at Marion to fully 100 feet in the vicinity of its mouth. It is excavated mainly in drift, but at some points has extended a few feet into the underlying rock strata.

The lower portion of this stream furnishes water power, which has been put to use at several points.

*Eel River.*—Eel River, a northeastern tributary of the Wabash, entering at Logansport, has a length of about 85 miles. Its source is on the inner border of the great interlobate moraine a few miles north of Fort Wayne, at an elevation of about 850 feet above tide. The average fall of the stream is very nearly 3 feet per mile, the elevation of the mouth being 583 feet. The following table of distances and elevations is based upon Williams's list of altitudes given in the Tenth Report of the Indiana Geological Survey.

*Altitudes along Eel River.*

| | Distance from mouth. | Altitude. |
|---|---|---|
| | *Miles.* | *Feet.* |
| Source, about | 85 | 850 |
| Columbia City | 70 | 816 |
| Collamer | 58 | 768 |
| Liberty Mills | 50 | 750 |
| North Manchester | 45 | 721 |
| Eel River railroad bridge in Miami County | 30 | 688 |
| Mouth, at Logansport | 0 | 583 |

In this stream, as in the Mississinewa and Salamonie, the headwater portion has a poorly developed channel and sluggish current. It is only in the lower 25 or 30 miles that erosion of any consequence has occurred. Even here the valley scarcely exceeds 50 feet in depth.

*Tippecanoe River.*—Tippecanoe River is the main northern tributary of the Wabash within the State of Indiana. It has a length of about 125 miles, and drains a belt averaging perhaps 20 miles in width. Its source is in the midst of the great interlobate moraine of northeastern Indiana, at an elevation of nearly 1,000 feet above tide. It descends the northwest face of the moraine from southwestern Noble County into Kosciusko County, reaching a level 800 feet above tide north of Warsaw. It follows the north border of the moraine a few miles southwestward to the point where the Saginaw and Erie moraines become differentiated. It then passes through a gap in the Saginaw moraine and enters a sandy plain formerly occupied by the waters of the glacial lake Kankakee. After traversing this plain a distance of about 60 miles it leaves the old lake area near Monticello and passes through an Erie moraine which follows the northwest border of the Wabash River and enters the Wabash from a narrow plain on the inner slope of this moraine.

Although bordered in places by elevated knolls and ridges in the upper portion of its course, it has no well-defined valley, nor has it excavated a valley of much depth in the old lake bottom. The main excavation occurs in the lower 30 miles of its course, and even here its channel is narrow and scarcely reaches 100 feet in depth. In this lower portion the rate of fall is about 3 feet per mile. The fall is less in the section traversing the old lake bottom, being about 150 feet between Rochester and Monticello, a distance of 60 miles. The great fall of the upper portion is chiefly made in short sections connecting marshes whose levels become successively lower in passing down the slope of the moraine.

The lower portion of the stream furnishes water power which has been utilized at several points by flouring mills. The source of the

stream being in a region fed by marshes, the run-off is more regular than in the case of rivers with better-drained areas which have a rapid run-off. It seldom, therefore, reaches a sufficiently low stage to lessen the value of the water power.

*Small tributaries of the Wabash between Tippecanoe and White rivers.*—Below the mouth of the Tippecanoe there are several creeks having a length of 35 to 75 miles. One of the longest is Wildcat Creek, which enters from the east just above the city of Lafayette. This stream has a length of about 75 miles and a fall of fully 400 feet. Its course being through a till area where the run-off is rapid and but a small portion of the rainfall reaches the stream by percolation, it is very irregular in its volume, being flooded at times of freshet and nearly dry in seasons of drought.

Sugar Creek, another eastern tributary which enters in northern Parke County, is also fully 75 miles in length and has a fall of not less than 400 feet. The lower course of this stream is in places excavated in rock strata to a depth of 50 to 75 feet or more, and furnishes much picturesque scenery. Like Wildcat Creek, it is subject to great variations in volume because of the rapidity of its run-off.

Other tributaries worthy of mention are Coal Creek, which enters in southern Fountain County, whose length is about 35 miles; Big Pine Creek, a northern tributary entering near Williamsport, which has a length of about 40 miles; Big Raccoon Creek, which enters near Montezuma, in western Parke County, and whose length is not less than 60 miles; and Busseron Creek, which enters the Wabash about 10 miles above Vincennes and has a length of about 35 miles. Two western tributaries of the Wabash, Big Vermilion and Little Vermilion rivers, enter it within the limits of Indiana, but their drainage basins lie almost entirely in Illinois.

Big Raccoon still furnishes water power for several mills, but steam is used part of the year in every instance. Many mills on the streams just mentioned have been abandoned. By a judicious system of ponding they probably would furnish a sufficient amount of water for ordinary milling purposes.

*West White River.*—The chief tributary of the Wabash is West White River, which enters it from the east at a point about 90 miles from the mouth. If we include with the West White its entire system of drainage it will embrace about one-third of the State of Indiana, or an area about as great as that drained by the Wabash and its other tributaries within that State. The West White proper, however, drains only about one-sixth of the State, the drainage basin of the East White, its principal tributary, being nearly as great as that of the main river.

The source of the West White River is in Randolph County, near the east line of the State. The course of the stream is westward to Hamilton County, a distance of nearly 75 miles, where it turns abruptly

southward and leads in a course somewhat west of south to the Wabash River.

The length of the valley of this stream is about 275 miles, but this does not represent the length of the stream, for in its lower part it winds greatly within its valley, adding perhaps another hundred miles to its length. The estimates given below are, however, based upon the length of the valley rather than that of the stream. They indicate the condition when the stream is out of bank, as is occasionally the case in high-water stages.

At its source the stream has an elevation of not less than 1,175 feet, while at its mouth the elevation is but 375 feet above tide. It has therefore an average fall of nearly 3 feet per mile, or more than double the average fall of the Wabash River, and about five times the rate of fall of the portion of the Ohio along the south boundary of the State. In its upper 15 miles the fall is estimated to be about 8 feet per mile, in the next 25 miles about 6 feet, and in the succeeding 20 miles about 5 feet, making a fall of 375 feet in a distance of 60 miles, which is reached near the city of Anderson. Below Anderson the fall for the 50 miles to Indianapolis is nearly $2\frac{1}{2}$ feet per mile. Below Indianapolis, for about 30 miles, the fall exceeds 3 feet per mile. In the remaining 130 miles of its course there is a fall of but 185 feet, or slightly less than $1\frac{1}{2}$ feet per mile.

With such a rapid fall and with the large volume of water which is carried by this stream excellent advantages are afforded for the use of water power. But so far as the writer could ascertain there are no mills in use below Indianapolis, and those on the headwaters are generally idle. The headwater portion of this stream leads through the midst of the natural-gas belt of Indiana, where fuel for manufacturing or milling purposes can be obtained at such slight expense that water power is no cheaper; indeed, it is more expensive sometimes to keep the dams in order than to obtain the gas for fuel. Should the supply of gas greatly decrease and the cost of obtaining it become greater than that of keeping the dams in repair there will naturally be a return to the use of the water power.

This stream, like the Wabash, can not be navigated except in flood stages, unless expensive improvements are made. It has in part a rocky bottom, a feature which would make improvement of the channel expensive, as would also the rapid fall.

Aside from its main tributary, East White River, there are but two tributaries of White River which exceed 50 miles in length, namely, Fall Creek, an eastern tributary entering just above Indianapolis, and Eel River, a western tributary entering at Worthington, in northern Greene County.[1] There are several tributaries with a length of over 20 miles, as follows: Pipe Creek, which drains northern Madison

[1] This river should be distinguished from a stream of the same name entering the Wabash at Logansport.

County, length about 25 miles; Duck Creek, draining the district immediately west of Pipe Creek, length 20 to 25 miles; Cicero Creek, draining southern Tipton and northern Hamilton counties, length about 30 miles; Eagle Creek, draining southeastern Boone and northwestern Marion counties, length about 40 miles; Lick Creek, draining eastern Hendricks and northern Morgan counties, length about 30 miles; Indian Creek, draining southwestern Johnson and southern Morgan counties, length 20 to 25 miles; Beanblossom Creek, draining northern Brown and northern Monroe counties, length about 45 miles; Richland Creek, draining northeastern Greene County, length about 25 miles.

Fall Creek has an elevation at its source of at least 1,000 feet and at its mouth of about 700 feet. Fully half of the 300 feet of descent is made in the upper 20 miles, leaving a fall of 150 feet for the lower 40 miles.

Eel River has a length of nearly 100 miles. Its east fork, known as Mill Creek, is about 40 miles in length, and its west fork, known as Walnut Creek, fully 50 miles. Below the junction of these forks the stream has a length of about 45 miles, if the minor windings of the channel are disregarded. This stream in the early days of settlement furnished water power for several mills, but with the building of railways and establishment of steam mills at the villages the water power has gradually gone into disuse.

*East White River.*—This large tributary enters the West or main White River about 40 miles above its mouth. It drains the district immediately east of that drained by the main river and has an area nearly as great, there being about one-sixth of the State tributary to it.

The headwater portion above Columbus, Indiana, is usually known by the name of Blue River, the name East White being applied to the stream below its junction with Flatrock Creek at that city. The name Driftwood is also applied to the lower portion of the river. Inasmuch as there is another stream within the State called Blue River, it is unfortunate that this name is applied to the headwater portion of East White.

The upper half of the drainage basin of the East White River lies within the glaciated districts of eastern and southeastern Indiana. The streams find their sources in the elevated Niagara limestone belt, in the eastern part of the State, and descend rapidly westward to the Devonian shale area. The main stream leads through the western part of the drainage basin, and hence receives nearly all its tributaries from the east. The drainage system is, therefore, very unsymmetrical.

Although these headwater tributaries make a great descent in passing from the Niagara down to the basin of Devonian shale, they have carved very insignificant channels. The valleys are usually so shallow that their bridges may be seen for miles back from the borders of the streams. A portion of the Muscatatuck drainage system is, however, characterized by deeper channels, a feature which is probably attribu-

table to the greater age of that system. It lies outside the limits of the newer drift, while the principal tributaries of the East White farther north flow, throughout most of their course, within the limits of the newer drift sheet.[1]

The northern tributaries, Blue River and Flatrock Creek, have their sources in northeastern Henry County at an elevation of about 1,100 feet above tide. They make a descent of about 500 feet in the 100 miles from their source to the junction at Columbus, an average fall of about 5 feet per mile. In the lower 35 miles of its course, from Shelbyville to Columbus, Blue River has a fall of about 4½ feet per mile, nearly as great as the fall of the headwater portion above Shelbyville. From Columbus to the mouth of the Muscatatuck, a distance of 55 miles, the average fall is very nearly 20 inches per mile. In the remaining 125 miles, where the stream is flowing in a preglacial valley, the fall is about 10 inches per mile. In this portion there are, however, occasional riffles and rapids in which a descent of several feet is made within a mile. The most conspicuous of these rapids is at Hindostan, where a fall of about 5 feet occurs. At this point the stream, as already noted, has cut off an old oxbow and is excavating the rock in the ridge encircled by the oxbow.

The Muscatatuck River, in its lower 25 miles, has very little fall compared with that of the neighboring section on East White River. At the railway crossing south of Seymour the bed of the Muscatatuck is 40 feet lower than at the crossing on the East White immediately north of Seymour. This difference in gradient is due to a filling of the East White Valley by deposits of gravel at the later ice invasion. As the Muscatatuck drainage system lies outside the limits of this later ice invasion or the reach of its waters, its valley remains unfilled. The fall on the lower 25 miles of the Muscatatuck is apparently not more than 10 feet, while on East White River, in the 25 miles above the mouth of the Muscatatuck, there is a fall of about 50 feet.

The portion of the East White River Valley lying within the unglaciated districts of southern Indiana is cut to a comparatively low gradient, notwithstanding the hard rock formations through which its course is carved. The valley at present is silted up to a height of perhaps 100 feet above the preglacial rock floor. The bluffs rise 200 to 300 feet or more above the present valley bottom, thus giving the preglacial valley a depth of 300 to 400 feet. Notwithstanding this great depth and the hardness of the formation, the width of the valley is seldom reduced to less than one-third mile, and probably averages more than one-half mile between rock bluffs. The valley of this stream, like that of the Ohio in the corresponding section, presents a series of oxbow curves, with very little straight channeling.

Within this unglaciated portion the East White receives one impor-

[1] See Third Ann. Rept. U. S. Geol. Survey, pp. 333–334, for discussion of the extent of the newer drift; also the present paper, pp. 434–438.

tant northern tributary, Salt Creek. This stream has a length of about 60 miles from its headwaters, in Brown County, to its mouth, near Bedford, in Lawrence County. It drains the greater part of the elevated district in Brown, Jackson, Monroe, and Lawrence counties. In its headwater portions, in Brown County, it has valleys cut to a depth of 300 and occasionally 500 feet below the level of the neighboring hills, and has developed a dendritic system of drainage strikingly in contrast with the irregular and unsymmetrical drainage systems of the streams within the drift-covered regions to the north and east. At its headwaters the valleys have been filled to a marked degree by deposits of sand and gravel made by streams issuing from the edge of the ice which for a time overhung the northern portion of Brown County. The valley is apparently filled to nearly as great an extent as the portion of the East White with which it connects. Its rate of fall is more rapid than that of the East White, but is less rapid than that of some of the large streams of the glaciated district. The fall of the north fork from Nashville, a few miles from its source, to the mouth of the stream is only about 150 feet, or scarcely more than 3 feet per mile.

Lost River, a tributary entering East White River from the east, in southern Martin County, has a length of about 50 miles. The peculiar subterranean drainage of a portion of this stream is discussed below (p. 483). It has a very narrow drainage basin compared with that of Salt Creek.

It is reported that the East White River was navigated in the early days of settlement by small boats and barges as far up as Hindostan, a distance of about 40 miles from its mouth, the valuable quarries at Hindostan being the incentive for carrying navigation to this point. Navigation is, however, difficult except at times of high water, and the railway facilities now offered make it unnecessary to attempt it.

East White River and many of its tributaries furnish a large amount of available water power, of which at present very little use is made. At several points mills have been abandoned and the dams removed. It should be noted, however, that on some of the small tributaries mills are still in successful operation. Thus on Boggs Creek, a small northern tributary entering just below Shoals, a small gristmill is run entirely by water power. As this creek has a drainage basin above the mill site with an area of less than 75 square miles, the amount of water available for water power is rather unusual. The supply is, however, largely from springs along its course. On Lost River there is a mill known as the Wagner Mill, located at Windom, which is run entirely by water power.

Many mills were constructed on the headwater portions of the East White drainage system, but only a few are now in operation. Some of these mills are said to have furnished products that have gained a continental reputation, having found a market in Europe as well as this country.[1]

[1] Eleventh Ann. Rept. Indiana Geol. Survey, 1881, p. 210.

*Patoka River.*—The Patoka River drains a narrow belt along the south border of the drainage basin of the East White River. The stream has a length of over 100 miles, but its drainage basin nowhere exceeds 20 miles in width. Its source is in the hills of the Chester sandstone and millstone grit in southern Orange County, at an altitude of about 800 feet. Its mouth is just below that of White River, at an elevation of 375 feet above tide. This valley has not been personally visited, but is reported to have a remarkable breadth for so small a stream.[1] It is also reported to have a very sluggish stream in its lower course, through Gibson County.

## WHITEWATER RIVER SYSTEM.

Several streams which have their sources in a moraine in southern Randolph County, Indiana, and southwestern Darke County, Ohio, converge southward to form the Whitewater River. These are known as West Fork, Martindale Fork, Greens Fork, Nolands Fork, and East Fork. The first four become united between Cambridge City and Connersville to form the West Whitewater; the fifth (East Fork) unites with the West Whitewater at Brookville. The area of the Whitewater drainage basin is about 1,500 square miles. The headwater portions for 15 to 20 miles are flowing in channels cut in the drift. The East Fork then, near Richmond, enters the rock, and has carved its course partly in rock from that point to Brookville. The West Fork encounters rock only at a few points. Below Connersville it is in a partially filled preglacial valley with broad bottom and elevated uplands on either side.

The West Fork, with its several headwaters, constituted an important line of drainage for the waters from the ice sheet at the time the moraine above referred to was forming, and probably also at earlier stages in the Glacial period. It is in consequence a gravel-filled valley, and the work of the present stream has been merely the removal of a small portion of these gravel deposits. Above Cambridge it has cut scarcely 20 feet into these deposits. The depth gradually increases southward to Brookville. At Brookville and below that city it has formed a channel 60 to 75 feet in depth. The surface of the gravel deposits had a southward descent amounting to not less than 6 feet per mile throughout the entire length of the stream; in the headwater portion above Cambridge it was nearly 10 feet per mile. From Cambridge to the State line at Harrison, Ohio, a distance of scarcely 70 miles, the gravel deposits have a descent of 350 feet, or fully 5 feet per mile. The present stream, having cut about 50 feet deeper into the gravel deposits at Harrison than at Cambridge, has a fall of nearly 6 feet per mile.

The Whitewater Valley Canal, leading from the Ohio River at Lawrenceburg to Hagerstown, only 20 miles from the head of the West Fork, was for many years an important line of transportation and also a valuable hydraulic force. The canal is no longer used for navigation,

[1] Fourth Ann. Rept. Indiana Geol. Survey, 1872, p. 239; Fifth Ann. Rept., 1873, p. 397.

having been supplanted by the Whitewater Valley Railway. The water power is at present used only along a small portion of the canal. The great advantage for water power here offered should be more generally used by the cities located in this valley.

## GREAT MIAMI RIVER SYSTEM.

The Great Miami is the main system of southwestern Ohio. Exclusive of the Whitewater, it has a drainage area of nearly 4,000 square miles, or about one-tenth of the State of Ohio. Its headwaters are at the continental watershed, and it drains the greater part of the Cincinnati arch from that watershed south to the Ohio River. One of the eastern tributaries, Mad River, heads in the elevated tract near Bellefontaine, at an elevation of fully 1,200 feet above tide. The other headwaters, except the Whitewater, have their sources at an elevation of about 1,000 feet. The Whitewater, as noted above, rises in the higher part of eastern Indiana, at an elevation of nearly 1,200 feet.

The valleys of the headwaters as far down as the vicinity of Dayton are narrow and comparatively shallow postglacial channels, with courses independent of preglacial drainage lines. Mad River, it is true, occupies a broad trough-like valley, but on its borders are moraines which cause most of the relief, the bluffs being generally but 20 or 30 feet high. Below Dayton the Miami and some of its tributaries occupy preglacial lines which are only partially filled with glacial deposits. The work of the present streams has been in the main a reexcavation of the valleys. In this work they have fallen far short of reaching the old rock floors, which lie 100 to 200 feet below their beds. The depth of this reexcavation is but 50 to 100 feet, and the width is but a small fraction of that of the old valley, seldom so much as one-fourth as great. The contrast between the southern and the northern portion of this drainage basin therefore is not found in the work of the present streams, but is due to the less complete concealment of preglacial drainage lines.

The fall of the Miami is rapid throughout its entire length, being seldom less than 3 feet and usually over 4 feet per mile. The streams in this drainage system seldom reach a very low stage in seasons of drought, for the valleys are usually filled with gravelly or sandy deposits which furnish strong springs. Even in the small tributaries, water-bearing beds outcrop along the banks or bluffs.

This stream and several of its tributaries afford valuable water power, the utilization of which is discussed by Prof. Dwight Porter in the Tenth Census Report.[1] From this report it appears that a total of 9,431 horsepower was used in 1880 by 290 mills, manufactories, etc., on the Miami and its tributaries, including Whitewater River.

[1] Tenth Census of United States, 1880, Vol. XVII, pp. 478–487.

## LITTLE MIAMI RIVER SYSTEM.

The Little Miami drainage basin lies immediately southeast of the Great Miami. It is much less extensive, the area being less than 2,000 and probably not more than 1,850 square miles. The source of the main stream is a few miles southeast of Springfield, and the mouth is just east of Cincinnati, the length of the stream being scarcely 100 miles. The East Fork has its source a few miles north of Hillsboro, and joins the main stream just above its mouth.

This stream and its tributaries have courses through areas of thin drift, and, in consequence, are generally bordered by rocky bluffs. The headwater portions have shallow valleys, but the lower portion of the main stream, from a few miles below Xenia to the mouth, occupies a valley 200 to 300 feet or more in depth. This deep portion apparently unites two or more independent preglacial valleys. The tributaries are generally in shallow valleys to within a few miles of the main stream. The stream as a rule falls at the rate of 3 to 6 feet per mile. The headwaters of the main stream are fed by numerous springs issuing both from the rock and from gravelly drift beds. The lower course and the East Fork, with its tributaries, are not so well favored by springs, for they traverse the shale beds of the Hudson River group, and the coating of drift is mainly till.

The main stream with its headwater tributaries furnishes considerable water power, but the remainder of the drainage system is rather unreliable. A table of statistics concerning the utilization of water power on the Little Miami and tributaries appears in Professor Porter's report above cited. At the time the report was made (1880) 59 mills and manufacturing establishments were using 1,947 horsepower.

## THE SCIOTO RIVER SYSTEM.

This river system drains a strip of land 10 to 50 miles in width and about 170 miles in length, mainly in the west-central portion of Ohio, and discharges into the Ohio River at Portsmouth. The main stream has a length, including its curves, of about 210 miles, and with its several tributaries drains an area of 6,400 square miles. The following table of drainage areas of the Scioto and tributaries is taken from Professor Porter's report.[1]

*Drainage area of the Scioto and tributaries.*

| | Sq. miles. |
|---|---|
| Olentangy River | 547 |
| Big Walnut Creek | 513 |
| Darby Creek | 592 |
| Deer Creek | 423 |
| North Paint Creek | 236 |
| Main Paint Creek | 857 |
| Scioto River above Columbus | 1,139 |
| Scioto River | 6,400 |

[1] Tenth Census of the United States, 1880, Vol. XVII, p. 477.

The source of the main stream is in eastern Auglaize County, at an altitude of about 1,050 feet. For nearly 60 miles its course is eastward into the Scioto basin, and in that distance it falls to about 900 feet, or only 2½ feet per mile. It then turns south and traverses the central portion of the Scioto basin. In the 40 miles from the bend of the river to Columbus the fall is about 5 feet per mile, a descent of 200 feet being made. From Columbus to the mouth, a distance of 110 miles, there is an average fall of about 2 feet.

The source of one of the headwater western tributaries, Rush Creek, is much higher than that of the main stream, being nearly 1,300 feet above tide. Some of the eastern tributaries have sources nearly 1,200 feet above tide.

The valleys of the Scioto and tributaries as far down as Circleville are postglacial, and are shallow and narrow, the depth seldom reaching 50 feet and the width seldom exceeding one-fourth of a mile. Paint Creek from Bainbridge eastward nearly to Chillicothe occupies a preglacial valley about a mile in width and 300 feet in depth. Before joining the Scioto, however, it turns into a narrow channel in the south bluff.[1] A short distance below Chillicothe the hills close in on the Scioto on both sides, and the remainder of its course is through a deep valley bordered by hills 400 feet or more in height. This deep valley was but partially filled by the gravelly drift carried southward from the ice sheet. In this drift the present stream has cut an insignificant valley one-fourth to one-half mile wide and 50 to 75 feet in depth. The preglacial drainage was northward from eastern Kentucky and from the Kanawha system of West Virginia into the Scioto basin along an abandoned channel a few miles east of the Scioto, from Wheelersburg to Waverly, Ohio, as indicated on the glacial map (Pl. XXXVI). The preglacial drainage along the Scioto Valley from Portsmouth northward was apparently the reverse of the present, but this matter needs further investigation.

There is a less regular flow in the streams of this basin than in those of the Great Miami. This difference is due to the more compact soil of the Scioto basin and to consequent freer escape of the rainfall. From Circleville to the mouth of the Scioto, however, the course of the stream is through a belt of gravel which tends to equalize the flow. The headwater portion of the main stream has poor drainage, owing to the slight fall, and marshes tend to give that portion a regular flow.

Professor Porter's report on water power of the Scioto and tributaries indicates that the main stream has been utilized less than some of the tributaries. The mills reported on the main stream are confined to the rapidly descending portion in Delaware and Franklin counties above Columbus. There were at that time (1880) 8 flouring mills, which utilized 202 horsepower. On the tributaries 103 mills of various kinds (flouring, saw, woolen, paper, etc.) utilized 2,731 horsepower.

[1] See Professor Orton's description of Paint Creek Valley: Geology of Ohio, Vol. II, pp. 653–655.

## HOCKING RIVER SYSTEM.

This small river system has its headwaters in the east border of the Scioto basin, near Lancaster, and connects with the Ohio at Hockingport, a few miles below Parkersburg, West Virginia. It embraces an area of only 1,200 square miles, and the length of the main stream is scarcely 100 miles. It is possible that the present valley has been formed by the union of several small independent preglacial streams, but insufficient study has been given it to warrant full interpretation.

The valley of the main stream is gravel-filled throughout much of its length, as are also valleys of tributaries which head within the glacial boundary. Tributaries outside the glacial boundary, such as Sunday Creek, have silt filling. Owing to gravelly deposits and to springs from sandstone strata which form the bordering bluffs, this stream maintains a fair flow through seasons of drought.

The fall of the stream is about 250 feet between Lancaster and the mouth, a distance of about 90 miles. Of this fall nearly 100 feet is made in about 25 miles below Lancaster. Professor Porter reports 18 mills on this stream and its tributaries, utilizing 451 horsepower.

## MUSKINGUM RIVER SYSTEM.

The Muskingum River drains the greater part of eastern Ohio and has an area estimated by Professor Porter at 7,740 square miles. The name Muskingum is applied only to the lower portion, below the junction of the Tuscarawas and Walhonding rivers, a length of 109 miles. From the sources of the Walhonding and Tuscarawas to their junction is a distance of 100 miles, thus giving the basin a length of 200 miles, or about as great as that of the Scioto. It is a broadly branching drainage system at the north with an extreme width of about 100 miles. At the south it receives few tributaries, there being none of importance below Zanesville.

The following estimates of the areas of the drainage basins are taken from Professor Porter's report:

*Drainage areas of Muskingum River and its tributaries.*

| | Sq. miles. |
|---|---|
| Walhonding River | 2,159 |
| Tuscarawas River | 2,547 |
| Wills Creek | 815 |
| Licking River | 703 |
| Muskingum and tributaries below Zanesville | 1,175 |
| Total area of Muskingum system | 7,740 |

The present system of drainage departs greatly from the preglacial system. Not only have changes occurred in the glaciated district, which encroaches on the north and west borders of this drainage system, but also in the course of discharge for the main river. Prof. W. G. Tight has shown that this drainage system is connected with the Scioto system by a broad valley leading from Dresden (a few miles above Zanesville) westward past Newark to the Licking reservoir and thence into

the Scioto basin north of Circleville.[1] It is thought by Professor Tight that the Muskingum discharged through this valley to the Scioto basin. The available data, however, do not, in the present writer's opinion, make it clear whether the direction of flow was from the Muskingum to the Scioto or from the Scioto to the Muskingum. The deep and broad channeling of the Cuyahoga at Cleveland recently brought to notice by Mr. Warren Upham[2] and the great thickness of drift in the lowlands on the present watershed between the Tuscarawas and Cuyahoga, showing a rock floor there as low as the surface of Lake Erie, opens the question of a possible northward discharge for the Muskingum, which would carry with it the Scioto. The present southward course from Zanesville is evidently but recently opened, the valley being very narrow compared with the abandoned valley or with the valleys of several main tributaries, and there being a higher rock floor than in portions of the drainage system farther north. The present writer, as well as Professor Tight, places the old divide between the Muskingum system and a small stream leading to the Ohio, at a point near the line of Muskingum and Morgan counties.

Numerous changes of drainage have occurred in the glaciated portion of the drainage system, only a few of which have been sufficiently examined to justify an interpretation. The changes are easily recognized, for the streams turn from broad valleys filled with drift deposits and pass into narrow ones, where they are now cutting into the rock floor. One of the most conspicuous instances of such a change is found in Owl Creek, which formerly discharged southward through the broad drift-filled valley traversed by the Baltimore and Ohio Railway between Mount Vernon and Newark, but which now turns east and soon enters a narrow gorge with rocky rapids, through which it passes to the Walhonding.

The glacial deposits have been transported down the valleys far beyond the limits of the ice sheet, and have filled them greatly. From Zanesville southward, where the stream is in a new course, the filling amounts to but 75 or 100 feet, but from that city northward it increases rapidly, soon reaching 200 feet, while at the present continental watershed, near the head of the Tuscarawas, it is fully 400 feet. Notwithstanding this greatly increased filling toward the north, the gradient of the streams is not high, the fall being less on the Tuscarawas than on the Scioto and Miami rivers. From the canal summit, near the head of the Tuscarawas, to the junction of the Tuscarawas and Walhonding there is a fall of about 3 feet per mile, and from the junction to the mouth of the Muskingum about 1½ feet per mile. On the Walhonding the descent is more rapid, as its headwaters, near Mansfield, are about 400 to 450 feet above the level of the stream at its junction with the Tuscarawas.

The effect of the glacial filling is extended into certain valleys which

[1] Bull. Dennison University, Granville, Ohio, Vol. VIII, 1894, part 2, pp. 35–62.
[2] Bull. Geol. Soc. America, Vol. VIII, December, 1896, pp. 7–13.

were not lines of discharge for the glacial waters. Thus on Wills Creek and its tributaries, and on the tributaries of the Tuscarawas which enter from the southeast, there are silt deposits which so fill the lower courses of the valleys as to give them a very slight fall. It has been noted that these streams are laboring at a great disadvantage because of the extremely low gradient. Precise measurements are not at hand, but it is known that in some cases they have long stretches in which the fall is but an inch or two per mile, and the average fall, except for a few miles at the sources of the streams, will scarcely exceed 1 foot per mile.

The run-off from the portion of this drainage basin above Zanesville has been carefully gaged at that city for the past nine years, gage readings having been taken four times per day. Capt. H. M. Chittenden, of the United States Army Engineers, has had the record carefully worked up from December 1, 1887, to November 30, 1895, and has found that the mean run-off for the eight years amounts to 13 inches per annum, or about 33 per cent of the rainfall. In the three driest years—1889, 1894, and 1895—it was reduced to 7¼ inches per annum, which is 22 per cent of the mean rainfall for those years. These results, together with diagrams showing curves for rainfall and run-off each year, are presented in his recent report to the Chief of Engineers.[1]

The following table taken from Captain Chittenden's report gives the monthly mean for the eight years and for the three dry years 1889, 1894, and 1895:

*Table showing rainfall and run-off in the Muskingum drainage basin above Zanesville, Ohio.*

| Month. | Mean for eight years 1888–1895. | | Mean for three dry years 1889, 1894, and 1895. | |
|---|---|---|---|---|
| | Rainfall. | Run-off. | Rainfall. | Run-off. |
| | *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| December | 2.34 | 0.821 | 2.37 | 0.910 |
| January | 3.27 | 1.605 | 3.24 | 1.521 |
| February | 3.34 | 2.529 | 1.80 | 1.241 |
| March | 2.85 | 1.907 | 1.93 | 1.104 |
| April | 2.69 | 1.274 | 2.15 | 0.739 |
| May | 4.33 | 1.426 | 3.02 | 0.371 |
| June | 4.42 | 0.870 | 3.26 | 0.349 |
| July | 3.85 | 0.467 | 3.21 | 0.296 |
| August | 3.25 | 0.338 | 3.13 | 0.148 |
| September | 3.22 | 0.488 | 3.56 | 0.140 |
| October | 2.87 | 0.502 | 1 97 | 0.105 |
| November | 3.22 | 0.778 | 3.44 | 0.334 |
| Total | 39.65 | 13.005 | 33.08 | 7.258 |
| Percentage | 33 | | 22 | |

[1] Survey of the Miami and Erie Canal, etc., by Capt. Hiram M. Chittenden, Corps of Engineers, U. S. Army, House Doc. No. 278, Fifty-fourth Congress, first session, 1896, pp. 41-43.

The available water power on the main river from Zanesville to the mouth is restricted to the sites of the Government dams, ten in number, made for the purpose of affording slack-water navigation, and which embrace a fall of 103 feet. But a small portion of the power afforded by these dams is at present utilized. Professor Porter's report shows the utilized power of the Muskingum and tributaries in 1880 to have been 7,066 horsepower, of which only 1,165 horsepower were on the main stream.

## BEAVER RIVER SYSTEM.

The Beaver River, formed by the junction of the Shenango and Mahoning rivers, although situated in Pennsylvania, affords a line of discharge for the portion of eastern Ohio drained by the Mahoning and some of the headwaters of the Shenango. Of the 3,000 square miles of its drainage area, about 1,200 square miles are in Ohio, and of this perhaps 1,000 square miles are tributary to the Mahoning.

The Mahoning leads northward from its source in Columbiana County to near Warren, Ohio, where it makes an abrupt turn to the southeast. From this bend the deeply drift-filled Grand River basin leads northward to Lake Erie. This basin, as noted above, apparently afforded a northward discharge in pre-Glacial times for a large part of the upper Ohio system aside from the Mahoning.[1] The old line of drainage of the upper Ohio followed the Ohio from Pittsburg to Beaver, Pennsylvania, and then followed the Beaver (reversed) to the junction of the Shenango and Mahoning. It then appears to have crossed the narrow neck of land between these streams to the Shenango at Harbor Bridge, Pennsylvania, and followed the Shenango (reversed) to Sharon, Pennsylvania, from which point it passed southwest through an abandoned valley, utilized by the Lake Shore and Michigan Southern and Erie railways, to Youngstown, Ohio, and thence northward along the Mahoning (reversed) to the Grand River basin. The present Mahoning below Youngstown crosses an old divide, but takes a much more direct course than that of the prelacial line.

The fall on the Mahoning from Alliance to the bend near Warren is about 150 feet in a distance of 40 miles. From the bend of the Mahoning to its junction with the Shenango the fall is about 100 feet in a distance of 35 miles. The fall of the Beaver from this junction to its mouth, a distance of 25 miles, is also about 100 feet. Of this fully 50 feet occurs in the lower 4 miles, leaving the remainder of its course a rather sluggish stream. The Shenango falls about 200 feet in 56 miles from Jamestown, Pennsylvania, to its junction with the Mahoning.

The lower course of Beaver River affords valuable water power, which has been largely utilized. The flow is estimated to reach a minimum of

[1] See P. Max Foshay, Am. Jour. Sci., November, 1890; T. C. Chamberlain and Frank Leverett, ibid., April, 1894; I. C. White, Am. Geologist, December, 1896.

300 feet per second in the low water of a dry year and 450 in the low water of an average year. There is thought to be available for ten months an average of 700 feet per second. Nearly 40 feet fall is available, without much detrimental influence from backwater on the Ohio.

The Mahoning, Shenango, Connoquenessing, and Neshannock each furnish water power, which has been extensively utilized, and smaller tributaries have also furnished power for a few mills. The Shenango and Neshannock drain districts in which the drift is gravelly and the flow regular. The Connoquenessing drainage basin is partly outside the glacial boundary, but is fed by numerous springs and thus rendered regular. The Mahoning drains a district with clayey drift, in which run-off is more irregular than in the other tributaries. Professor Porter reports, however, that it supplies power for 5 gristmills. Its tributaries also are reported to supply 5 gristmills. The Shenango, at the time of Professor Porter's report (1880), supplied 4 gristmills and its tributaries 5; the Neshannock supplied 2, and the Connoquenessing and tributaries supplied 4. In addition to gristmills, numerous sawmills, tanneries, or other establishments made use of water power.

## TRIBUTARIES OF LAKE ERIE.

The portion of Ohio north of the continental divide, embracing an estimated area of 12,000 square miles, together with an area of about 1,000 square miles in northeastern Indiana, discharges its waters to Lake Erie. Attention has been called to the former northward discharge of much of the present Ohio system to the Lake Erie basin, an area several times as great as that of the present tributaries. The present water-parting between tributaries of Lake Erie and of the Ohio has its position largely determined by drift deposits, there being, as noted above, a system of moraines occupying much of this water-parting. There are probably but few points at which the present water parting is coincident with the preglacial water-parting.

The streams draining to Lake Erie are in several instances known as rivers, but such streams in other localities are usually termed creeks. In but three instances do these streams have a length exceeding 50 miles. Since they have their source in the continental divide, at elevations of 900 to 1,200 feet above tide, and the level of Lake Erie is but 573 feet, the fall is necessarily great. In the majority of them it averages not less than 10 feet per mile. The streams of northwestern Ohio and northeastern Indiana, however, because of their length and the low altitude of the divide in that region, have a much lower rate of fall, a rate not greatly different from that of tributaries of the Ohio. One of the streams, as indicated below, has notable falls, and several of them have small falls and rapids. The following table indicates the average rate of descent of the more important streams.

*Table showing rate of descent of tributaries of Lake Erie.*

| Stream. | Altitude of source above tide. | Estimated length. | Fall per mile. |
|---|---|---|---|
| | *Feet.* | *Miles.* | *Feet.* |
| Conneaut Creek | 1,080 | 40 | 12.67 |
| Grand River | 900 | 50 | 6.54 |
| Chagrin River | 1,200 | 35 | 17.9 |
| Cuyahoga River (above falls) | 1,200 | 48 | 4.5 |
| Cuyahoga River (at falls) | 985 | 2 | 110.0 |
| Cuyahoga River (below falls) | 765 | 35 | 5.5 |
| Rocky River | 1,100 | 30 | 17.6 |
| Black River | 1,100 | 50 | 10.5 |
| Vermilion River | 1,200 | 45 | 14.0 |
| Huron River | 1,100 | 40 | 13.2 |
| Sandusky River | 1,150 | 90 | 6.4 |
| Maumee River | 737 | 150 | 1.1 |
| Auglaize River | 1,000 | 74 | 4.4 |
| St. Mary River | 975 | 100 | 2.38 |
| St. Joseph-of-the-Maumee River | 1,050 | 100 | 3.13 |

*Conneaut Creek.*—Conneaut Creek finds its source in a moraine near Conneaut Lake, in Crawford County, Pennsylvania. It leads northward through a broad valley, described by Mr. Carll, of the Pennsylvania survey, as the Conneaut outlet, and which in preglacial times was the line of discharge for the middle portion of the Allegheny River drainage busin.[1] Upon reaching the low country on the border of Lake Erie the stream is diverted westward by a morainic ridge, whose outer border it follows into the State of Ohio until it finds a passage near Kingsville, which permits it to turn northward into the lake, though there is a slight diversion to the east, caused by a beach line. The preglacial line of discharge entered the Lake Erie basin in the northwestern corner of Pennsylvania. Its point of entrance is now completely filled by deposits of till. The stream encounters rock strata throughout much of its westward course, and is there flowing in a narrow gorge, strikingly in contrast with the broad, shallow valley of the old middle-Allegheny outlet. The headwater portions of the stream are fed by numerous springs, which give it a somewhat regular flow. No data have been obtained concerning the utilization of water power.

*Grand River.*—Grand River is a small stream draining the basin from which it receives its name (see p. 432). Its northward course, like that of Conneaut Creek, is through a former outlet of a much larger stream, and, like Conneaut Creek, it is diverted westward, near the bor-

[1] J. F. Carll, Second Geol Survey Pennsylvania, Rept. III, 1880, pp. 356-366; T. C. Chamberlin and Frank Leverett, Am. Jour. Sci., April, 1894.

der of Lake Erie, by a morainic ridge running parallel with the lake shore. This morainic ridge holds the stream in a westward course nearly to its mouth, at Painesville. The preglacial stream which discharged through the Grand River basin came to the present shore of Lake Erie a few miles west of Ashtabula, near the village of Geneva. Grand River, like Conneaut Creek, encounters rock strata throughout much of its westward course, and there flows in a narrow gorge, strikingly in contrast with the broad, shallow valley of the Grand River basin. This stream is subject to very low stages in seasons of drought, owing to the compact nature of the formations on its borders. Where flowing in the drift there is a compact silt, and where flowing in the rock an impervious shale, neither of which furnishes much water in seasons of drought. No data have been obtained concerning the utilization of water power.

*Chagrin River.*—Chagrin River has two headwater forks, each of which finds its source in marshes among the knolls of an interlobate moraine on the elevated upland east of the Grand River basin. The two streams join near Chagrin Falls, above which point the valleys are inconspicuous. At the falls there is a descent of a few feet over sandstone ledges. The stream then enters a preglacial channel which has been partially filled with drift. The name Chagrin River is said to have been applied to this stream because its valley was mistaken for that of the Cuyahoga by early surveyors, who upon discovering their mistake expressed their chagrin in this way. This old valley can scarcely have drained a large area, since the larger systems discharging through the Grand River basin and the Cuyahoga would have absorbed nearly all the drainage except a narrow strip lying between their trunk streams.

*Cuyahoga River.*—The present Cuyahoga River has its head near the source of the east fork of Chagrin River, on the uplands east of the Grand River basin, only a few miles from the shore of Lake Erie. It leads southwestward for nearly 50 miles, away from the lake, occupying a shallow valley bordered by marshes throughout much of its course, and having an average fall of but 4.5 feet per mile. It then makes a fall at the village of Cuyahoga Falls of 220 feet within a distance of 3 miles and enters a broad preglacial valley, which it follows northward to Lake Erie at Cleveland.

In this preglacial valley there is a heavy drift filling, both beneath the stream and on the borders of the valley. Wells in Cleveland indicate that the valley floor is about 400 feet below the mouth of the present stream. Silt deposits on the borders of the valley indicate that it was filled to a height of fully 200 feet above the present stream, or to within 100 feet of the level of the bordering uplands. From these data it appears that the preglacial valley was about 700 feet in depth. Its width was scarcely 2 miles, but being bordered at the brow of the bluffs by ledges of resistant sandstone, it has preserved a somewhat

narrow channel. As noted above, this valley may be the line of discharge for a large drainage basin embracing the greater part of southeastern Ohio and considerable portions of West Virginia and eastern Kentucky.

The following data concerning the flow at Cuyahoga Falls have been furnished by Prof. F. W. Claypole:

*Discharge of Cuyahoga River at Cuyahoga Falls, Ohio.*

Average discharge, about 195 cubic feet per second.

Maximum discharge, about 400 cubic feet per second; maintained for twenty-five or thirty days each year.

Minimum discharge, 65-100 cubic feet per second; maintained two to three months each year. The discharge becomes so reduced in summer, and often in winter, that the water power at mills is supplemented by steam.

*Rocky River.*—Rocky River has two forks, which unite near the town of Berea. These tributaries are mainly in drift-filled preglacial valleys, but the united stream northward from Berea is largely in a new course. It crosses the preglacial valley from west to east a short distance north of this city, as pointed out by Dr. D. T. Gould,[1] who has traced a preglacial valley from a point a short distance above Berea northward on the east side of that city to Lake Erie, which it enters a short distance west of the present mouth of the stream. Each of the forks has falls and rapids in passing over the Berea grit, those on the east fork being at the city of Berea and those on the west fork at the village of Olmsted Falls. The present channels of the streams are shallow above these falls and rapids, being but 25 to 40 feet in depth, but upon passing the outcrop of Berea grit the soft Cuyahoga shale is entered and a narrow canyon-like gorge 100 feet or more in average depth is excavated.

*Black River.*—Two streams with this name unite at the city of Elyria, and pass thence northward to the lake at Lorain. The eastern or main fork has its source on the borders of an extensive marsh near Lodi, and flows thence northward mainly through a drift-filled valley. At the city of Elyria it has falls nearly 40 feet in height which furnish power recently rehabilitated. The west fork heads in a moraine near the village of Nova and takes a course east of north, channeling a passage much of the way through rock strata, its course not being coincident with the preglacial drainage line. The united stream is mainly in a new course from Elyria to its mouth. Prof. A. A. Wright, of Oberlin, states that six mills have been in operation on the east and two on the west branch, which utilized water power for part of the year. Those on the west branch are discontinued, though one dam remains to impound water for Elyria waterworks. Some use is still made of water power on the east branch in Elyria, but the stream is not large enough at low-water stage to furnish much power.

[1] The Berea Advertiser, April 16, 1886.

*Vermilion River.*—This stream heads in the midst of the watershed series of moraines near Greenwich, and flows east of north mainly through a rock-bound postlacial valley. It drains a somewhat elevated sandstone district. Its channel is narrow throughout its course, being usually but 15 or 20 rods wide, and for a few miles near the mouth it is 100 to 150 feet in depth. Two mills, Brownhelm and Birmingham, use water power, supplemented by steam (A. A. Wright).

*Huron River.*—Huron River has its source in extensive marshes between moraines of the watershed series near New Haven. It drains a low district, underlain by shale, along the western border of the Berea grit. Its valley is shallow compared with that of the Vermilion, seldom exceeding 50 feet in depth. Professor Wright reports that this stream can not be used for supplying water power in any great amount, owing to its very low stage in seasons of drought, but thinks profitable use might be made in fall and spring.

*Sandusky River.*—Sandusky River is a larger, more widely branching stream than any of the tributaries of Lake Erie thus far discussed. It consists of a westward and a northward flowing portion. The westward flowing portion leads from the escarpment of Eocarboniferous sandstone near Crestline westward down the slope to the axis of the Scioto basin. Instead of turning south, as the neighboring streams do, to enter the Scioto River, it turns north, and flows down a gradual slope to Lake Erie. It enters Sandusky Bay at the western end. The valley of this river is small, being only 20 to 50 feet in depth and one-fourth mile or less in average width. It is generally cut into rock a few feet. No data concerning the use of water power have been obtained.

*Maumee River.*—The Maumee River system has the greater portion of its drainage area within the State of Ohio, but small portions are found in Indiana and Michigan. As indicated above, the drainage of this system was formerly southwestward to the Wabash, the northeastward outlet of Lake Erie being at that time occupied by the ice sheet. Upon the withdrawal of the ice sheet from the St. Lawrence basin the glacial lake which occupied the western end of the Lake Erie basin lowered itself to the level of new outlets that were formed and thus ceased to flow to the Wabash. The mouth of the old lake being near the point where the St. Mary and St. Joseph rivers had their discharge, and being higher than the portion of the basin toward the east and the portion of the outlet toward the west, there was a natural summit formed upon the withdrawal of the lake, from which the waters of the St. Joseph and St. Mary rivers were free to flow either to the east or to the west. By some accident of deposition or of slope the stream found it easier to turn eastward than to maintain its original course westward, and thus the Lake Erie drainage basin embraces these streams as well as those which have been formed in the old lake bottom or were tributary to the old lake.

The Maumee River has a length of about 150 miles and a fall of 164 feet, the source being 737 feet and the mouth 573 feet above tide. It is not itself a navigable stream, but is followed closely by the Wabash and Erie Canal, which for many years afforded a means of water transportation.

St. Mary River has its source in Shelby County, Ohio, at an elevation of about 975 feet above tide, or 238 feet above the level of its mouth. The length of the stream being about 100 miles, the average fall is scarcely 2½ feet per mile. The portion within the State of Indiana has a fall of but 18 feet in a distance of 35 or 40 miles, or about 6 inches per mile. It is, therefore, very sluggish in its lower course. The course of the river, both in Ohio and Indiana, is largely determined by a moraine which lies on its north border. The descent of the river corresponds closely to that of the plain in which it flows, and the stream has formed but a shallow channel, seldom more than 25 feet in depth.

The St. Joseph-of-the-Maumee has its source in southern Michigan and flows southwest across the northwestern corner of Ohio, entering Indiana about 35 miles above its mouth. Its length, like that of the St. Mary River, is about 100 miles. It has a more rapid fall, since its source is in a more elevated district, standing about 1,050 feet above tide. The portion in Indiana has a fall of nearly 2 feet per mile. The river flows throughout much of its course in a narrow plain between two morainic ridges, and its descent is determined by that of the plain. Its valley cuts only 25 to 50 feet into the plain and has very narrow bottoms. The stream has been well utilized for mill power, three mills having been constructed within the limits of Indiana.

The principal southern tributary of Maumee River in Ohio is the Auglaize River, which enters at Defiance. The relation of the course of this stream and of its principal tributaries to the morainic ridges may be seen by reference to the glacial map (Pl. XXXVI). It will be observed that the main stream and also two of its eastern tributaries, Hog Creek and Blanchard River, have their westward courses along the outer border of morainic ridges, while their northward courses and the courses of the smaller tributaries are directly away from the St. Mary moraine.

It should be noted also that Tiffin River, a northern tributary entering the Maumee at Defiance, follows the outer border of the Blanchard moraine, while its tributaries, like those of the Auglaize, lead away from the St. Mary moraine.

The drainage of the district lying between the Blanchard moraine and Lake Erie, in northwestern Ohio, is in lines flowing directly away from the moraine. A large part of the drainage is into the Maumee, but Portage Creek carries the drainage of a narrow belt directly to Lake Erie.

## THE LAKE MICHIGAN SYSTEM.

There are two tributaries of Lake Michigan worthy of note which cross the northwestern part of Indiana. Of these the more important is the St. Joseph River, and the one of lesser importance is the Calumet.

*St. Joseph River.*—The St. Joseph River, although having a length of about 200 miles, flows for a distance of only 35 or 40 miles within the State of Indiana, its course being mainly within the State of Michigan. The former southwestward discharge of this river from South Bend into the Kankakee has already been discussed.

The portion of the stream in Indiana traverses a plain of gravel built up as an outwash from the ice sheet.. It has cut a channel in this plain 40 or 50 feet in depth. The fall is sufficient to afford excellent water power, which has been extensively utilized at Elkhart and South Bend, as well as at Niles, Michigan.

There are several tributaries of the St. Joseph in northern Indiana which drain almost the entire area of Elkhart and Lagrange counties, considerable portions of Steuben and Noble counties, and a small portion of St. Joseph County. Of these tributaries, Elkhart and Pigeon rivers are the most important.

Elkhart River has a length of about 60 miles and a drainage basin of perhaps 500 square miles. Its source is in the great interlobate Erie-Saginaw moraine and near the border of Lagrange and Noble counties. About half its length is occupied in descending the northwestern slope of that moraine. It winds about greatly through a series of marshes and shallow lakes, inclosed by morainic hills, and makes most of its descent in passing from one marsh to another. Its lower portion is in a gravel plain on the outer southwestern border of one of the Saginaw moraines. It enters the St. Joseph at the city of Elkhart. The water power of Elkhart River has been utilized at several points in its lower course, and especially at Goshen and Elkhart. Mr. F. E. C. Hanks, of the Goshen Milling Company, estimates that at low stages in July and August only about 300 horsepower are available, but at ordinary stages there are two or three times that amount.

Pigeon River, a tributary entering the St. Joseph just north of the State line, flows throughout the greater part of its course within the State of Indiana. Its source is on the east side of the great interlobate morainic belt, in Cedar Lake, in the extreme northeast corner of Indiana. It flows for nearly 20 miles in a southwestward course, parallel with the moraine, and then turns abruptly northwestward through it. The moraine at this place is broken by a deep channel about 150 feet lower than the neighboring portions of its crest, which has the appearance of being produced by stream action. It is thought to have been formed by a stream issuing from the Erie ice lobe. That ice lobe appears to have persisted on the plain east of the interlobate moraine until the Saginaw lobe had withdrawn from northern Indiana, thus preventing

the drainage from the east slope of the moraine from passing to the Maumee basin and forcing it across the moraine into the St. Joseph River. Upon reaching the northwest border of the interlobate moraine, the stream enters a gravel plain formed along the outer border of a Saginaw moraine and follows this gravel plain to its mouth. In this portion of its course it receives several tributaries from the south, but has none whatever from the north, thus presenting a very one-sided development. In its headwater portion east from the interlobate moraine the stream has a shallow channel cut in the drift plain through which it flows. In its course through the moraine it passes through several marshes or shallow lakes occupying the channel of its broader predecessor. In the gravel plain it has a well-defined but small channel cut to a depth of 25 to 40 feet.

Immediately north of Pigeon River is another stream having a nearly parallel course. Though commonly called Crooked Creek, the name for a portion of its course is Fawn River. It is the outlet for several of the lakes inclosed among the morainic ridges of northern Steuben County. It is deflected into the State of Michigan by the Saginaw moraine that lies along the north border of Pigeon River, but soon passes through that moraine and enters the gravel plain through which the Pigeon River flows. In the lower 25 or 30 miles of their course these rivers are but 1 to 4 miles apart, but maintain separate channels to the St. Joseph River.

*Calumet River.*—Calumet River drains a narrow strip between Lake Michigan and the Valparaiso moraine from the vicinity of Michigan City westward to the edge of Illinois. It has a length of fully 100 miles, but its drainage basin averages less than 10 miles in width. Within a few miles of its source it reaches a level only 40 or 50 feet above the lake, and has therefore throughout the greater part of its course a very sluggish current. At Blue Island, Illinois, it reaches a level no higher than the high stages of Lake Michigan. The region which it traverses contains a series of marshes and sand ridges, which it drains very inadequately.

## ILLINOIS RIVER SYSTEM.

*Kankakee River.*—One of the principal headwaters of the Illinois River, the Kankakee, flows for nearly 100 miles within the State of Illinois. At its source, near South Bend, the marshy channel through which the St. Joseph River formerly flowed stands about 705 to 710 feet above tide. At the State line the elevation of the river is 620 feet above tide. The rate of descent is therefore nearly 1 foot per mile. But, on account of the great breadth and shallow depth of the stream, this fall is inadequate to give a strong current. Extensive tracts along the course of the stream, as well as on the borders, still remain in a marshy condition, and the high grass greatly obstructs the flow of

the water. By systematic ditching this marsh may be drained, and probably with profitable returns for the outlay.

Some of the eastern tributaries in St. Joseph and Marshall counties have their sources in a moderately elevated upland and have developed good drainage lines, as have also tributaries on the north border, which head in the Valparaiso moraine described above. But from Marshall County westward, along the south side of the Kankakee, there is no relief sufficient to develop drainage lines for a distance of 20 miles or more back from the river. By means of artificial ditches, however, a large amount of land in this region has been brought into a condition suitable for agriculture. Where not drained in this manner the region is a forbidding waste of marshes and sand ridges.

The Iroquois River, a southern tributary of the Kankakee, entering near the city of Kankakee, Illinois, has its headwaters in northwestern Indiana. Its course leads westward from eastern Jasper County through a plain having sufficient descent to give it fair drainage, there being a fall of 25 or 30 feet in the 30 miles between Rensselaer and the State line.

## LAKES.

The State of Ohio has an important resource in Lake Erie, with its several excellent harbors. Extensive commerce is carried on from Toledo, Sandusky, Cleveland, and Ashtabula, which extends to the mining regions of the north as well as to the Atlantic seaboard.

The State of Indiana, although bordering upon Lake Michigan, has but one harbor, that at Michigan City. The great amount of sand drifted into the head of the lake in northerly storms makes the maintenance of a harbor difficult. An important harbor is, however, maintained.

The northern part of Indiana and parts of northern Ohio carry small lakes occupying depressions in the glacial drift. These lakes seldom exceed 1 or 2 square miles in area, and are usually but a fraction of a square mile. In a few cases, however, an area of 5 or 6 square miles is reached. In Indiana these lakes are found mainly in the great interlobate moraine, which traverses Steuben, Lagrange, Noble, Whitley, Kosciusko, and Fulton counties. In addition to this system of lakes there are several along the Valparaiso moraine in Laporte, Porter, and Lake counties and along the Maxinkuckee moraine in Marshall and St. Joseph counties. There is also a lake of some importance in Stark County (Cedar Lake), which does not lie in a morainic belt. In addition to these morainic lakes there are lake-like expansions of the Kankakee River, as at Mud Lake and English Lake. There are also portions of the Kankakee marsh which never become dry. The greater part of the surface of Indiana is entirely free from lakes, though in wet seasons marshes and ponds are formed in the poorly drained tracts. The extent of these marshes and ponds has been greatly reduced by cultivation and systematic ditching and underdrainage.

In Ohio several lakes are found in an interlobate moraine west of the Grand River basin in Geauga and Portage counties and a few in the midst of moraines in Summit, Stark, Medina, Wayne, and Ashland counties. These lakes are seldom more than a square mile in area and usually occupy but a few acres.

In western Ohio there are several artificial lakes, formed as reservoirs for feeding the canals. The Lewiston reservoir, situated near the head of the Great Miami River, in Logan County; Grand reservoir, situated near the head of a tributary of the Wabash River, in Auglaize and Mercer counties; Loramie reservoir, on Loramie Creek, in Shelby County; and Six Mile reservoir, on a tributary of the Maumee River, in Paulding County, each cover an area of several square miles. Their sites were originally heavily timbered plains, and have been covered by water by the erection of large dams across the course of streams which traverse these plains. Another artificial lake, Licking reservoir, was made in central Ohio to feed the Ohio Canal, connecting the Ohio at Portsmouth with Lake Erie at Cleveland.

In Ohio, as in Indiana, there are many ponds and marshes in wet seasons which become dry in seasons of drought. Cultivation and ditching have greatly reduced the extent of these poorly drained tracts.

Aside from the classes of lakes already discussed there are a few small lakes or ponds found in the sink holes of the limestone districts of southern Indiana; one of these—Palmyra Lake, in Harrison County—covers several acres and is reported to have a depth of 14 feet. Lakes of this class are usually formed by the natural obstruction of the outlet, but in a few cases have been formed artificially by filling the hole in the bottom of the basin.

There are also small lakes formed in abandoned channels of streams. The Ohio and Wabash and other streams in southwestern Indiana furnish several examples. These may in some cases be drained, but are often too low to admit of complete drainage, their bottoms being nearly on a level with the beds of the neighboring streams.

The small lakes of northern Indiana and northeastern Ohio, and also the reservoirs of Ohio, afford an excellent habitat for fish. A report on the lampreys and fishes of Indiana, by Prof. O. P. Hay, recently published by the Indiana Geological Survey, describes about 150 different species, many of which are found in these lakes.[1]

Considerable attention has been given the lakes of Indiana by the State geological survey and State university, and also by private corporations, with a view to determining their resources. In the report of the geological survey for 1873, Dr. G. M. Levette gives a general description, and in the report for 1875 a detailed discussion of the features, together with soundings, of several of the larger lakes. Dr. David Starr Jordon has an extended discussion of the cisco of Lake Tippecanoe in the geological report for 1874. Messrs. W. H. Thompson and S. E. Lee

[1] Nineteenth Ann. Rept. Indiana Geol. Survey, 1894, pp. 146-296.

have a detailed description of Lake Maxinkuckee and brief references to other lakes of Marshall County in the geological report for 1885–86. Dr. C. R. Dryer has presented, in the geological reports published in 1891 and 1893, a detailed description of the lakes of Steuben, Whitley, Noble, and Lagrange counties, giving soundings and notes as to character of the lake bottoms as well as reports upon the fauna. The most detailed study of these lakes yet attempted is that of Turkey Lake in Kosciusko County, carried on by Mr. C. H. Eigenmann, under the auspices of the State university. A report has already appeared in the Proceedings of the Indiana Academy of Sciences for 1895–96, but the investigations are to be continued for a period of years. It will involve a complete biological classification, as well as temperature tests and other matters of value in determining the conditions for fish culture. The equable conditions furnished by these lakes and reservoirs, compared with those of streams, promise to afford profitable fields for fish culture. In some cases the enemies of food-fish may interfere with such culture, but carefully conducted investigations and experiments will no doubt furnish a sufficient knowledge of the conditions to render the culture of a number of species of fish profitable.

The beauty of scenery which these lakes and the surrounding morainic hills afford renders them very attractive resorts for summer homes, and already many of them have their banks dotted with cottages.

## UNDERGROUND WATERS.

### GENERAL STATEMENT.

The following classification of underground waters seems to the writer to be based upon clear distinctions, and to include the most important phases or classes of underground distribution to be found in the region under discussion. In nearly all cases it is not difficult to decide to which class a given water should be referred. The word "artesian" is avoided, since there is much difference of opinion concerning the scope of its application, some writers maintaining that it should be restricted to deep wells which overflow, others to wells which overflow whether deep or shallow, while others maintain that the overflow is a secondary matter, and include under this head all wells having strong hydrostatic pressure whether they be flowing or nonflowing.

Class 1. Ground water supplied by direct percolation of the rainfall into the soil and substrata, and subject to but little lateral transmission and little hydrostatic pressure. The water level rises and falls with the degree of saturation by rains.

Class 2. Waters in close association with streams, as in valley bottoms, in which lateral transmission is great and hydrostatic pressure is small. It differs from the former class not only in the great lateral transmission, but also in being fed partly by stream percolation. The level rises and falls with that of the neighboring streams. This

class should perhaps include the waters of sand plains and gravel plains which have no surface streams traversing them, for waters in such plains usually have great lateral transmission and but little hydrostatic pressure.

Class 3. Water included in porous beds of glacial drift or other nonindurated formation lying beneath impervious beds but without strong hydrostatic pressure. Such water is supplied from more or less distant absorption areas and is less directly influenced by rainfall than the preceding classes.

Class 4. Water with strong hydrostatic pressure included in porous beds of glacial drift or of alluvium. This affords many flowing wells and also wells in which water rises nearly to the surface.

Class 5. Streams in caves and subterranean passages in the rock, fed by sink holes and brooks, and also by direct percolation from ground water.

Class 6. Rock water with little current and slight hydrostatic pressure.

Class 7. Rock water under strong hydrostatic pressure. This includes not only waters which overflow when tapped, but also waters which rise nearly to the surface.

## GROUND-WATER WELLS.

Wells of this class are ordinarily called surface or seep wells, and the local source of supply is thus recognized. The level of the water in these wells is about the same as in bordering formations, and rises and falls with the fluctuations of the ground water. In wet seasons the water stands near the top of the well, but in seasons of drought it may sink to a considerable depth.

Throughout the glaciated portions of Ohio and Indiana the drift is usually sufficiently thick and pervious to absorb rainfall in such amount as to furnish the surface or seep wells, but in a few places the drift is almost wanting, and the rainfall is directly absorbed by the underlying rock. If a well from the rock derives its supply by percolation from the soil or surface deposits on its immediate borders it seems legitimate to include it in this class, though there is perhaps an advantage in restricting this class of wells to the nonindurated formations and throwing the shallow wells in rock into class 6. In the unglaciated portions of the State the shallow wells, except in valleys filled deeply with alluvium or glacial gravel, are obtained from the rock, there being very seldom much water in the residuary clay that mantles the rock.

As the surface formations vary greatly in their capacity to absorb rainfall, the strength of wells in them may be expected to vary also. Wells in gravelly or sandy drift are stronger than those in bowlder clay or in the lacustrine or other silts. The bowlder clay or till shows great local differences in texture, varying from an oily clay without joints to a coarse-textured clay, or a clay with many fissures filled in with

sandy or gravelly material. A well of considerable strength may be obtained where a series of fissures lead into it and contribute the water they have absorbed. Bowlder clay is often intimately associated with deposits of sand or gravel. If such deposits are of limited extent and completely inclosed by bowlder clay they are of value only in extending the reservoir beyond the limits of the well; but if of great extent they usually furnish strong and lasting wells. Observations made by Prof. F. H. King, of the Wisconsin Agricultural Experiment Station, have shown that a well which drains the strata for but a short distance in wet seasons may greatly extend its drainage area in seasons of drought.

Both in Indiana and Ohio bowlder clay is by far the most widespread source of supply for ground-water wells, and such wells are often exhausted in seasons of drought. The plains between moraines have, as a rule, more continuous sheets of bowlder clay at their surface than the morainic belts, for the latter frequently are made up largely of gravelly deposits. The flatness of surface on these plains favors the filling of wells in wet seasons, and a failure to obtain a well is comparatively rare, whereas the undulating surface of the moraines is unfavorable to such filling, and shallow wells are often unsuccessful. On the whole, however, the moraines afford as strong shallow wells as the plains, for they gain in coarseness of material as much as they lose in undulation of surface. The moraines of knob-and-basin type are usually more gravelly than those of the smooth ridge type and afford a correspondingly larger number of strong wells.

There are a few plains in which the drift is so coarse as to afford large supplies of water. Perhaps the most extensive of these plains is found in Marshall and northern Kosciusko counties, Indiana, but western Shelby and eastern Johnson counties carry also an extensive gravelly plain. In Ohio the most conspicuous gravelly plain noted is that on the borders of the Scioto from Columbus south to Chillicothe. This plain extends out several miles from the river in the vicinity of Circleville. Near Newark there are plains covering perhaps 25 or 30 square miles in which the drift is largely of gravelly constitution. There are also similar plains northwest of Mount Vernon covering several square miles. Much of Clark, northwestern Greene, and eastern Montgomery counties carry a gravelly drift both on moraines and plains, and this gravelly drift leads down the broad valleys of the Mad and Miami rivers.

The number of ground-water wells in these States is far greater than that of all other wells combined. If the unglaciated portions of the State are excluded, there are probably twenty-five ground-water wells for every deeper well, whether in drift or in rock. In the 60,000 square miles of glaciated territory within these States there are estimated to be not fewer than fifteen ground-water wells for every square mile.

The value of the wells is not so much in the quantity of water furnished as in its ready accessibility.

Deeper wells are gradually supplanting ground-water wells in localities where the latter are liable to fail in seasons of drought, and also where surface contamination is suspected. The ordinary ground-water well is but 10 to 20 feet in depth. If on ground that is readily pervious, there is danger of locating the well too near sources of contamination, such as cesspools and manure heaps. Examples of such risk are found not only in villages where wells are necessarily located at only short distances from sources of contamination, but also in rural districts, where there is no need for such crowding. Some danger arises from the use of shallow wells in clay, for the clay often opens large fissures in dry seasons, in which filth accumulates or is washed when showers occur. On another page observations made by Hon. M. C. Read, of Hudson, Ohio, are presented, which show that these fissures afford great opportunity for surface contamination. (See p. 548.) The abandonment of polluted shallow wells has hardly kept pace with the knowledge of danger from their use, and such foolhardiness can scarcely be justified. This class of wells is not likely to be entirely superseded by deeper wells, for in many localities the best as well as most convenient supply is from this source. Their use should be guarded by the most watchful attention to the sanitary conditions and to the character of the water, and when pollution is detected there should be prompt discontinuance of the use, or, if no better water can be obtained, the water used for drinking should be properly boiled.

It is quite generally believed by old settlers that the shallow wells are becoming weaker and permanently lower, but in the absence of statistics only the probable influence of settlement upon such wells can be considered. The effect of settlement has been to afford better surface drainage by opening ditches and removing obstructions, and thus to lessen the amount of saturation. Cultivation of fields, leading as it usually does to a more rapid escape of water over the surface, also tends to lessen the degree of saturation. A somewhat reduced supply to shallow wells and a more frequent failure of such wells than in the days of early settlement are therefore to be expected.

The effects of the droughts of 1894 and 1895 upon ground-water wells are quite generally reported to be more severe than those of any other drought since the settlement of these States. A large number of wells 10 to 20 feet in depth became exhausted for the first time in their history. The level of ground water appears to have been generally lowered in bowlder clay to a depth of 10 feet or more below the surface. Such a lowering requires a long period of rain to restore the ground water, and though the rainfall of 1896 has been greater than in the preceding two years, many wells remain weak compared to their strength prior to the drought.

### SHALLOW WELLS IN VALLEYS.

In the valleys of nearly all the large streams of Indiana and Ohio there are deposits of either glacial gravel and sand or of alluvium, which fill with water to the level of the surface of the stream. When the streams are at a low stage, the level of water in these wells usually sinks to a corresponding level. In some valleys, however, the streams extend below the level of porous beds into bowlder clay or rock, and the wells there are largely independent of the streams, being formed, as in deep wells on the upland, either in beds of gravel beneath the bowlder clay or in the rock. It is only wells of the former class that are here considered. The depth of this class of wells varies with the height of the well mouth above the stream. In most valleys the terraces underlain by alluvium or porous beds stand but 20 or 30 feet, or even less, above the stream. In the Ohio Valley, however, their height is seldom less than 50 feet, and occasionally reaches 100 to 120 feet above the low-water stage. The average altitude of the bottoms is probably fully 60 feet above the low stage. It is found that wells on the higher terraces as well as those on the lower must usually be sunk to river level to obtain a permanent supply.

This class of wells, like the shallow ground-water wells of the uplands, may become contaminated if care is not taken in their location. The flow of the underground water in valleys is usually from the bluff toward the stream and also down the valley. Wells should, if possible, be located on the upland side of cesspools, barnyards, or other sources of contamination. In cities or villages where waterworks are constructed, good water may usually be obtained by sinking infiltration wells on the upstream side of the town. Several cities along the Ohio, in West Virginia, Ohio, and Kentucky, have introduced a system of wells on bars in the river, which are cemented at top so that when the stream is high enough to cover the well mouth the water must enter from the bottom of the well at depths of 5 to 10 feet below the river bed. In the tables of city water supply given below the use of infiltration wells is indicated, and also the use of shallow wells in valleys. Where no waterworks system has been introduced, the wells in cities and villages located in valleys often are contaminated, and the speedy abandonment of private wells seems a necessity. Cisterns filled with rain water from roofs of dwellings are frequently used in such villages and furnish water of fair quality if properly filtered.

### DRIFT WELLS WITH WIDE OR REMOTE ABSORPTION AREAS.

In the classes of wells just discussed the water supply is derived from the ground immediately surrounding the well mouth, or is liable to receive a part of its supply from the immediate border. In the class of wells now to be discussed the supply depends scarcely at all

upon the ground around the well mouth. The wells are usually so deep that no water gains access to them from this source. Commonly their supply is derived from beds of gravel or sand which are interbedded with the sheets of bowlder clay or till. They are supposed to be fed, like the water supplies found in the rock strata, from surface outcrops of the water-filled bed or through joints or other openings in the overlying drift sheet. In this discussion the wells in which a strong hydrostatic pressure occurs are not considered, since they form a separate class discussed below. There is usually, however, a decided rise in the water above the level at which it enters the well. But a few instances have been reported where a sheet of water has been found beneath bowlder clay that does not show a perceptible rise in the wells.

Wells of this class are represented very widely in the glaciated portions of Indiana and Ohio. In Indiana they may be found over the greater part of the State north of the latitude of Indianapolis and for 30 or 40 miles south of that latitude, where they supplant to considerable extent the use of shallow wells. There are, however, small areas along the Wabash Valley and its south border, and also in Jasper, Pulaski, and White counties, where the rock is struck at slight depths, as may be seen by reference to the accompanying map (Pl. XXXVII). In very few localities in northern Indiana have deep wells in the drift failed to obtain an abundance of water. It is often necessary, however, to sink to depths of 150 or 200 feet. Usually tubular borings 4 to 6 inches in diameter are made, and unless a well is found to yield at least 4 gallons per minute it is not considered sufficient for the demands made on such wells.

In southern Indiana, even where drift covered, the rock is usually encountered at depths of 20 to 30 feet or less. The wells in the drift are, therefore, usually ground-water wells. On lowland tracts and along morainic ridges, however, wells 50 to 100 feet in depth are often obtained without entering the rock.

In Ohio thick deposits of drift prevail less widely than in the northern half of Indiana. A few counties in the northwest corner of the State have a deposit exceeding 100 feet in average thickness, and a belt with similar thickness leads from west to east across the middle portion of western Ohio and thence southeastward to the Scioto basin, south of Columbus. With these exceptions the thick drift of the State is largely confined to valleys or lowland tracts which were probably occupied by streams in pre-Glacial times. Along the morainic ridges, however, there is usually about 100 feet of drift. In these regions of thick drift in Ohio, as in Indiana, deep wells are obtained in the drift, and failures are rare.

In the greater part of northern Ohio and also in the drift-covered portion of southern Ohio, outside the limits of the thick drift above outlined, it is often possible to obtain wells of this class at depths of 50 to 75 feet, or even less. There is, however, so much of this area in

which rock is encountered at less than 50 feet that the average value of deep drift wells is not so great.

Wells of this class are of inestimable value to the many villages and cities where they may be obtained and to the stock raisers in the rural districts. The quality of water is the best to be found at any horizon, for there is freedom from the contamination to which surface water and water from shallow wells is liable, and there are also very few wells in which the mineral ingredients are at all objectionable. The water is moderately hard and usually slightly chalybeate. The average depth of these wells probably does not exceed 75 to 100 feet, but even where it is necessary to sink a well to a depth of 200 feet or more, the excellent quality and large quantity of the water usually justify the outlay.

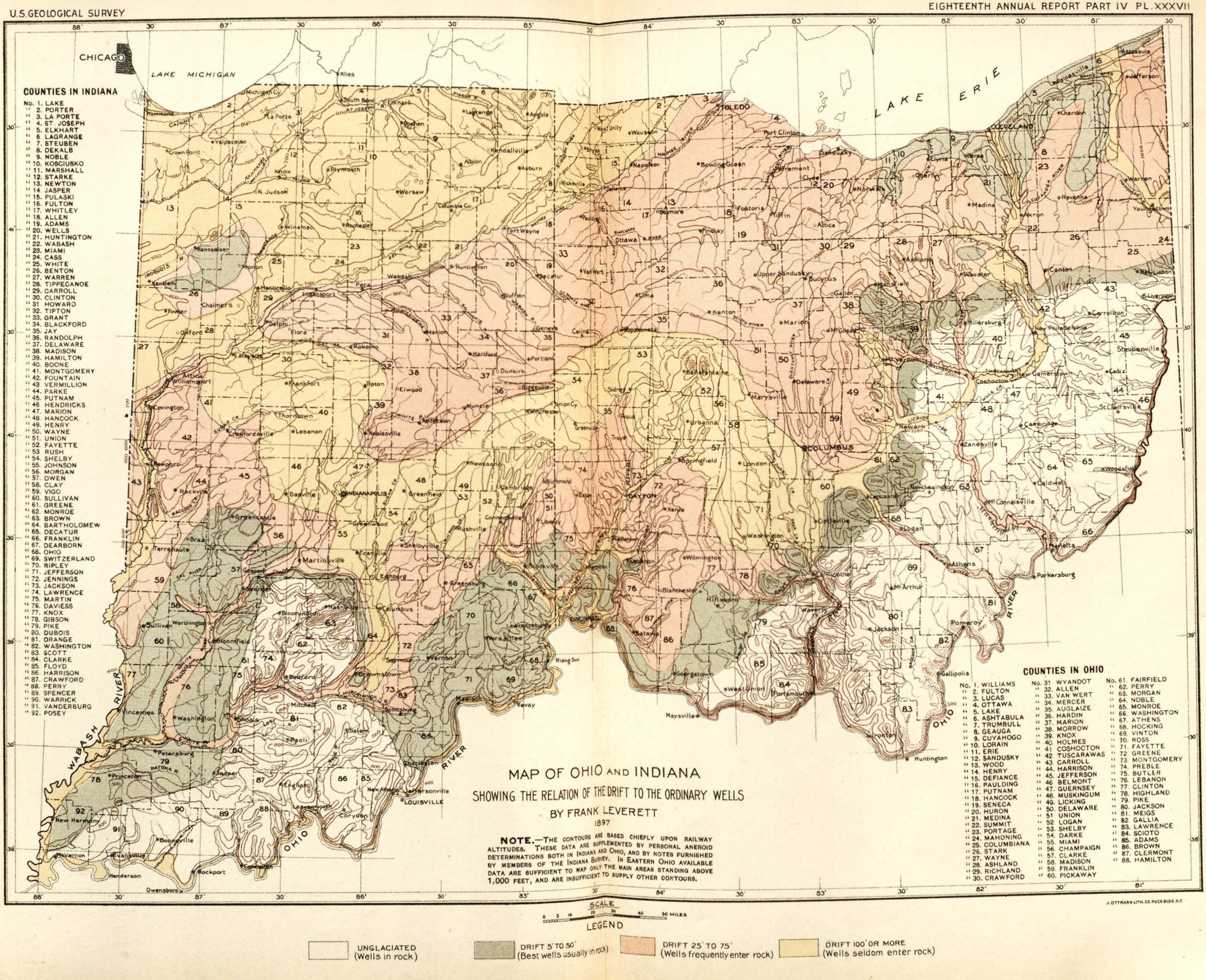
### DRIFT WELLS WITH STRONG HYDROSTATIC PRESSURE.

Wells in the drift having strong hydrostatic pressure are widely distributed in Indiana and Ohio, but they are found usually either on the slopes of moraines or along valleys or in basins in which there is a thick filling of drift. The source of supply and cause for strong pressure are usually readily found. When on the slope of a morainic ridge, the water appears to be derived from porous beds exposed in the moraine or on elevated tracts outside of it. It is found that the sheets of drift often have an imbricate arrangement, the later sheets lapping over the earlier ones and burying beds of sand or gravel which have been deposited on the earlier sheets. Where the ice was advancing up a slope its sheets of drift outcrop on the higher parts of the slope and dip toward the lower parts. If, therefore, water is absorbed in porous beds outcropping on the higher portions of the slope, either along a moraine or in elevated districts outside, it may be expected to pass down the slope and yield wells with strong hydrostatic pressure wherever tapped. Flowing wells obtained in valleys or in basins probably are supplied in most cases by absorption on the borders of the valley or basin.

In Indiana wells are found to have a strong hydrostatic pressure and to occasionally overflow on either slope of the great interlobate moraine which stretches from the northeast corner of the State southwestward to the vicinity of Rochester. The high hydrostatic pressure is maintained for a considerable distance to the northwest from the moraine, in Kosciusko, Marshall, and St. Joseph counties, producing flows at Plymouth and other points.

On the northwest face of the Valparaiso moraine, in Laporte, Porter, and Lake counties, wells have a strong hydrostatic pressure, and occasionally overflow. The absorption area is probably mainly in the moraine, but may perhaps include the Kankakee marsh outside.

Among the drift ridges in Benton County, in western Indiana, adjacent to the flowing-well district of Iroquois County, Illinois, the wells have a strong hydrostatic pressure. This flowing-well district, as




# MAP OF OHIO AND INDIANA

## SHOWING THE RELATION OF THE DRIFT TO THE ORDINARY WELLS

BY FRANK LEVERETT

1897

**NOTE.**—The contours are based chiefly upon railway altitudes. These data are supplemented by personal aneroid determinations both in Indiana and Ohio, and by notes furnished by members of the Indiana Survey. In Eastern Ohio available data are sufficient to map only the main areas standing above 1,000 feet, and are insufficient to supply other contours.

J. OTTMANN LITH. CO. PUCK BLDG. N.Y.

shown in a paper in the Seventeenth Annual Report, Part II, is apparently supplied from the water absorbed on the moraines which encircle the district on the southeast, south, and southwest.

Along the Iroquois River, from the vicinity of Rensselaer westward, flowing wells may be obtained which are apparently fed by water absorbed in the sandy districts near the head of the Iroquois. In these sandy districts the rock is encountered at a much higher altitude than in the flowing well district to the west, and the drift beds apparently have a westward dip, in correspondence with the decreasing altitude of the rock surface.

A few flowing wells have been obtained on the slopes of an elevated tract of drift in Clinton, Boone, Tipton, and Hamilton counties, which are apparently fed by water absorbed on the higher parts of this drift area.

Farther south, in the vicinity of Danville, Indiana, there are flowing wells which apparently have their absorption areas in the morainic tracts immediately to the west.

In eastern Indiana, on the slopes of the somewhat elevated tract which has its culmination in southern Randolph County, numerous flowing wells have been obtained along valleys, and wells on the bordering upland have strong hydrostatic pressure. The absorption area is readily found in the high part of the dome on whose slopes they occur.

A conspicuous instance of flowing wells along a valley is found in the case of the St. Joseph River. The city water supplies of South Bend and Elkhart are obtained from wells of this class. There is considerable hydrostatic pressure in wells between these cities, and a few overflow.

Another valley tract yielding numerous flowing wells is that of Flatrock Valley, in Rush County, from Rushville northward to Raleigh. The city of Rushville obtains the supply for waterworks from this source.

Along the Mississinewa Valley there are occasional flowing wells, one of which, at Marion, supplies a considerable portion of water for the waterworks. In the Salamonie Valley also, near Warren, several flowing wells have been obtained. These, however, in some cases enter rock.

In the valley of Treaty Creek, a small tributary of the Wabash in Wabash County, a series of flowing wells have been obtained which supply the waterworks of the city of Wabash.

The water in the flowing wells is usually slightly chalybeate, but this is also a characteristic of most of the deep drift wells, irrespective of hydrostatic pressure.

The wells are of various depths, some being but 12 to 20 feet, while others exceed 200 feet. They are usually obtained in beds of gravel

beneath sheets of till or of other very compact clay, as at South Bend. In a few instances the head is as great as 30 feet above the surface, but as a rule the flow ceases at a height of 10 feet or less. The accompanying table sets forth the location and depth of some of the strongest flowing wells. Further data will be given in a detailed discussion of the wells of Indiana which is to be published soon as one of the Water-Supply and Irrigation Papers. It will be observed that at certain localities the depth of the wells varies greatly. In such cases the flow begins at the least depth mentioned and usually becomes stronger at greater depths.

*Table of flowing wells from drift in Indiana.*

| | Feet. |
|---|---|
| Northern Lake County, several wells | 60–100 |
| Northern Porter County, several wells | 60–200 |
| Northwestern Laporte County, several wells | 60–250 |
| South Bend waterworks, many wells | 100–125 |
| Elkhart, several wells | 30–120 |
| Near North Liberty, a few wells | 45– 70 |
| Teegarden and vicinity, many wells | 40–100 |
| Plymouth waterworks, several wells | 40– 50 |
| Lake Maxinkuckee, many wells | 20– 75+ |
| Warsaw waterworks, several wells | 120± |
| Columbia City and vicinity, several wells | 50–225 |
| North Manchester waterworks, etc., several wells | 50–100 |
| Wabash waterworks, several wells | 42– 55 |
| Iroquois Valley, many wells | 30–120 |
| Oxford, one well | 55 |
| Templeton, one well | 300 |
| Flora, several wells | 12– 47 |
| Frankfort, several wells | 15– 65 |
| Danville waterworks, several wells | 110 |
| Greenfield and vicinity, several wells | 150± |
| Newcastle waterworks, several wells | 90–240 |
| Moreland, one well | 90 |
| Near Liberty, two or more | 40± |
| Raleigh, several wells | 65–106 |
| Rushville, many wells | 14– 75 |
| Middletown waterworks, etc., several wells | 100± |
| Franklin, several wells | 30– 90 |
| Martinsville, several wells | 40– 75 |
| Northeastern Allen County, several wells (Dryer) | 35– 45 |

In Ohio flowing wells are found as frequently as in Indiana, and in similar situations. Those in connection with moraines find conspicuous illustrations in the northwestern counties of the State, and also on either side of the elevated tract in the west-central part of the State. In several lowlands flowing wells of great strength have been found. Those at Mount Vernon and Mansfield are adequate to supply the waterworks. The wells of this class in Ohio will be discussed more at length by Dr. Edward Orton, in a bulletin for this Survey.

## SUBTERRANEAN DRAINAGE LINES.

It is probable that there is movement in all underground waters, but the movement seldom is sufficiently rapid to be noticeable, and in many cases requires instrumental aid for its detection. In rocks not broken by fissures, such as sandstones and sandy shales, the transmission is apparently that of a slow current varying in rapidity with the texture of the rock, the slope of the bed, and the hydrostatic pressure. In fissured rocks, such as limestones and certain shales, the movement of water is chiefly through fissures and often assumes the force of a stream or line of surface drainage. In certain very soluble limestones the underground water has dissolved the rock and formed great caverns in which it flows with as much freedom as in surface streams. Indeed, surface streams of considerable size may be completely diverted into underground passages, forming so-called "lost rivers." It is only the last class of subterranean drainage that is here considered, for the other classes are considered under other heads.

Several kinds of limestone have caverns, but by far the most cavernous one of this region is the St. Louis limestone, and it is in this formation that the notable caves with their lines of subterranean drainage are developed. The St. Louis limestone outcrops in a narrow belt in Indiana leading from the Ohio River, in southern Harrison County, west of north, crossing East White River near Mitchell and White River near Spencer. It continues much farther north, but is largely concealed by drift. Caves have, however, been discoverd in it as far north as Greencastle. Where not covered by the drift, sink holes abound and surface drainage lines are very imperfect. The main drainage lines which cross this region have channels opened on the surface, but very few tributaries have a surface channel opened. There are many strong springs at points where the subterranean passages of tributaries open into the main drainage lines, springs which are adequate in some cases to run a mill or to supply a town. Thus Harrison Spring, a few miles west of Corydon, as noted above, has sufficient force to run both a gristmill and a sawmill. A cave spring near Salem supplies the waterworks of that city. One conspicuous instance of the diversion of a surface stream into a subterranean passage is found in Lost River, which disappears for a few miles in the vicinity of Orangeville and finds passage "in a complex system of mains and leads." In heavy freshets the stream can not be entirely absorbed by the subterranean channel and it then flows on the surface through the midst of a forest. Stampers Creek, a small stream in the same locality, is so completely absorbed that it has no surface channel opened beyond the sink. These subterranean streams and the caves of southern Indiana have long been known to geologists, and are described in considerable detail in the Geology of Indiana.[1]

[1] See Geology of Indiana, 1859, pp. 149-158, map p. 361; 1872, pp. 145-182; 1873, pp. 280-308; 1875, pp. 208, 209, 224-226, 1878, pp. 292-294, 306-309, 456-510, 1883, pp. 78, 79; 1884, pp. 73-75; 1886, pp. 151, 152; 1897, pp. 121-212.

The Burlington and Keokuk limestone of Eocarboniferous age and the Niagara limestone of Upper Silurian age usually afford fair transmission for subterranean streams. Where these limestones outcrop along valleys copious springs often occur, which testify to the strength of subterranean drainage. Occasionally a cave has been found of sufficient size to admit of exploration, though small compared with the caves St. Louis limestone.

## ROCK WELLS WITH SLIGHT HYDROSTATIC PRESSURE.

In places where the drift does not furnish an abundance of water, either because of its slight depth or its compactness of texture, wells are frequently sunk into the rock to a moderate depth. In the driftless portions of Indiana and Ohio, also, wells of this class form a main source of supply. In the early days of settlement such wells were excavated or blasted and have a diameter of several feet, but since the drill has been introduced into this region large wells are rare. Usually a 4-inch or 6-inch drill is employed, and the well is sunk to a depth of several feet beyond the point where water enters, in order to obtain either a basin or a greater contributing surface. Where wells are sunk in sandstone such deepening usually results in a strengthening of the well, and in limestone there is but rarely a loss of water supply caused by sinking to a level below the water vein.

In this class of wells the head is seldom such as to cause an overflow, for the supply is usually from a moderate depth and is furnished by absorption of rain water in the immediate vicinity of the well. The depth of this class of wells ranges from 10 feet or less to 200 feet or more. The deeper wells, however, are not usually supplied by absorption from the immediate vicinity.

There is much difference in the strength of these wells in different rock formations. In some formations strong wells may usually be obtained, while in others the majority are weak. Probably the best horizon for this class of wells in the region under discussion is the Niagara limestone. This limestone is not only fissured extensively, but is also in places sufficiently porous to transmit water readily. Its extensive outcrops in eastern Indiana and western Ohio and also in northwestern Indiana insure for these districts an abundance of water at comparatively slight depths. The water is often sulphurous, owing to the presence of iron pyrites in the limestone, but is on the whole pleasant and of good sanitary quality. This limestone in some cases affords wells that overflow or have strong hydrostatic pressure. This is especially true of the wells on the slope of the dome which finds its culmination in southern Randolph County, Indiana. Wells 200 to 250 feet or less in depth often have sufficient head to overflow.

The limestones of Lower Silurian age, which are extensively exposed in southwestern Ohio and southeastern Indiana, usually afford water

at convenient depth in sufficient amount to supply households, but are seldom of sufficient strength to supply a large number of cattle or other stock. Stock raising is therefore, as a rule, not undertaken on an extensive scale unless a farm is situated near a living stream. The water from this horizon, though hard, is usually very palatable and rarely has a sulphurous character.

Probably the poorest source for water is the Devonian shales, but these form only a small part of the area of either Indiana or Ohio as a surface outcrop. Where not overlain by rock they are usually covered by a drift sheet which yields a fair amount of water.

The Knobstone or Waverly group is a source of strong wells and numerous springs, both in the Indiana and the Ohio outcrops, as are also the other sandstones of Eocarboniferous age. The quality of water is excellent, being perhaps unsurpassed in average quality by water from any other horizon. It is usually sufficiently soft to be used for laundry purposes without "breaking," and thus avoids the difficulty experienced in the use of nearly all waters from the glacial drift, as well as from limestone formations.

The Eocarboniferous limestones which outcrop extensively in southern and western Indiana all furnish a fair amount of hard water and rank with the Niagara limestone as a water yielding formation.

The Carboniferous sandstones and shales which outcrop extensively in southwestern Indiana and in eastern Ohio are very irregular in their water capacity. They vary also greatly in the quality of water, some water being salt or sulphurous, while other water is soft and pleasant. In some places "copperas water" is found that is highly objectionable. In these formations the shallow wells usually afford a better class of water than the deep wells, though instances are reported of wells 300 feet or more in depth in southwestern Indiana which furnish water of agreeable taste.

The statistics concerning water supplies for cities and villages, given on subsequent pages, serve to indicate the depth at which wells are usually obtained in each of the several formations, and make further details unnecessary. The rock water of Ohio will be discussed by Dr. Edward Orton in a separate paper for this Survey.

## ROCK WELLS WITH STRONG HYDROSTATIC PRESSURE.

A few artesian wells were made in the early days of settlement, but the great majority of borings in Ohio and Indiana have been sunk since the discovery of natural gas in these States about 1886. These borings for oil and gas were made without reference to the determination of water resources, and but little attention was given the water. The value of the water is greater than is popularly supposed, for the strong pressure exerted by it in the territory surrounding the gas and oil fields causes the pressure exhibited by the gas wells, and makes them

much more valuable than would be the case if there were not this strong hydrostatic pressure.

The sinking of these wells for oil and gas has also brought to light the existence of large supplies of potable water in the formations which are penetrated before the rocks yielding gas and oil are reached. In many instances these wells have passed potable water in the Niagara and found salt water in the Trenton. By plugging such wells between the potable and the salt water the former has been turned to use as a source for city water supply or for manufacturing and other industries.

Statistics are not available concerning the head except in a few instances. As a rule the water obtained from the Niagara limestone in the vicinity of the gas and oil field of eastern Indiana and western Ohio has greater head than that in lower strata. There are instances in which it reaches an elevation of fully 900 feet, while the Trenton water seldom much exceeds 600 feet in the same localities. But in northwestern and western Indiana the difference in head between the waters from the Niagara and from lower formations is usually slight, not far from 600 feet. It appears to be somewhat higher in northwestern Indiana than in the western and southwestern portions of the State. In southern Indiana a few wells have been obtained which show a head not far from 600 feet, and the head in central Indiana is apparently about the same.

Several wells from the Niagara in western Indiana yield a sulphosaline water which has gained a wide reputation as a restorative to diseased and enfeebled persons. Several sanitariums have been constructed for the accommodation of persons who resort to these wells. Those at Martinsville, Spencer, Greenwood, Lafayette, and Montezuma have wide reputations. Analyses of the waters from these and other deep wells in western Indiana appear on subsequent pages.

Concerning the absorption areas from which deep wells are supplied some uncertainty exists. It is thought that wells from the Niagara limestone in the eastern part of Indiana and western Ohio have their absorbing area in the elevated area of Randolph County, Indiana, and adjacent counties. In northwestern Indiana the source is apparently from outcrops in northern Illinois or southeastern Wisconsin. Between these two districts there is a large area in which the direction of intake and transmission is uncertain. It is also uncertain in southwestern Indiana.

The horizons from which water is usually obtained in the artesian wells of Illinois and southern Wisconsin, namely, the Potsdam and St. Peter sandstones, and to a less amount in Lower Magnesian and Trenton limestones, are at so low a level in the States of Indiana and Ohio that they do not furnish a convenient source of supply, even if the water should be of suitable quality. The borings for natural gas, however, have shown that the water in all these formations is brackish or too saline to be of suitable quality for drinking. It is not likely, therefore, to be sought for any purpose, unless it be as a source for salt.

The Eocarboniferous limestone and sandstone, and also certain sandstones of the Carboniferous in southwestern Indiana, yield water having strong hydrostatic pressure and occasionally furnishing an overflowing well. Wells in these formations vary greatly in the quality of water; a few are fresh, but the majority are brackish, and some are highly saline, as may be seen by the analyses on another page. On the whole, these formations do not promise to yield waters of a quality to justify extensive development. Wells sunk to a depth of 100 to 200 feet seem more likely to obtain a potable water than those of greater depth.

Since the character of the rock water of Ohio is to be discussed by Professor Orton, for this Survey, further remarks concerning its character seem unnecessary in this place. A few detailed records of wells in Indiana, illustrative of the above statements, are given below.

## WELLS IN INDIANA.

*Anderson.*—This city has one artesian well, 800 feet in depth, situated in White River Valley near the waterworks pumping station. This water is pumped to nine hydrants in the city. It is reported to be strongly impregnated with magnesia, iron, and sulphur. Probably the supply is largely from Niagara limestone.

*Attica.*—A strong overflow was obtained in a boring in the Wabash Valley at this city. The water is strongly sulphurous, but otherwise not unpleasant. The depth, head, and geological horizon are not known to the writer.

*Bloomington.*—A section of a boring 2,730 feet in depth is published in the Geology of Indiana,[1] and is interpreted by Dr. Phinney to enter the Lower Magnesian limestone about 50 feet. Water is reported at only two levels; first, in the St. Louis limestone, within 30 to 35 feet of the surface; second, in the Lower Magnesian limestone, at 2,722 to 2,730 feet. It was the original intention to continue the boring to a depth of 3,000 feet, but the machinery became fastened and the work was abandoned.

*Brownstown.*—The gas-well boring at this village shows an interesting difference in the head of the water in the Niagara limestone and that in the St. Peter sandstone, an overflow being obtained from the former at an altitude about 650 feet above tide, while from the latter the head is only about 350 feet. The upper water is a sulphurous-magnesian water, while the lower water is strongly saline.[2] The St. Peter sandstone was penetrated 47 feet, but the salt water was found only at the bottom of the well, and adequate passage for the water may not have been opened.

*Columbia City.*—The waterworks are supplied from three 8-inch wells in limestone about 280 feet in depth, which overflow to a height of about 5 feet above the surface and about 800 feet above tide. The supply is perhaps in part from the sand beds in the lower part of the drift. A gas-well boring at this city, 1,375 feet in depth, struck salt water at 900 feet, which rose to within 20 feet of the surface, but water struck in the Trenton at the bottom of the well rose only 300 feet, or to a level 1,075 feet below the surface and about 260 below tide.[3] The extremely low head in the Trenton water is perhaps due to a failure to open a passage for this water, for at the neighboring village of Larwill, where a well penetrated the Trenton 50 feet, the water rose to 750 feet above tide.

*Columbus.*—Dr. Phinney reports that salt water struck in the Trenton limestone at a depth of 1,005 to 1,020 feet overflows at an altitude 635 feet above tide. St.

[1] Fifteenth Report, 1885–86, p. 332.

[2] Phinney, Eleventh Ann. Rept. U. S. Geol. Survey, p. 726.

[3] Ibid., p. 736.

Peter sandstone was entered at about 1,550 feet and penetrated to a distance of 150 feet, but its head, compared with that of the Trenton, was not determined.

*Converse.*—Many wells in the vicinity of this village obtain water in the Niagara limestone at depths of 200 to 250 feet, which rises nearly to the surface. The water-works supply is from wells 230 feet in depth, which rise within about 8 feet of the surface, or about 800 feet above tide. Brackish water is entered at about 435 feet. Care is therefore taken to stop drilling where the water is fresh.

*Corydon.* –A well 1,200 feet in depth, bored for salt brine in 1871 and 1873, struck saline sulphur water in St. Louis limestone at 48 to 57 feet. The brine became stronger farther down, having a strength of 30 degrees at 520 feet and 38 degrees at about 700 feet, where the maximum strength was reached. In Upper Silurian limestone at 879 to 900 feet and in Lower Silurian limestone at 986 feet sulphur water was found.[1] A white sulphur water is obtained in the St. Louis limestone at a well 1 mile east of the village, which has been used in a small natatorium.

*Crawfordsville.*—A gas-well boring at this city struck sulphur water at a depth of 750 feet. Water was also obtained in the Eocarboniferous limestone at 240 feet.

*Crown Point.*—Dr. Phinney reports that a gas-well boring at this village struck salt water in the Trenton at about 930 feet, which rose to within 120 feet of the surface, or to a level 616 feet above tide.

*Delphi.*—Salt water struck in the Trenton at about 910 feet rises nearly to the top of the well, 600 feet above tide. (Phinney.)

*Edinburg.*—Salt water struck in the St. Peter sandstone at a depth of 1,580 feet rises within 83 feet of the surface, or 585 feet above tide. An analysis of this water appears on a subsequent page. (Phinney.)

*Elkhart.*—At this city a flow of water is obtained from limestone immediately below the Devonian shale at a depth of about 550 feet. As noted above, fresh water is obtained in the drift, which also overflows.

*Elwood.*—The public water supply is from a series of wells drilled to depths of 75 to 150 feet, which rise to within 15 to 25 feet of the surface. Wells of much greater depth are likely to enter a brackish water.

*Evansville.*—Several deep wells have been sunk at Evansville, which obtain a brackish water. One of these wells, 1,100 feet in depth, has been used to supply a natatorium.

*Fort Wayne.*—A well 3,000 feet in depth was sunk at the court-house in 1875, which has a head 8 feet below the surface, or 785 feet above tide. The water appears to be from a horizon near the surface of the well, for its temperature is but 51½° F. Dr. C. R. Dryer reports that a well in the Maumee Valley at this city overflows with considerable force.[2]

*Goshen.*—Salt water overflows at this city from the Niagara and possibly from the Trenton limestone. It is struck in the former at about 1,000 feet and in the latter at about 1,800 feet. The altitude of the well mouth is 785 feet, or higher than the Trenton water is known to reach at any other point. The Niagara water, as already indicated, reaches greater elevation than this at points to the East.[3]

*Gosport.*—A well 926 feet in depth was bored in the autumn of 1895 in the valley of White River adjacent to this village at an altitude 580 feet above tide. The well is cased about 500 feet to shut out salt water. It obtains a strong flow of "white sulphur" water, probably from Niagara limestone near the bottom of the boring. The water will flow freely at top of a pipe 30 feet above the mouth of the well, or 610 feet above tide. A strong vein of fresh water was struck at 125 to 150 feet, which rose within 20 feet of the top. (Data furnished by G. B. Spicer and L. D. Ray, Gosport, Indiana.)

*Greenfield.*—The city water supply is from overflowing wells obtained in the Niag-

[1] Geology of Indiana, 1872, pp. 146 to 147; 1878, pp. 353 to 355.
[2] Indiana Geology, Sixteenth Report, 1888, p. 127.
[3] See Eleventh Ann. Rept. U. S. Geol. Survey, p. 735.

ara limestone at a depth of 176 feet. The altitude of the well mouth is nearly 900 feet above tide. It is possible that a portion of the supply is from the sand beds in the drift, though it is generally supposed to be entirely from the rock. (Data furnished by S. S. Boots, M. D.)

*Greenwood.*—Two deep wells have been sunk at this village, one to a depth of 600 feet, the other to 1,975 feet. The former is cased only to the rock—210 feet—and water rises within 45 feet of the surface. It terminates in the Hudson River limestone, and probably receives much of its water from the Niagara, which is entered at about 320 feet. The deeper well has a head 240 feet below the surface. The water enters at a depth of 1,840 to 1,865 feet, and is apparently from the St. Peter sandstone. A sanitarium has been constructed into which water from both wells is pumped. The water from the deeper well is pumped into elevated tanks without intermixture with other water and thence conveyed to all parts of the sanitarium building. The water from the shallower well is much more fresh than that in the deeper one. (Data furnished by John A. Polk.)

*Hammond.*—Artesian well water from wells about 1,900 feet in depth were used some years ago for domestic purposes and also for distilleries and factories. The use of such water has been displaced by that of the public water supply from Lake Michigan, as it was found unsuitable for boilers. (Data furnished by W. F. Bridge, city engineer.)

*Huntington.*—A gas-well boring 1,030 feet in depth entered Trenton limestone at 1,002 feet, from which salt water rose within 87 feet of the surface, or to a level about 640 feet above tide.[1]

*Indianapolis.*—Wells drilled by the Indianapolis Water Company near the bank of White River strike water in the Niagara limestone which rises a few feet above the level of the river, or about 700 feet above tide. (Data furnished by F. A. W. Davis, superintendent.) Dr. Phinney reports several borings in the vicinity of Indianapolis which struck salt water in the Trenton at a depth of about 1,000 feet, from which there is a rise of 700 feet or more in the wells.[2]

*Kentland.*—A well bored for gas to a depth of 1,325 feet has an abundant supply of sulphur water, which stands within 45 feet of the surface, or 635 feet above tide. The water supply is probably in large part from the Niagara limestone, for wells in the neighborhood of the town obtain a similar water to that of the deep borings from the Niagara limestone at depths of 250 to 300 feet. The deep boring entered the Trenton limestone about 260 feet, but water from that horizon may not reach the surface. Several flowing wells are obtained from the drift in the vicinity of this village at depths of 40 to 120 feet. (Data furnished by W. T. Drake.)

*Kewanna.*—Dr. Phinney reports a rise of 990 feet in salt water struck in the Trenton at this village at a depth of 1,074 feet, the altitude of the well being about 790 feet. The head is about 700 feet above tide [3]

*Kokomo.*—The district immediately west from Kokomo yields water instead of gas. The water from the Trenton is salt, but that from the Niagara is comparatively fresh and has been turned to account by some of the farmers on whose land the wells were sunk, for many of the wells overflow or rise nearly to the surface. One instance of the use of a well for irrigation is reported, the well being on the farm of W. H. Wolf. It is probable that the fresh water of the Niagara fills the upper portion of all deep borings and the supply of potable water may be obtained without penetrating to the lower strata.

*Lacrosse.*—A gas-well boring drilled in sec. 23, T. 33, R. 4 W., about 3 miles from Lacrosse, obtained a supply of water which is said to be preferred by cattle and other animals to the water found in the shallow wells or the surface water of the Kankakee marsh. Water stands at about the level of the surface of the ground (675 feet above tide). Depth of well, 838 feet. (Data by R. Huncheon.)

[1] Phinney, Eleventh Ann Rept U. S. Geol. Survey, p. 739. [2] Ibid., pp. 700, 701. [3] Ibid., p. 733.

*Lafayette.*—"White sulphur" water was found at this city about forty years ago by boring to a depth of 235 feet in the valley of the Wabash River. The water is obtained near the top of the Niagara limestone. It flows about 10 barrels per hour and has a temperature of 55° to 56°. An analysis appears on a subsequent page. A gas-well boring a thousand feet in depth also obtains a strong flow of sulphur water. The head is not determined, but the altitude at the wells is nearly 550 feet above tide. (Data furnished by Prof. H. A. Huston.)

*Larwill.*—Dr. Phinney reports that at the gas-well boring made at this village the first vein of salt water was struck at 935 feet and rose 800 feet; a second vein was struck at 997 feet, which rose 850 feet, and salt water again appeared in the Trenton at 1,566 feet, which rose within 200 feet of the surface, or to an elevation of about 750 feet above tide.[1]

*Leavenworth.*—A weak flow of sulphureted chalybeate water was obtained in this village some thirty years ago at a depth of 235 feet. The well is located in the Ohio River valley, in the eastern part of the town, at an elevation about 400 feet above tide.[2]

*Lodi.*—A boring for oil at this village made in 1865 reached a depth of 1,155 feet, and struck several veins of brackish water. Near the bottom it struck a white sulphur water either in the Devonian or Upper Silurian limestone. A detailed section of this boring is given in the Geology of Indiana, 1869, and also in the report for 1881. An analysis of the water is also published in both reports and may be found on a later page in the present paper. The water has a wide reputation for medicinal properties and is shipped to distant points, as well as resorted to by people of the vicinity.

*Logansport.*—The gas-well borings of this city, about 1,100 feet in depth, struck a salt water in the Trenton limestone which overflows at an altitude of about 610 feet. (Phinney.)

*Marion.*—Fine artesian flows of fresh water are found at Marion and other localities in Grant County, in the Niagara limestone, at depths varying from 240 to 290 feet. A portion of the waterworks supply is obtained from wells 240 feet in depth, which overflow. It is estimated that a well 8 inches in diameter has a capacity of 150,000 gallons per day. (Information furnished by Dr. Phinney and by city mayor.)

*Martinsville.*—The natural-gas boring made at this city a few years ago brought a flow of sulphur water which has since gained such wide reputation for its medicinal properties that at the present time six sanitariums are necessary to accommodate the persons who are availing themselves of this water. Each sanitarium has a well sunk to a depth of nearly 700 feet, the shallowest being 668 feet and the deepest 704 feet. The gas boring referred to above reached a depth of 1,472 feet. Analyses of waters from several of these wells appear on a subsequent page. It will be observed that they present some differences in relative amounts of each of the mineral ingredients, but the waters are all sulpho-saline. The head has been determined at several of these wells and found to be 620 feet above tide. After penetrating the drift, which is 90 to 117 feet in thickness, the wells pass through a heavy shale formation over 400 feet in thickness. Limestone is then entered, which, at about 600 feet from the surface, becomes water bearing. The amount of water increases within the next 75 or 100 feet to its maximum flow. The rate of flow per minute has been determined at several of the sanitariums, as follows: Home Lawn Sanitarium, 40 gallons; Highland Sanitarium, 25 gallons; Barnard's Sanitarium, 28 gallons; Martinsville sanitarium, 35 gallons. The rate of flow at the other two sanitariums has not been determined. The size of the wells differs slightly, but is usually between 5 and 6 inches. The tests recorded above are made through pipes of smaller diameter forming an inside casing. There are two other borings in the vicinity of Martinsville, not accompanied by sanitariums, which reach a similar depth and have an overflow

[1] Eleventh Ann. Rept. U. S. Geol. Survey, p. 736.

[2] See Geology of Indiana, 1878, p. 436.

of sulpho-saline water. One is located on the grounds of the Forest Grove Park Association and the other on the farm of C. S. Cunningham, about 1½ miles southwest of the city.

*Michigan City.*—A boring was made several years ago at the Northern Indiana Penitentiary, about a mile west of Michigan City, which obtained a strong flow of water highly charged with sulphureted hydrogen. The rate of discharge is estimated to be about 300 gallons per minute. The head is 22 feet above the surface, or about 620 feet above tide. The water has a temperature of 57° F. The section of the well is as follows: Glacial drift, 172; Devonian shale, 76; Limestone, largely Niagara, 293 feet; total, 541 feet. A gas-well boring in the city and a boring on the Blair farm, 2 miles west, each obtain strong flows of sulphurous water from the Niagara limestone. In all three wells strong flows of water were also obtained in sand beds in the lower part of the glacial drift.

*Mitchell.*—A gas boring 1,200 feet in depth struck two veins of brackish water, from which water rises within 30 feet of the surface, or to a level about 645 feet above tide. This water is used for street sprinkling, there being no waterworks in the village. (Data furnished by J. T. Dilley.)

*Monon.*—A gas boring at this village struck salt water at 880 feet, near the top of the Trenton, which rose almost to the surface, 650 feet, more or less, above tide. At Monticello, only a few miles distant, salt water struck in the Trenton at 1,050 feet rose only 500 feet in the well. It is probable that the latter well failed to open an adequate passage for the water. Possibly, also, the Monon well owes the high head partly to an influx of water from the Niagara limestone.[1]

*Montezuma.*—A boring about 1,700 feet in depth struck a vein of salt water at 300 feet and another about 450 feet which have sufficient head to rise to the surface. At about 1,200 feet, immediately beneath the Devonian shales, a sulphur water was struck which rises with great force to a height of fully 100 feet above the surface, or about 610 feet above tide. It is reported that water was made to rise in a tube 115 feet above the surface, or 625 feet above tide. An analysis of the water is given on a subsequent page. A large swimming pool has been constructed, which is filled with this water. The rate of flow of the well is estimated to be about 475 gallons per minute. (Data furnished by Joseph Burns.)

*Muncie.*—The city water supply is obtained from artesian wells drilled in the valley of White River. The supply is from the Niagara limestone. (Data obtained from Manual of American Waterworks.)

*New Haven.*—The waterworks supply is from a well in the Niagara limestone, 300 feet in depth. The first vein of water was struck at 150 feet and raised within 1 foot of the surface. A second vein struck at about 300 feet has a head 11 feet above the surface, or nearly 750 feet above tide. An analysis of the water is given on a subsequent page. (Data furnished by D. H. F. Berberick.)

*North Manchester.*—A gas boring struck salt water at 1,180 feet which rose 990 feet in the well, reaching an elevation of about 600 feet above tide. Flowing wells are obtained from the drift in this vicinity at about 100 feet, as noted above. The waterworks supply is from such wells.

*North Vernon.*—A gas boring 1,400 feet in depth struck salt water in St. Peter sandstone at 1,400 feet which rose to about 200 feet from the surface or 500 feet above tide. (Phinney.) A flowing well of great strength was obtained near North Vernon, in Niagara limestone, at 66 feet.

*Peru.*—A gas-well boring struck salt water in the Trenton at about 900 feet, which rose 800 feet in the well, or to an elevation of about 550 feet above tide.[2]

*Reelsville.*—An artesian well was made many years ago at Reelsville, in the valley of Walnut Creek, at an elevation of about 600 feet above tide. The depth was 1,240 feet, and salt water was obtained at several horizons. The well terminated in the

[1] Phinney, Eleventh Ann. Rept. U. S. Geol. Survey, p. 731.
[2] Ibid., p. 733.

Niagara, where a white sulphur water was obtained.[1] At the time this well was struck the water rose in a copious stream to a height of fully 20 feet above the surface. No recent data concerning it have been obtained.

*Rensselaer.*—A well was made many years ago just east of the village, which obtained a strong flow of sulphureted water from a depth of 180 feet, but the boring was extended to a depth of 800 feet. Another well at the court-house struck water at similar depth, which rises nearly to the surface.[2] Numerous wells in the drift in that vicinity obtain a flow of water, and wells at all depths in the rock show a strong rise of water.

*Seymour.*—In a gas-well boring sulphur water was struck at 250 to 257 feet, and again at 345 to 385 feet in limestone, probably of Upper Silurian age. The head is sufficient to bring the water nearly to the surface, 630 feet above tide. The total depth of this boring is 1,204 feet. A boring owned by the Seymour Mineral Company was drilled in 1892 to a depth of 500 feet, obtaining water at the same horizon noted above in the gas well.

*Shoals.*—A boring 960 feet in depth made in the East White Valley, just east of the village, has a weak flow of salt water, which contains also a notable amount of lithium chloride and magnesium bromide, as shown by an analysis on a subsequent page. This water has been shipped to distant points, and is held in high esteem by the residents as an alterative and restorative.

*South Bend.*—A gas-well boring at this city reached a depth of 1,600 feet, and struck salt water at three horizons, as follows: At 375 feet, near the top of the Devonian limestone; at 610 feet, in limestone, thought to be the equivalent of the Lower Helderberg, and at 1,670 feet in the upper part of the Trenton. From the latter depth it is reported to rise within 200 feet of the surface, or to about 525 feet above tide. (Phinney.) As noted above, numerous flowing wells are obtained along the St. Joseph Valley in South Bend and vicinity.

*Spencer.*—Three wells at this city have been sunk to the Niagara limestone for the purpose of obtaining the sulpho-saline water which it yields. The depth of each of the wells is about 1,150 feet. A salt water is found in Subcarboniferous limestone at a depth of 450 feet, which is cased out in order to obtain the unmixed water from below. At one of these wells a large sanitarium has been built by Dr. E. V. Green, and an analysis of the water appears on a subsequent page. The capacity of the well at the level of the surface of the ground is about 200 gallons per minute, as it issues from a 4-inch casing. The head is sufficient to cause it to overflow from a pipe at a level 65 feet above the well mouth, or 625 feet above tide, and it apparently will rise much higher. A well made at the court-house supplies hydrants in the city, which are used extensively. The third well is on the Fletcher farm, about one-half mile northeast of the court-house.

*Sullivan.*—A gas well was sunk to a depth of 1,000 feet, and obtained a very strong brine, which rises within 15 feet of the surface, or about 525 feet above the tide. The water is used for street sprinkling, and makes a heavy coating of salt when evaporated. Another boring made by the Evansville and Terre Haute Railway Company in the valley of Busseron Creek, about 2 miles southeast of Sullivan, obtained an overflowing well of great strength, which is not put to use. Its depth is thought to be about the same as that of the well in Sullivan.

*Summitville.*—The gas-well boring at this village is reported by Dr. Phinney to have obtained a strong flow of water from the Niagara limestone at a depth of 140 feet. The altitude of the well being 896 feet, the flow was unexpected. Whether it is maintained has not been learned.[3]

*Terre Haute.*—A boring made by Mr. Chauncey Rose many years ago reached a depth of 1,793 feet, passing through three horizons of salt water in the Carbonifer-

[1] See Geology of Indiana, 1869, p. 31.

[2] See Geology of Indiana, 1872, p. 298.

[3] See Eleventh Annual Report U. S. Geol. Survey, p. 709.

ous rocks, and one or more in the Subcarboniferous. In the lower 100 feet of the well a strong flow of sulphur water was obtained. It is thought that the well terminated near the base of the Subcarboniferous limestone. An analysis of the water appears on a subsequent page. Afterwards several other wells were sunk in this city on account of a showing of oil found in the Rose well, one of which was continued through the Devonian into the Niagara and Clinton. As these wells were sunk for the purpose of obtaining oil, the water was cased out and few data appear to be available. Several detailed records of rock strata are published in the Twenty-first Annual Report of the Indiana Geological Survey, 1897.

*Wabash.*—A well at the court-house square on the bluff of Wabash River, 85 feet above the stream and more than 700 feet above tide, was sunk to a depth of 2,270 feet. The boring started in the Niagara limestone, and water was reached at 85 feet, the level of the river. No increase in head was obtained from the lower veins, though several were encountered. Temperature tests were made at 100, 500, 1,000, and 2,270 feet, which show the water to be uniform at 50½° F. at all these depths. The inference to be drawn from this uniform temperature is that the well is filled with water from an upper stratum and the temperature which it receives at that horizon is, by means of the greater specific gravity of cold water, carried down to the bottom of the well. This matter is discussed quite fully in the Geology of Indiana.[1]

*West Fork.*—At West Fork, Crawford County, Indiana, a few miles west of Leavenworth, a sulphur well of some note, known as "Eaton's sulphur well," was bored in the years 1862 and 1863. It is 4 inches in diameter and 284 feet in depth, and the flow is obtained from the lower part of the St. Louis limestone. The water from this well has a high reputation and has been sold extensively. A hotel is built for the accommodation of patrons of the well.[2] An analysis appears on a subsequent page.

*Williamsport.*—A gas-well boring 1,200 feet in depth struck a strong vein of fresh water at a depth of 65 feet and another at a depth of 165 feet. The second vein furnished an overflow. Salt water was struck at about 1,200 feet. After failing to obtain gas the salt water was plugged off and the fresh water was made available. (Data furnished by J. C. Russell.)

*Winamac.*—A gas-well boring 1,200 feet in depth obtained a flow of water which discharges at the rate of 45 gallons per minute. The depth of the water vein is not reported. It is said to be chalybeate.

*Worthington.*—A boring 1,445 feet in depth struck a strong flow of sulphur water at 1,430 feet, which appears to be similar to that struck at Spencer at about 1,100 feet, and probably from the Niagara limestone. The water has been piped to a hotel, where it may be used for drinking and bathing. (Data furnished by A. F. Wilson.)

## MINERAL SPRINGS.

In a bulletin of this Survey prepared by Dr. A. C. Peale, a brief discussion of the mineral springs of Indiana and Ohio is included.[3] Thirty springs are noted from Indiana and twenty from Ohio which are or have been used either commercially or as a resort, and analyses of those most extensively used are presented. Many unimproved springs are also listed, and artesian wells used for medicinal purposes are included in Dr. Peale's tables.

Many of the springs have only a local reputation, but a few have become widely known. Perhaps those of widest reputation in Indiana

[1] Report for 1875, pp. 43–48.

[2] See Geology of Indiana, 1878, pp. 443–444.

[3] Mineral Springs of the United States, by Albert C. Peale, M. D.: Bull. U. S. Geol. Survey No. 32, 1886, pp. 130–141.

are French Lick and West Baden springs, Orange County; Degonia springs, Warrick County; Indian and Trinity springs, Martin County; West Saratoga springs, Pike County; Van Cleve springs, near Crawfordsville; and Hawkins springs, at Richmond.

In Ohio, among the springs of wide reputation should be mentioned Bellbrook magnetic spring, at Bellbrook, Greene County; Blue Rock spring, in East Cleveland; Cuyahoga lithia and bitter springs, near Cleveland; Odevene and Lenape springs, at Delaware; Ohio magnetic springs, at Magnetic Springs, Union County; the electro-magnetic springs, near Woodstock, in Champaign County; and Green spring, in Seneca County.

As the writer has not made a special canvass of this subject, there may be other springs to which his attention has not been directed which are as important as those just noted. Many springs have come into prominence through well-directed advertising by their proprietors, which are apparently superior in no way to dozens of others which are unknown to the public, but which may have a local reputation. In preparing a list of mineral sp ings there is room for indefinite extension. There is scarcely a township in the drift-covered portions of Indiana and Ohio which does not afford springs that are slightly chalybeate. It is probable that an analysis would show waters similar to the iron springs of health resorts. So, also, there are numerous sulphur and iron springs, as well as calcic springs, issuing from rock ledges in many of the valleys of Indiana and Ohio. A list such as that prepared by Dr. Peale can not be considered complete, but it probably includes the majority of springs which have been brought into prominent notice. A reference to the reports of the State geological surveys will serve to show how widely such springs are distributed.

The temperature of the water, as reported by Dr. Peale, ranges in the Indiana springs from 43° F. at Blue Lick spring, in Clark County, to 57° at Trinity and West Baden springs. A shallow thermal well near Shelbyville has a temperature of 76°. The majority of the springs have a temperature of 50° to 55° F. The reported temperature ot the springs in Ohio ranges from 47° in Lenape spring, at Delaware, to 60° at Blue Rock spring, in East Cleveland. The temperature is given, however, for only a small per cent of the springs, so that the range may be wider than indicated by the table.

Many of the springs listed by Dr. Peale have a flow of less than 1,000 gallons per hour, and the cold (Blue Lick) spring in Clark County, Indiana, just noted, has a flow of but 1½ gallons per hour. Trinity springs, in Martin County, Indiana, are estimated to furnish 18,000 gallons per hour. West Baden springs flow 1,500, and French Lick at least 1,100 gallons per hour.

The following springs used as resorts in Indiana are reported by Dr. Peale to have a saline-sulphureted water: French Lick, Orange County; Hartford sulphur springs, Crawford County; Blue Lick, Clark County;

Indian and Trinity springs, Martin County; New Middletown springs, Harrison County; and West Baden springs, Orange County. In Ohio, Blue Rock spring, at East Cleveland, is of this character. The magnetic springs at Bellbrook and Delaware and at Magnetic Springs are all reported by Dr. Peale to be calcic, no mention being made of chalybeate character. Two analyses from the Lenape springs show about one-half grain of iron oxide per gallon, and one from the Bellbrook gives less than one-fourth grain, while the Ohio Magnetic, at Magnetic Springs, and the Electro-Magnetic, near Woodstock, show only a trace of iron oxide. Hawkins chalybeate springs, at Richmond, Indiana, appear to be misnamed, as only 0.18 grain of ferrous carbonate is reported in the analysis.

## WATER ANALYSES.

In Ohio the State board of health is required by law to approve all public water supplies when introduced, and it has in accordance with this law in every case made an analysis of the proposed supply. The analyses may be found in their annual reports. In Indiana also steps are being taken by the State board of health for a similar publication of analyses.

In many cases waters have been analyzed independently of the boards of health. Several such analyses have been sent to the writer in connection with the schedules for city water supply, and are here presented. A few analyses of the artesian wells, mineral springs, and other waters of special interest also appear. Sanitary analyses are presented in the discussion of city water supplies.

It will be observed that the deep wells usually contain a much larger amount of mineral matter than the springs and shallow wells. The French Lick, Indian, and West Baden springs of southern Indiana are, however, heavily charged with mineral matter, as are also the springs near Cleveland and Green spring in Seneca County, Ohio. The majority of springs and shallow wells are slightly saline, while the deep wells are usually strongly saline. The tables following illustrate what has already been stated to be a general condition in Indiana and Ohio. They also set forth fairly, as it seems, the variations in quality of water found in this region, and afford a basis for instructive comparisons.

In a few of the waters included in this table of analyses substances have been found which are not reported in the table. They may be found in a large proportion of the waters, since analyses are seldom complete.

Alumina is found in measurable quantities in the following: Marion, Indiana, 0.29 grain; Greencastle, Indiana, "No. 1," 0.15 grain; "No. 2," 0.07 grain; Shoals, Indiana, 0.62 grain; Spencer, Indiana, 0.697 grain; Cuyahoga lithia springs, near Cleveland, Ohio, 17.67 grains; Dayton, Ohio, "No. 1," 0.3599 grain; "No. 2," 0.3251 grain; Defiance, Ohio, 0.36 grain; Green spring, 0.98 grain; Ohio Magnetic spring, 0.12 grain;

New Paris, Ohio, 0.22 grain; Ripley, Ohio, 0.68 grain; Van Wert, Ohio, 0.09 grain.

Aluminium sulphate is reported as follows: West Baden "No. 1," 4.55 grains; Bellefontaine, Ohio, 2.92 grains; Cuyahoga bitter spring, 515.51 grains. In this connection attention is called to the occurrence of "bitter water" in wells in the drift in the vicinity of Bellefontaine and thence eastward past Marysville to the vicinity of Delaware, Ohio. Numerous instances are reported in the Geology of Ohio, and such water is in some localities so prevalent as to give them the name of "bitter water districts." So far as known to the writer no analyses of these waters have been made. They may contain aluminium sulphate, but their bitter taste appears to be due to some other ingredient.

Aluminium chloride is reported in but one analysis, the Cuyahoga lithia water, which contains 17.67 grains.

Calcium phosphate is reported as follows: Lafayette, Indiana, 0.50 grain; Lodi, Indiana, 1.20 grain; Montezuma, Indiana, trace; New Paris, Ohio, 2.13 grains.

Calcium sulphide appears in the following: Montezuma, Indiana, 3.55 grains; Shoals, Indiana, 24.43 grains; Spencer, Indiana, 0.392 grain; Ripley, Ohio, 14.90 grains. At Shoals, Indiana, 18.88 grains of calcium disulphide and 33.072 of calcium hyposulphide are reported. The water at Ripley, Ohio, also contains calcium hyposulphide, 2.58 grains.

Iron is usually reported in the form of oxide, but in the following cases ferrous carbonate is reported: Anderson, Indiana, springs, 0.98 grain; Crawfordsville, Indiana, 0.62 grain; French Lick spring, 2.49 grains; Greencastle spring, "No. 1," 0.40 grain; "No. 2," 2.37 grains; Mifflin, Indiana, well, 8.925 grains; Richmond, Indiana, springs, 0.18 grain; West Baden spring, "No. 2," 3.60 grains (including aluminium carbonate); Eaton's well at West Fork, Indiana, 2.38 grains; Cuyahoga lithia spring, 0.82 grain; Cuyahoga bitter spring, 0.47 grain; Green spring, Seneca County, Ohio, 19.70 grains; New Paris, Ohio, 1.32 grains; Stryker, Ohio, 9.93 grains; Woodstock, Ohio, 16 grains. In the following cases ferrous sulphate is reported: Indian springs, 24.28 grains; Marion, Indiana, well, 1.48 grains; Green spring, Seneca County, Ohio, 6.53 grains. At Shoals, Indiana, and Ripley, Ohio, the iron is reported as sulphide, and at the Ludlow Grove salt well as chloride.

Lithium chloride is found in several of the wells and springs, as follows: Montezuma, Indiana, trace; Shoals, Indiana, 5.93 grains; Cleveland Blue Rock spring, 2.16 grains; Cuyahoga lithia spring, 2.74 grains; Cuyahoga bitter spring, 4.26 grains; lithium carbonate (8.84 grains) is reported in the Ripley analysis.

Magnesium bromide appears in the following analyses: Lodi, Indiana, 0.88 grain; Shoals, Indiana, 2.32 grains; Cincinnati sulpho-saline well, 0.39 grain; Ripley, Ohio, 0.52 grain. Potassium bromide (16.76 grains) is reported in the Green spring analysis, and sodium bromide (28.21 grains) in the salt well at Ludlow Grove, Ohio. In this connection it

may be remarked that the brines of Ohio are generally found to be rich in bromine.

Magnesium iodide is reported in three analyses, as follows: Shoals, Indiana, 0.004; Cincinnati artesian, 0.19 grain; Cincinnati sulpho-saline, 0.30 grain. Sodium iodide appears in small amount in two analyses, there being a trace at Montezuma, Indiana, and 0.20 grain in the Cleveland Blue Rock spring.

Magnesium sulphide is reported only in the Ripley analysis, 19.26 grains. Potassium sulphide is reported only at Spencer, 1.9 grains. Potassium nitrate is reported only at Shoals, 7.86 grains.

Sodium phosphate appears in two analyses: Cincinnati sulpho-saline well, 1.34 grains; Cleveland Blue Rock springs, 5.25 grains. Sodium silicate is reported only at Columbia City, Indiana (0.14 grain), and sodium sulphide at Spencer, Indiana (0.94 grain).

Ammonium chloride is reported in considerable amount, 8.35 grains, in the Shoals, Indiana, analysis.

*Analyses of the waters of Indiana and Ohio.* (*Grains per United States gallon.*)

INDIANA WATERS.

| Locality. | Total solids. | Calcium carbonate and bicarbonate. | Calcium chloride. | Calcium sulphate. | Iron. | Magnesium carbonate and bicarbonate. | Magnesium chloride. | Magnesium sulphate. | Potassium carbonate. | Potassium chloride. | Potassium sulphate. | Silica. | Sodium carbonate and bicarbonate. | Sodium chloride. | Sodium sulphate. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anderson (springs) | 20.00 | 9.08 | ..... | 5.56 | 0.98 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | E. T. Cox. |
| Andrews (well) | 45.10 | 18.66 | ..... | 1.59 | ..... | 1.20 | 9.77 | ..... | ..... | ..... | ..... | ..... | ..... | 14.37 | ..... | W. E. Stone. |
| Brookville (waterworks) | (?) | 12.37 | ..... | 0.008 | ..... | 6.41 | ..... | ..... | ..... | ..... | 0.035 | 0.032 | ..... | 0.043 | 0.02 | H. A. Huston. |
| Columbia City (waterworks) | (?) | 18.96 | ..... | ..... | 0.107 | 0.52 | ..... | ..... | ..... | 0 02 | ..... | ..... | 0.07 | 0.19 | 0.096 | T. C. Van Nuys and I. T Metz. |
| Crawfordsville (spring) | 22.84 | 9.80 | ..... | ..... | 0.62 | 3.82 | ..... | 7.32 | 0.14 | ..... | ..... | 0.07 | 0.17 | 0 70 | 0.20 | T. M. Stevens |
| Edinburg (gas well) | 993.32 | 5.06 | 65.48 | 2.10 | 0.997 | ..... | ..... | 32.93 | ..... | ..... | ..... | 1.99 | 10.43 | 874.32 | ..... | J. N. Hurty. |
| Elwood (waterworks) | 22.85 | 11.08 | ..... | 1.70 | ..... | 6.41 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.99 | ..... | (?) |
| French Lick (spring) | 350.52 | 20 29 | ..... | 141.00 | 2.49 | 4.50 | 8.05 | 29.33 | ..... | 5.01 | ..... | 1.69 | 10.52 | 90.92 | 36.72 | J. G. Rogers. |
| Greencastle: | | | | | | | | | | | | | | | | |
| Spring No. 1 | 22.10 | 14.50 | ..... | ..... | 0.40 | 4.72 | ..... | 1.05 | 0.09 | ..... | ..... | 0.09 | 0.10 | 0.79 | 0.13 | E. T. Cox. |
| Spring No. 2 | 21.80 | 11.90 | ..... | ..... | 2.37 | 5.34 | ..... | 1.03 | 0.07 | ..... | ..... | Trace. | 0.06 | 0.70 | 0.01 | Do. |
| Greensburg (waterworks) | 21.55 | 12.48 | ..... | ..... | 0.30 | 6.44 | ..... | ..... | ..... | ..... | 0.23 | 0.71 | 0.51 | 0.59 | ..... | E. G. Smith. |
| Indian springs | 196.45 | 39.73 | ..... | ..... | 24.29 | 22.74 | 0.07 | 36.48 | 2.89 | ..... | 2.88 | 0.54 | 4 38 | 47.26 | 14.20 | E. T. Cox. |
| Lafayette (artesian) | 419.54 | 12.02 | 3.72 | 56.01 | ..... | 0.40 | 21.66 | ..... | ..... | ..... | ..... | 0.46 | ..... | 324.77 | ..... | C. M. Wetherell. |
| Lodi (artesian | 672.45 | 2.01 | 47.93 | 55.56 | ..... | 0.66 | 53.54 | 3.26 | ..... | ..... | 0.80 | 0.52 | ..... | 502.46 | 2.13 | J. C. Pohle. |
| Marion (flowing well) | 23.20 | 14.00 | ..... | ..... | 1.48 | 2.34 | ..... | 3.38 | 0.03 | ..... | ..... | 1.34 | ..... | 0.32 | ..... | (?) |
| Martinsville: | | | | | | | | | | | | | | | | |
| Barnard's Sanitarium | (?) | 7.33 | 10.13 | ..... | ..... | ..... | 7.51 | ..... | ..... | 20.45 | 0.89 | Trace. | ..... | 18.71 | 1.09 | (?) |
| Home Lawn Sanitarium | (?) | 6.55 | ..... | ..... | ..... | 5.35 | ..... | ..... | ..... | 14.77 | ..... | 8.45 | 3.27 | 55.86 | 1.69 | W. E. Stone. |
| Martinsville Sanitarium | (?) | 16.90 | ..... | ..... | ..... | 15.35 | ..... | ..... | ..... | 1.77 | ..... | 0.55 | 2.48 | 58.58 | 1.87 | Do. |
| Mifflin (well) | 6,003.33 | 663.20 | ..... | 29.07 | 8.92 | 179.38 | ..... | 87.12 | ..... | ..... | 23.38 | ..... | 5,021.40 | ..... | 21.53 | G. M. Levette. |
| Montezuma (artesian) | 426.28 | 11.18 | 11.65 | 7.11 | ..... | 17.88 | 9.97 | ..... | ..... | 2.68 | ..... | 0.82 | ..... | 357.71 | ..... | W. A. Noyes. |
| New Haven (waterworks) | (?) | 7.18 | ..... | 12.23 | ..... | 0.06 | ..... | 8.52 | ..... | ..... | ..... | 7.58 | ..... | 14.80 | ..... | (?) |

*Analyses of the waters of Indiana and Ohio.* (*Grains per United States gallon.*)—Continued.

INDIANA WATERS—Continued.

| Locality. | Total solids. | Calcium carbonate and bicarbonate. | Calcium chloride. | Calcium sulphate. | Iron. | Magnesium carbonate and bicarbonate. | Magnesium chloride. | Magnesium sulphate. | Potassium carbonate. | Potassium chloride. | Potassium sulphate. | Silica. | Sodium carbonate and bicarbonate. | Sodium chloride. | Sodium sulphate. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Newcastle: | | | | | | | | | | | | | | | | |
| Waterworks No. 1 | 22.51 | 12.75 | ..... | ..... | ..... | 6.12 | ..... | ..... | ..... | ..... | ..... | 0.40 | 1.87 | 0.98 | 0.12 | (?) |
| Waterworks No. 2 | 22.13 | 10.15 | ..... | ..... | ..... | 7.82 | ..... | ..... | ..... | ..... | ..... | 0.46 | ..... | 1.78 | 1.90 | (?) |
| Richmond (springs) | 26.85 | 9.45 | 0.32 | 11.69 | 0.18 | ..... | ..... | 1.60 | 1.16 | ..... | ..... | 0.16 | ..... | 0.33 | ..... | E. T. Cox. |
| Shoals (artesian) | 1,518.54 | 32.52 | 20.30 | 2.65 | 1.37 | ..... | 9.68 | ..... | ..... | 47.30 | ..... | 2.72 | ..... | 1,303.48 | ..... | Karl Laugenbeck. |
| Spencer (artesian) | ? 121.67 | 12.22 | 8.11 | ..... | 0.553 | 2.38 | 5.03 | ..... | ..... | 18.12 | ..... | 0.32 | 4.17 | 66.84 | ..... | J. N. Hurty. |
| Tell City (artesian) | ..... | ..... | 252.61 | 102.90 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1.28 | ..... | 3,006.08 | ..... | Do. |
| Terre Haute (artesian) | 365.07 | 25.03 | 4.82 | 2.32 | ..... | 6.42 | 6.43 | ..... | ..... | 1.23 | ..... | 1.20 | 0.52 | 316.00 | ..... | J. G. Pohle. |
| Trinity springs | 26.73 | 5.61 | 0.70 | 1.27 | ..... | 4.11 | 1.10 | 4.18 | 0.07 | ..... | 0.10 | 0.82 | 0.12 | 8.34 | 0.35 | |
| West Baden: | | | | | | | | | | | | | | | | |
| Spring No. 1 | 235.25 | 41.28 | 7.26 | 11.18 | 0.08 | 39.10 | 11.39 | 36.15 | 0.06 | ..... | 1.36 | 0.44 | 1.11 | 79.60 | 3.10 | E. T. Cox. |
| Spring No. 2 | 301.80 | 19.44 | 6.13 | 108.34 | 3.60 | 6.05 | 9.20 | 27.77 | ..... | ..... | ..... | ..... | 9.70 | 80.21 | 31.70 | Do. |
| West Fork (Eaton's well) | 263.50 | 47.51 | ..... | 11.46 | 1.98 | 16.80 | ..... | 43.80 | ..... | ..... | 5.40 | ..... | ..... | 125.40 | 10.95 | G. M. Levette. |

OHIO WATERS.

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland (waterworks) | (?) | 12.32 | ..... | ..... | ..... | 3.00 | ..... | 2.83 | ..... | ..... | ..... | 1.28 | 1.56 | 1.00 | ..... | S. W. McKeown. |
| Bellbrook (spring) | 26.79 | 15.52 | ..... | 1.20 | 0.25 | 7.20 | ..... | ..... | ..... | ..... | 1.07 | 0.67 | ..... | 0.85 | 0.03 | N. W. Lord. |
| Bellefontaine (waterworks) | 20.48 | 8.33 | ..... | 3.62 | ..... | 5.19 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.42 | ..... | C. C. Howard. |
| Cincinnati: | | | | | | | | | | | | | | | | |
| Artesian, 1,245 feet | 617.32 | 17.33 | 22.26 | 27.27 | 0.37 | 8.14 | 18.14 | ..... | ..... | 3.27 | ..... | 0.49 | ..... | 519.60 | ..... | E. S. Wayne. |
| Well, 240 feet | 642.16 | 19.34 | 22.19 | 29.20 | 0.43 | 9.13 | 17.27 | ..... | ..... | 3.95 | 2.30 | 0.79 | ..... | 534.77 | ..... | Do. |
| Cleveland (blue-rock spring) | 303.27 | 3.75 | ..... | ..... | ..... | 56.81 | ..... | ..... | 6.75 | 16.10 | ..... | 1.00 | 1.00 | 210.25 | ..... | J. L. Cassells. |

*Analyses of the waters of Indiana and Ohio.* (*Grains per United States gallon.*)—Continued.

OHIO WATERS—Continued.

| Locality. | Total solids. | Calcium carbonate and bicarbonate. | Calcium chloride. | Calcium sulphate. | Iron. | Magnesium carbonate and bicarbonate. | Magnesium chloride. | Magnesium sulphate. | Potassium carbonate. | Potassium chloride. | Potassium sulphate. | Silica. | Sodium carbonate and bicarbonate. | Sodium chloride | Sodium sulphate. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cuyahoga: | | | | | | | | | | | | | | | | |
| Lithia spring | 515.82 | 11.08 | ..... | 120.39 | 0.82 | ..... | ..... | 116.54 | ..... | ..... | 4.38 | 15.87 | ..... | 222.19 | 4.14 | (?) |
| Bitter spring | 791.58 | 8.75 | ..... | 50.16 | 0.47 | ..... | ..... | 172.07 | ..... | ..... | 1.57 | 19.31 | ..... | 8.05 | 11.43 | (?) |
| Dayton: | | | | | | | | | | | | | | | | |
| Waterworks in 1887 | 16.87 | 7.94 | ..... | 0.53 | ..... | 5.22 | ..... | ..... | ..... | ..... | 0.52 | 0.18 | ..... | 0.26 | 1.79 | H. S. Jewett. |
| Waterworks in 1895 | 21.98 | 11.76 | ..... | 0.006 | ..... | 6.12 | ..... | ..... | ..... | ..... | 0.44 | 0.38 | ..... | 0.42 | 2.52 | Do. |
| Delaware: | | | | | | | | | | | | | | | | |
| Lenape spring | 55.70 | 27.42 | 0.63 | 6.20 | 0.54 | 15.21 | ..... | 0.93 | ..... | ..... | 1.34 | 0.05 | ..... | 3.35 | ..... | E. S. Wayne. |
| Lenape spring, No. 2 | 40.64 | 17.73 | ..... | 5.12 | 0.41 | 12.11 | ..... | 2.31 | ..... | ..... | ..... | ..... | ..... | 2.15 | ..... | Do. |
| Odeveuel spring | 375.11 | 33.87 | 15.26 | 102.47 | 0.05 | 2.64 | 55.93 | ..... | ..... | 18.65 | ..... | 0.37 | ..... | 145.87 | ..... | A. A. Breneman. |
| Defiance Sanitarium (artesian) | 88.26 | 26.36 | ..... | 4.58 | 0.80 | 7.62 | ..... | 3.95 | ..... | Trace | ..... | 1.29 | ..... | 20.85 | 2.35 | J. N. Hurty. |
| Eaton (waterworks) | (?) | 8.39 | ..... | 2.18 | 0.017 | 4.95 | ..... | ..... | ..... | ..... | ..... | 0.29 | 5.19 | 1.16 | ..... | (?) |
| Green spring, Seneca County | 216.49 | 22.39 | ..... | 105.41 | 19.70<br>6.53 | ..... | ..... | 36.14 | ..... | 2.48 | ..... | 6.10 | ..... | ..... | ..... | O. N. Stoddard. |
| Ludlow Grove (salt well 271) | 5,738.10 | 6.33 | 786.61 | 6.07 | 53.46 | 14.06 | 542.04 | ..... | ..... | ..... | ..... | 1.22 | ..... | 4,300.10 | ..... | E. S. Wayne. |
| Magnetic springs | 44.90 | 19.20 | 3.27 | ..... | 0.16 | 17.61 | ..... | 2.30 | ..... | ..... | 0.22 | 0.24 | ..... | 0.79 | 0.42 | Do. |
| Marion (waterworks) | (?) | 13.53 | ..... | 1.24 | Trace. | 5.97 | ..... | ..... | ..... | ..... | ..... | 1.40 | ..... | ..... | 7.82 | (?) |
| Massillon (waterworks) | 21.38 | 12.65 | ..... | 0.79 | 0.06 | 5.47 | ..... | ..... | ..... | ..... | 0.13 | 0.59 | ..... | 0.76 | 1.16 | E. G. Smith. |
| New Paris (Cedar spring) | 18.11 | 3.96 | ..... | 1.24 | 1.32 | 5.82 | ..... | ..... | ..... | ..... | ..... | ..... | 2.26 | 0.98 | 0.18 | A. Fennel. |
| Oberlin (waterworks) | 35.35 | 1.16 | ..... | 14.75 | 0.29 | 11.94 | ..... | ..... | ..... | ..... | 0.39 | 0.35 | ..... | 2.96 | 3.44 | F. F. Jewett. |
| Ripley (artesian) | (?) | ..... | ..... | 1.46 | 0.041 | ..... | ..... | ..... | ..... | 23.18 | ..... | 1.62 | ..... | 530.76 | ..... | Karl Laugenbeck. |
| Springfield (waterworks) | 21.30 | 1.26<br>12.13 | ..... | 0.09 | ..... | 5.12 | ..... | ..... | 0.53 | ..... | ..... | 0.10 | 0.91 | 0.21 | ..... | (?) |
| Stryker (well) | 621.51 | 68.30 | ..... | ..... | 9.93 | ..... | 118.96 | ..... | ..... | ..... | 185.34 | 2.63 | ..... | 231.86 | ..... | S. H. Douglass. |

*Analyses of the waters of Indiana and Ohio.* (*Grains per United States gallon.*)—Continued.

OHIO WATERS—Continued.

| Locality. | Total solids. | Calcium carbonate and bicarbonate. | Calcium chloride. | Calcium sulphate. | Iron. | Magnesium carbonate and bicarbonate. | Magnesium chloride. | Magnesium sulphate. | Potassium carbonate. | Potassium chloride. | Potassium sulphate. | Silica. | Sodium carbonate and bicarbonate. | Sodium chloride. | Sodium sulphate. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Van Wert (waterworks) | 78.49 | 13.51 | ..... | 27.37 | 0.12 | ..... | ..... | 26.14 | ..... | ..... | 0.69 | 0.89 | ..... | 2.02 | 7.66 | E. G. Smith. |
| Woodstock (springs) | 61.33 | 26.24 | 4.22 | ..... | 0.16 | 11.41 | 2.12 | ..... | ..... | ..... | 2.91 | 0.24 | ..... | 13.64 | ..... | E. S. Wayne. |
| Wyoming (waterworks) | 19.72 | 10.06 | ..... | 0.56 | 0.87 | 6.67 | ..... | ..... | ..... | ..... | ..... | 0.87 | ..... | 0.64 | ..... | (?) |
| Yellowsprings (spring) | 23.17 | 19.57 | 1.54 | 1.35 | 0.39 | ..... | 0.17 | ..... | ..... | ..... | ..... | ..... | ..... | 0.15 | ..... | Wayne and Locke. |
| Zanesville: | | | | | | | | | | | | | | | | |
| Well | 68.90 | 9.11 | ..... | 42.01 | ..... | 5.99 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.78 | ..... | J. D. Lisle. |
| Waterworks | 33.55 | ..... | ..... | 7.58 | Trace. | ..... | ..... | 3.74 | ..... | ..... | ..... | ..... | ..... | 0.73 | ..... | Do. |

## WATER SUPPLIES FOR CITIES AND VILLAGES.

There is considerable variation in the water resources for the supply of cities and villages, some cities being entirely dependent upon wells, while others have easy access to streams, springs, and lakes. Several cities on the border of Lake Erie obtain their supplies largely by pumping from the lake. Lake Michigan is drawn upon to a slight extent by towns in Indiana situated on its borders. The cities along the main streams may generally use the stream water with safety. In addition to this they have usually an available supply of good water from wells of slight depth. Cities not located near the lakes or large streams resort, in some cases, to storage reservoirs formed by damming small streams, but the greater number depend entirely upon wells. In a few instances small lakes furnish the chief water supply. In rural districts and in villages which have no waterworks the supply is mainly from wells of moderate depth. Deep wells are less extensively used than in Illinois, owing to the salinity of the water in much of this region.

A study of the development of the water supply in cities shows that in the early days almost without exception they used shallow wells. But with the growth of the city these often either became inadequate or were found to be contaminated. A change was then made to streams if they were available.

The statistics concerning the cost of waterworks and systems used, contained in the tables which follow, in most instances have been furnished by the officers in charge of the waterworks or by citizens competent to furnish them. In the case of a few cities no response was obtained to the application for data, but in nearly all such cases the statistics necessary for completing the tables have been found in the Manual of American Waterworks,[1] published by the Engineering News.

In many cities where waterworks are constructed a large part of the citizens use private wells, in some cases because they consider the city water unpleasant, but more often to avoid the water tax. In the great majority of the towns on the uplands a good quality of water may be obtained at slight depth in beds of sand or gravel below till or other clay, or at reasonable depth in the underlying rock, where drift is thin or is absent. The cities and villages most liable to have polluted water from shallow wells are situated either in valleys or in the sand-covered districts which occur in the northwest part of Indiana, or on gravel districts on the border of moraines. In these situations there is liable to be too little clay to prevent the infiltration from cesspools. Several cities in valleys have regulations against the use of private wells that are subject to contamination, but there is need for more stringent regulations.

[1] The letter "M" appended to name of city or village indicates indebtedness to this Manual.

## SURFACE WATER.

The use of surface water in Indiana and Ohio as a source of city water supply is shown in the following list, nearly complete, of the cities and villages in which this is the chief source of supply. The table of population indicates that surface water is used to some extent by about 400,000 people, or nearly one-fifth of the population of Indiana, but it is probable that not more than half the population in the cities which use surface water in that State obtain their supply from the waterworks, for private wells are extensively used in nearly all the cities and villages. Probably less than one-tenth of the population are dependent upon this source of supply.

In Ohio the cities using surface water have an aggregate population of about 1,130,000. In this State a much larger proportion of the population depends upon the waterworks system than in Indiana, for such cities as Cincinnati and Cleveland and several smaller cities, situated in valleys, supply nearly their entire population through waterworks systems. It is probable that at least one-fourth the population of Ohio, or nearly 1,000,000 people, are dependent upon surface water supplied to them through waterworks.

The sanitary analyses, some of which are given later in this paper, indicate that this source of supply is usually but little contaminated. Where proper precautions have been taken to locate the pumping stations out of reach of contamination by the city's sewage this source of supply is found to be less dangerous than that of a large proportion of the private wells. The city of Cleveland, which receives its water supply through a tunnel extended out beyond the reach of contamination by the city's wastage, is not often forced to use contaminated water. It is more fortunate in this respect than the city of Chicago, where seldom a year passes in which polluted water is not driven out to the intakes and pumped back for city use. Some dissatisfaction is felt because of the sediment carried by streams in their flood stages, but this is not generally a source of danger, and may to some extent be lessened by an improvement in the filter galleries. Several cities along the Ohio River have already introduced a system of infiltration wells which enables them to furnish water nearly free from sediment.

*Cities in Indiana using surface water for waterworks.*

| Name. *a* | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *b* | When put in. |
| Anderson (part) | 10,741 | White River (filtered) | Direct pumping | $150,000<br>Ex. 5,000 | 1886 |
| Attica (M.) | 2,320 | Springs | Pumped to reservoir | 50,000<br>Ex. 1,500 | 1874 |
| Bedford | 3,351 | White River | Pumped to standpipe | 65,000 | 1893 |
| Bloomington | 4,018 | Springs | Direct pumping | 80,000 | 1893 |
| Borden (M.) | (?) | Impounded water | Pumped to reservoir | 3,600 | 1894 |
| Boonville | 1,881 | do | Pumped to standpipe | 31,000 | 1896 |
| Brookville | 2,028 | Infiltration well from Whitewater River | Pumped to reservoir | 24,000<br>Ex. 1,275 | 1895 |
| Cannelton | 1,991 | Ohio River | do | (?) | 1892 |
| Columbus (M.) | 6,719 | East White River | Direct pumping | 32,000 | 1871 |
| Connersville | 4,548 | Whitewater River | do | 100,000<br>Ex. 1,800 | 1869 |
| Covington (part) | 1,891 | Springs | Pumped to standpipe | 50,000 | 1892 |
| Crawfordsville (M.) | 6,089 | Springs and wells | Pumped to reservoir | 425,000 | 1886 |
| Delphi | 1,923 | Springs and creek | Pumped to tank and direct | 45,000<br>Ex. 1,100 | 1892 |
| East Chicago (M.) | 1,255 | Lake Michigan | Pumped to standpipe | 98,000 | |
| Evansville | 50,756 | Ohio River | Direct pumping | Ex. 30,000 | 1870 |
| Fairmount | 1,462 | Back Creek (?) | (?) | 25,000<br>Ex. 1,000 | 1894 |
| Greencastle (M.) | 4,390 | Walnut Creek and wells | Pumped to standpipe | 303,000 | 1886 |
| Hammond | 5,428 | Lake Michigan | do | 150,000 | 1888 |
| Huntingburg | 3,167 | Impounded water | Standpipe and direct pressure | (?) | 1893 |
| Huntington (part) | 7,328 | Wabash River | Direct pumping | 100,000 | 1891 |
| Indianapolis (24 per cent) | 105,436 | White River | do | 2,500,000 | 1870 |

*a* In the tables concerning water supply, towns with the letter "M" appended did not send in returns, and the Manual of Waterworks is our authority.
*b* "Ex." in this column means running expenses per annum.

*Cities in Indiana using surface water for waterworks*—Continued.

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *a* | When put in. |
| Jasper | 1,281 | Patoka River | Pumped to reservoir | $10,000 | 1895 |
| Jeffersonville | 10,666 | Infiltration from Ohio River | Pumped to standpipe | 200,000<br>Ex. 4,500 | 1888 |
| Lafayette | 17,485 | Infiltration from Wabash River | Pumped to reservoir | 250,000<br>Ex. 10,000 | 1876 |
| Laporte (M.) | 7,126 | Clear Lake | Direct pumping | 150,000<br>Ex. 6,000 | 1870 |
| Leavenworth (M.) | 792 | Spring | Pumped to reservoir | | 1896 |
| Logansport | 13,328 | Eel River | Direct pumping | 225,000<br>Ex. 5,000 | 1876 |
| Madison | 8,936 | Infiltration from Ohio River and springs | Pumped to reservoir | (?) | 1849 |
| Michigan City | 10,776 | Trail Creek and driven wells | Direct pumping | Ex. 6,500 | 1888 |
| Mishawaka (part) | 3,371 | St. Joseph River | do | 60,000 | 1891 |
| Mount Vernon (M.) | 4,705 | Ohio River | Pumped to standpipe | (?) | 1860 |
| New Albany | 21,059 | do | Pumped to reservoir | 300,000<br>Ex. 25,000 | 1875 |
| North Vernon | 2,012 | Muscatatuck | Pumped to standpipe | 28,000 | 1892 |
| Peru | 7,028 | Wabash River | Pumped to reservoir | 170,000 | 1879 |
| Princeton | 3,076 | Patoka River | Pumped to standpipe | 70,000 | 1893 |
| Paoli (M.) | 707 | Stream | Pumped to reservoir | 5,500 | 1893 |
| Richmond | 16,608 | Springs | Pumped to reservoir from filter galleries | 250,000<br>Ex. 10,000 | 1886 |
| Rockport | 2,314 | Ohio River | Pumped to standpipe or direct | 25,000<br>Ex. 1,000 | 1886 |
| Salem | 1,975 | Spring from a cave | Pumped to reservoir | 20,000<br>Ex. 700 | 1886 |
| Seymour | 5,337 | East White River | Pumped to standpipe | 80,000<br>Ex. 3,600 | 1889 |

*a* "Ex." in this column means running expenses per annum.

*Cities in Indiana using surface water for waterworks*—Continued.

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *a* | When put in. |
| Sullivan (M.) | 2,222 | Busseron Creek | Pumped to standpipe from impounding reservoir; filtered. | $40,000 | 1896 |
| Tell City | 2,094 | Ohio River | Pumped to fire cisterns | (?) | (?) |
| Terre Haute | 30,217 | Wabash River | Direct pumping | 600,000<br>Ex. 23,000 | 1873 |
| Valparaiso | 5,090 | Flint Lake | do | 100,000<br>Ex. 6,500 | 1886 |
| Vernon (M.) | 613 | Muscatatuck River | Pumped to standpipe | 4,300 | 1895 |
| Vevay | 1,663 | Infiltration from Ohio River | Pumped to reservoir. | 18,000 | 1895 |
| Vincennes | 8,853 | Wabash River | Pumped to standpipe or direct | 370,000 | 1885 |
| Whiting | 1,408 | Lake Michigan | Pumped direct | (?) | 1890 |
| Washington | 6,664 | White River | Pumped to standpipe | 130,000<br>Ex. 2,000 | 1888 |
| Warsaw (part) | | Small lake | Pumped to standpipe and direct | | 1886 |

*a* "Ex." in this column means running expenses per annum.

*Cities in Ohio using surface water for waterworks.*

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *a* | When put in. |
| Akron (part) | 27,601 | Small lake | Pumped to reservoir | $200,000 | 1880 |
| Alliance | 7,607 | Mahoning River | Pumped to standpipe from settling basins | 190,000 | 1883 |
| Athens | 2,620 | Infiltration wells from Hocking River | Pumped to standpipe and direct | 40,000 | 1894 |
| Ashtabula | 8,338 | Infiltration wells from Lake Erie | Pumped to standpipe | 300,000 | 1887 |
| Bellevue | 3,052 | Impounded water | ....do | 60,000 | 1873 |
| Bridgeport | 3,369 | Ohio River | Martins Ferry works | (?) | (?) |
| Bellaire | 9,934 | .... do | Pumped to reservoir | 175,000 | 1872 |
| Bucyrus (part) | 5,974 | Sandusky River | Direct pumping | 60,000<br>Ex. 5,180 | 1884 |
| Conneaut | 3,241 | Infiltration wells from Lake Erie | Pumped to standpipe | 125,000 | 1890 |
| Canton (part) | 26,189 | Nimishillen Creek | Direct pumping | 450,000<br>Ex. 24,000 | 1869 |
| Cambridge | 4,361 | Wills Creek | Pumped to standpipe (under construction) | 60,000 | 1896 |
| Chillicothe (M) | 11,288 | Infiltration well, Scioto River | Pumped to reservoir | 300,000 | 1881 |
| Cleveland | 261,353 | Lake Erie | Pumped to reservoirs | 7,088,486 | 1854 |
| Columbus (main part) | 88,150 | Scioto River | Direct pumping | 3,000,000<br>Ex. 100,000 | 1870 |
| Cincinnati | 296,908 | Ohio River | Pumped to reservoir | 8,000,000<br>Ex. 400,000 | 1820 |
| Circleville | 6,556 | Infiltration wells from Darby Creek | Pumped to standpipe and direct | 150,000<br>Ex. 4,000 | 1887 |
| Crestline (M) | 2,911 | Springs with collecting basin | Gravity | 120,000 | 1869 |
| Dennison | 2,975 | Stillwater Creek | Pumped to reservoir | 290,000 | 1888 |
| Defiance | 7,694 | Maumee and Auglaise rivers and canal | Pumped to standpipe | 200,000<br>Ex. 6,000 | 1888 |
| Elyria | 5,611 | Black River | Pumped to standpipe and direct | 125,000<br>Ex. 5,000 | 1879 |

*a* "Ex." in this column means running expenses per annum.

*Cities in Ohio using surface water for waterworks*—Continued.

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *a* | When put in. |
| East Liverpool | 10,956 | Ohio River | Pumped to reservoirs, high service and low service. | $200,000<br>Ex. 12,000 | 1879 |
| Fremont (main part) | 7,141 | Sandusky River | Pumped to standpipe | 150,000<br>Ex. 6,500 | 1883 |
| Fostoria (part) | 7,070 | Creek and impounded water | do | 220,000<br>Ex. 3,500 | 1891 |
| Findlay | 18,553 | Blanchard River | Direct pumping (filtered) | 337,000 | 1889 |
| Gallipolis | 4,498 | Ohio River | Infiltration wells | 88,000 | 1895 |
| Greenfield | 2,460 | Paint Creek | Pumped to standpipe and direct | 60,000<br>Ex. 3,000 | 1891 |
| Ironton | 10,929 | Ohio River | Direct pumping | 175,000<br>Ex. 10,000 | 1871 |
| Kent | 3,501 | Plum Creek and infiltration | Pumped to standpipe and direct | 200,000 | 1887 |
| Lancaster | 7,555 | Gallery and well from springs | Pumped to standpipe | 70,000<br>Ex. 2,260 | 1882 |
| Leetonia (M) | 2,826 | Spring and collecting basin | Direct pumping | 11,000 | 1889 |
| Loraine (M) | 4,863 | Lake Erie | Pumped to standpipe and direct | 130,000 | 1884 |
| Milford Center (M) | 718 | Springs | Direct pumping | 12,000 | 1895 |
| Martins Ferry | 6,250 | Ohio River | Direct and to reservoir | 145,000<br>Ex. 6,000 | 1854 |
| Marietta | 8,272 | do | Pumped to reservoir | 110,000<br>Ex. 5,000 | 1890 |
| Minerva (M) | 1,139 | Infiltration wells by Sandy Creek | Pumped to tank | 15,000 | 1886 |
| Milan | 627 | Huron River | Direct pumping | 17,000<br>Ex. 1,800 | 1888 |
| Marion | 8,327 | Infiltration wells from Little Scioto | Pumped to standpipe and direct | 200,000 | 1890 |
| Napoleon | 2,764 | Maumee River | do | 60,000 | 1895 |
| New Lisbon (75 per cent) | 2,278 | Little Beaver River | Pumped to reservoir. (See Wells in rock) | 25,000<br>Ex. 1,500 | 1888 |

*a* "Ex." in this column means running expenses per annum.

*Cities in Ohio using surface water for waterworks*—Continued.

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *a* | When put in. |
| Norwalk (M) | 7,195 | Impounded water (Huron River and creeks) | Direct pumping | $150,000<br>Ex. 6,000 | 1871 |
| Nelsonville | 4,558 | Infiltration well | Pumped to reservoir | 45,000 | 1895 |
| Oberlin | 4,370 | East Vermilion River, storage reservoirs | Pumped to standpipe or direct | 70,000<br>Ex. 1,550 | 1887 |
| Ottawa (part) | 1,717 | Blanchard River | Fire cisterns only | | |
| Painesville *b* | 4,755 | Lake Erie | Pumping to standpipe and direct | 250,000 | 1882 |
| Piqua | 9,090 | Canal system, with reservoirs | Direct pumping | 400,000 | 1875 |
| Port Clinton | 2,049 | Lake Erie | ....do | 42,000 | 1895 |
| Portsmouth | 12,394 | Ohio River | ....do | 300,000 | 1871 |
| Ripley | 2,483 | Settling basins from Ohio River | Pumped to reservoir | 21,000 | 1896 |
| Ravenna (part) | 3,417 | Crystal Lake | Direct pumping | 170,000<br>Ex. 3,300 | 1885 |
| Steubenville | 13,394 | Ohio River | Pumped to reservoir | *c* 200,000<br>Ex. 9,000 | 1835<br>1894 |
| Sandusky | 18,471 | Sandusky Bay | Pumped to standpipe | 525,000<br>Ex. 13,000 | 1875 |
| Shelby (M.) | 1,977 | Impounded water | ....do | 21,000 | 1897 |
| Sidney | 4,850 | Great Miami River | ....do | 100,000<br>Ex. 5,000 | 1873<br>1888 |
| Tiffin (part) | 10,801 | Sandusky River and wells | Direct pumping | (?) | 1878 |
| Toledo | 81,434 | Maumee River | Pumped to standpipe | 1,500,000<br>Ex. 38,000 | 1874 |
| Toronto | 3,536 | Ohio River | Pumped to reservoir | 75,000<br>Ex. 2,000 | 1891 |
| Troy | 4,494 | Infiltration wells | Direct pumping | 150,000<br>Ex. 2,250 | 1888 |
| Uhrichsville | 3,842 | Stillwater Creek | Pumped to reservoir | | 1888 |

*a* "Ex." in this column means running expenses per annum. *b* Including Richmond and Fairport. *c* Cost of new system introduced in 1894.

*Cities in Ohio using surface water for waterworks*—Continued.

| Name. | Population in 1890. | Supply. | Waterworks. | | |
|---|---|---|---|---|---|
| | | | System. | Cost (to 1895). *b* | When put in. |
| Upper Sandusky | 3,572 | Sandusky River and springs | Pumped to standpipe | $60,000<br>Ex. 3,000 | 1890 |
| Urbana (part) | 6,510 | Springs in east part of city *a* | | | |
| Wadsworth (part) | 1,574 | Springs | Gravity | 20,000 | 1880 |
| Warren (M.) | 5,973 | Mahoning River | Pumped to standpipe and direct | 180,000 | 1887 |
| Wellsville | 5,247 | Ohio River | Pumped to reservoir | 60,000 | 1881 |
| Wellston (M.) | 4,377 | Raccoon Creek | Pumped to standpipe | 60,000 | 1891 |
| Willoughby | 1,219 | Chagrin River, infiltration well | Pumped to reservoir | 30,000<br>Ex. 1,500 | 1892 |
| Wooster (part) | 5,901 | Impounded water and wells | do | | 1869 |
| Xenia | 7,301 | Springs, impounded water | Pumped to standpipe | 183,000<br>Ex. 4,500 | 1887 |
| Youngstown | 33,220 | Mahoning River | Pumped to standpipe and direct | 475,000<br>Ex. 18,000 | 1872 |
| Zanesville | 21,009 | Muskingum River | Pumped to reservoir | 500,000<br>Ex. 19,500 | 1842 |

*a* See "Wells in glacial drift," p. 526.
*b* "Ex." in this column means running expenses per annum.

## SHALLOW WELLS IN VALLEYS.

More than 100 cities of Indiana and Ohio are so situated in valleys that the most convenient source of water supply is from shallow wells sunk to the level of the stream. In many cases the wells reach no lower than the alluvial deposits of the valley, but in some cases they pass through glacial deposits beneath the level of the stream bed, penetrating sometimes a thick bed of clay or a nearly impervious stratum above the beds which yield the water. It is difficult to determine what proportion of the water supply in valley wells is polluted, but the danger of pollution is certainly great, and such wells should be subjected to frequent examination and promptly abandoned when found to be polluted. Those cities which obtain a supply for waterworks from beds of alluvium usually take the precaution to locate the wells on the upstream side of the city, where danger from contamination will be at a minimum. Such wells are much safer than the private wells sunk within the city limits.

In the following table, which embraces the principal towns deriving water from the shallow wells in valleys, the general nature of the cover or beds overlying the water-bearing stratum is indicated. In cases where the cover is noted to be "imperfect" there appears to be nothing to prevent surface filth from reaching the water bed. In the cases marked "doubtful" there are some indications of protection from contamination, either by the presence of a nearly impervious stratum where wells are shallow, or by the distance to the water bed where wells are comparatively deep. In cases marked "fair" there is thought to be very little danger of contamination, for the water horizon is either too deep to be within the reach of such pollution within the city limits or is known to be beneath a practically continuous sheet of an impervious clay. The only apparent danger arises from lack of continuity in this impervious cover. In cases where the water cover is said to be "good" there appears to be no ground for suspicion of surface contamination of any kind. A word seems necessary at this point concerning a careless pollution of wells. It is found that in places where wells would be otherwise free from contamination pollution is frequently introduced by throwing slops and refuse matter around the well mouth, where it can scarcely escape filtration into the well.

*Cities and villages of Indiana using shallow wells in valleys.*

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Brookville | 2,028 | 20–110 | Gravel | Doubtful to fair | | See "Surface water" | |
| Clinton | 1,365 | 20–75 | do | do | | None | |
| Connersville | 4,548 | 12–30 | do | Doubtful | | See "Surface water" | |
| | | 60–80 | do | Good | | | |
| Covington | 1,891 | 50 | do | Fair | | do | |
| Edinburg | 2,031 | 15–60 | do | Doubtful | $21,000 | Pumped to standpipe and direct | 1893 |
| | | W. W. 19 | do | do | Ex. 900 | | |
| Elkhart | 11,360 | 25–100 | do | Fair | (?) | Pumped to standpipe | 1883 |
| | | W. W. 34 | do | do | | | |
| Goshen | 6,033 | W. W. 34 | Sand | do | 90,000 | Direct pumping | 1881 |
| | | | | | Ex. 10,300 | | |
| Hammond | 5,428 | 6–18 | do | Imperfect | | See "Surface water" | |
| Huntington | 7,328 | 30 | Gravel or rock | Doubtful | | See "Wells in rock" | |
| Indianapolis (75 per cent) | 105,436 | 30–45 | Gravel | Imperfect | | Direct pressure | 1870 |
| | | 65–125 | do | Good | | | |
| Jeffersonville | 10,666 | 40–50 | do | Doubtful | | See "Surface water" | |
| Jonesville | (?) | 20–30 | do | do | | None | |
| Knox | 790 | 14–40 | Sand | Imperfect | | do | |
| Kouts | (?) | 25–35 | do | Fair | | do | |
| Lake | (?) | 20–25 | do | Doubtful | | do | |
| Ligonier | 2,195 | W. W. 34 | do | Fair | 32,000 | Pumped to standpipe and direct | 1889 |
| | | | | | Ex. 1,400 | | |
| Liverpool | (?) | 10–16 | do | Doubtful | | None | |
| Logansport (part) | 13,328 | 12–40 | Gravel | Imperfect | | See "Surface water" | |
| Martinsville | 2,680 | W. W. 30 | do | Doubtful | 25,000 | Direct pumping | 1894 |
| | | 40–60 | do | Good | | | |
| Mishawaka | 3,371 | 20 | do | Doubtful | | See "Surface water" | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Indiana using shallow wells in valleys*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Montezuma | 658 | 30–70 | Gravel | Imperfect to fair | | None | |
| New Albany (part) | 21,059 | 25–30 | do | Imperfect | | See "Surface water" | |
| Newcastle (W. W.) | 2,697 | 90–250 | do | Good | $27,000 Ex. 2,000 | Direct pumping | 1889 |
| Nashville | 395 | 12–35 | Sand or rock | Imperfect to good | | None | |
| New Harmony | 1,197 | 20–25 | Sand | Imperfect | | do | |
| Noblesville | 3,054 | 20–25 W. W. 65 | Gravel do | do Good | $60,000 Ex. 200 | Direct pumping | 1891 |
| North Judson | 572 | 10–30 | Sand | Imperfect | | None | |
| Peru | 7,028 | 15–60 | Gravel | Imperfect to good | | See "Surface water" | |
| Plymouth | 2,723 | W. W. 42 | do | Good | 17,000 Ex. 3,000 | Direct pumping | 1888 |
| Quincy | (?) | 20–30 | Sand | Doubtful | | None | |
| Rising Sun | 1,689 | 60–120 | Gravel | Fair | | do | |
| Rosedale | | 12–25 | Sand | do | | do | |
| Rochester | 2,467 | 16–20 | do | do | 35,000 | Pumped to standpipe and direct | 1893 |
| Seymour | 5,337 | 10–15 50 | do do | Imperfect Good | | See "Surface water" | |
| Shoals | 738 | 18–90 | Sand or sandstone. | Doubtful | | None | |
| Shelbyville | 5,451 | 33 | Gravel | Fair | 225,000 | Pumped to standpipe | |
| South Bend (W. W.) (62 wells). | 21,819 | 100–125 | do | Good | 270,000 Ex. 20,000 | do | 1873 |
| Spencer | 1,868 | 20–80 | do | Imperfect to fair | | None | |
| Tell City | 2,094 | 45–50 | Sand | Fair | | Fire cisterns only | |
| Terre Haute | 30,217 | 30–50 | Gravel | Imperfect | | See "Surface water" | |
| Vevay | 1,663 | 60–80 | do | Fair | | do | |
| Vincennes | 8,853 | 20 | Sand | Imperfect | | do | |
| Walkerton | 885 | 20–30 | Gravel | Fair | | None | |
| West Lafayette (M.) | 1,242 | (?) | (?) | (?) | 61,000 | Pumped to standpipe | 1894 |
| Worthington | 1,448 | 15–40 | Sand | Doubtful | | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio using shallow wells in valleys.*

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Ashtabula (part) | 8,338 | 8–20 | Gravel | Imperfect | | See "Surface water" | |
| Ashland (part) | 3,566 | 20–60 | Gravel or shale | Fair | $45,000<br>Ex. 1,800 | Pumped to standpipe and direct | 1895 |
| Bainbridge | | 30 | Gravel | Imperfect | | None | |
| Batavia | 953 | 15–45 | Gravel or sand | do | | do | |
| Bellville | 941 | 30 | Gravel | do | | do | |
| Bellaire | 9,934 | 60–100 | Gravel or sand | do | | See "Surface water" | |
| Coshocton | 3,672 | 30–35 | Gravel | do | 80,000 | Pumped to reservoir | 1890 |
| Camden | 846 | 12–30 | do | do | | None | |
| Canal Dover | 3,470 | 35–52<br>W. W. 52 | do<br>do | Doubtful<br>Fair | 35,000 | Pumped to standpipe | 1895 |
| Circleville (part) | 6,556 | 25–35 | do | do | | See "Surface water" | |
| Dennison | 2,925 | 12–40 | Sand | Imperfect | | do | |
| Defiance (part) | 7,694 | 10–15<br>40–50 | Gravel<br>do | do<br>Good | | do | |
| Dresden | 1,247 | 40 | do | Doubtful | | None | |
| Dayton | 61,220 | 35–60 | do | do | 1,300,000<br>Ex. 36,000 | Direct pumping | 1869 |
| Degraff | 1,076 | 15–20<br>60–80 | do | do | | None | |
| Elyria | 5,611 | 10–30<br>60–90 | Sand<br>do | do<br>Good | | See "Surface water" | 1879 |
| Eaton | 2,934 | W. W. 75 | Gravel | do | 80,000<br>Ex. 1,800 | Pumped to standpipe and direct | 1891 |
| Fremont (part) | 7,141 | 15–25 | Sand | Doubtful | | See "Surface water" | |
| Franklin | 2,729 | 20–30<br>W. W. 70 | do<br>do | do<br>Good | 45,000<br>Ex. 3,000 | Holly system | 1888 |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio using shallow wells in valleys*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Germantown | 1,437 | 20–25 | Gravel | Doubtful | | None | |
| Granville (M.) | 1,366 | (?) | do | Fair | $18,000 | Pumped to tank | 1885 |
| Hamilton | 17,565 | 45 | do | do | 360,000<br>Ex. 20,000 | Pumped to reservoir and direct | 1884 |
| Harrison | 2,010 | 25 | do | Doubtful | 55,000 | Pumped to standpipe | 1891 |
| Hillsboro | 3,620 | (?) | do | Fair | 80,000 | Pumped to standpipe and direct | 1895 |
| Kent | 3,501 | 18–25 | do | Doubtful | | do | 1887 |
| Lancaster | 7,555 | 35–40 | do | Fair | | See "Surface water" | |
| Lockbourne | | 10–20 | do | Doubtful | | None | |
| Lodi | 568 | 15–25 | do | do | | See "Surface water" | |
| Logan (waterworks) | 3,119 | 35 | do | Fair | 35,000 | Direct pumping | 1896 |
| Lynchburg (M.) | 763 | W. W. 16<br>14–20 | do<br>Gravel or rock | Doubtful<br>do | 16,000 | Pumped to tank | 1896 |
| Manchester | 1,965 | 80–140 | Sand | Fair | | | |
| Mansfield | 13,473 | 40–60<br>W. W. 140 | Gravel<br>Sandstone | do<br>Good | 325,000 | Direct pumping | 1870 |
| McConnellsville | 1,771 | 20–80 | Gravel | Doubtful | | None | |
| Martins Ferry | 6,250 | 25–75 | do | Imperfect | | See "Surface water" | |
| Marietta | 8,272 | 30–90 | do | do | | do | |
| Marion | 8,327 | 10–15 | do | Fair | | Pumped to standpipe and direct | 1889 |
| Middleport | 3,211 | 20–110 | do | Doubtful to fair | | None | |
| Middletown | 7,681 | 33 | do | Doubtful | 75,000<br>Ex. 3,500 | Direct pumping | 1873 |
| Milan | 627 | 12–14 | do | do | | See "Surface water" | |
| Millersburg | 1,923 | W. W. 24<br>10–30 | do | do | 23,000 | Direct pumping | 1896 |
| Morrow | 842 | 15–35 | do | do | | do | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio using shallow wells in valleys*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Moscow | 591 | 40–60 | Gravel | Doubtful to fair | | Direct pumping | |
| Mount Vernon | 6,027 | 17–20 (W. W. 63–97) | do | Doubtful<br>Good | $75,000 | Pumped to standpipe | 1882 |
| Napoleon | 2,764 | 15–30 | do | Fair | | See "Surface water" | |
| Navarre | 1,010 | 18–65 | Sand | Doubtful to fair | | None | |
| Newark | 14,270 | 15–30 | Gravel | Doubtful | (?) | Pumped to reservoir | 1885 |
| Nelsonville | 4,558 | 25 | do | Fair | 45,000 | do | 1894 |
| New Comerstown | 1,251 | 20–30 | do | Doubtful | | None | |
| New Philadelphia | 4,456 | 20–50 | do | do | (?) | Pumped to reservoir | 1886 |
| New Richmond | 2,379 | 28–72 | do | Doubtful to fair | | None | |
| Niles | 4,289 | 40–60 | do | Fair | 70,000 | Pumped to reservoir | 1891 |
| North Lewisburg | 866 | 10–15 | do | Doubtful | | None | |
| Osborne (M.) | 713 | 18 | do | Imperfect | 22,000 | Pumped to standpipe | 1896 |
| Oxford (M.) | 1,922 | (?) | (?) | (?) | 36,000 | Direct pumping | 1896 |
| Piqua | 9,090 | 10–25 | Gravel | Doubtful | | See "Surface water" | |
| Pomeroy | 4,726 | 60–65 | Sand | do | | None | |
| Ripley | 2,483 | 60–70 | do | Fair | | See "Surface water" | |
| Springfield | 31,895 | 15–20<br>W. W. 70 | Gravel<br>do | Imperfect<br>Good | 650,000<br>Ex. 16,500 | Pumped to standpipe | 1886 |
| Troy | 4,494 | 15–50 | do | Doubtful to fair | 150,000<br>Ex. 2,250 | Direct pumping | 1886 |
| Uhrichsville | 3,842 | 20 | Sand | Doubtful | | Pumped to reservoir. (See "Dennison") | |
| Waverly | 1,567 | 45–65 | Gravel | Fair | | None | |
| Wellsville | 5,247 | 16–50 | do | Imperfect | | See "Surface water" | |
| West Liberty | | 14–18 | do | do | | None | |
| Waynesville | | 15–30 | do | Doubtful | | do | |
| Zanesville | 21,009 | 10–50 | do | do | | See "Surface water" | |

*a*. "W. W." in this column means that the well is a waterworks well.

*b*. "Ex." in this column means running expenses per annum.

## WELLS IN GLACIAL DRIFT.

Within the glaciated portions of Indiana and Ohio a large number of cities and villages obtain their entire supply of water from the glacial drift. Water-bearing beds of gravel or sand are in many towns adequate to supply a waterworks system, and the quality of water furnished is usually superior either to surface water or to water from wells in the rock. There is less danger of pollution than in the wells of similar depth in the valleys, noted in the preceding table, for the cover is generally a compact bowlder clay. There is also less concentration of water than in the valleys, and consequently less danger of surface contamination being distributed to the wells in the neighborhood. In the following table, which embraces the principal towns depending upon wells in glacial drift, the character of the cover is indicated, as in the preceding table. It will be observed that very few instances have been found in which the cover appears to be imperfect or of doubtful protection from surface contamination. It will be noted that in some cities water is obtained at two horizons, and that in some cases the upper horizon has a doubtful cover, while the lower has a good cover. The advisability of sinking to the lower stratum is coming to be recognized in such towns, and the shallow wells are rapidly going out of use.

*Cities and villages in Indiana using wells in glacial drift.*

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Akron | (?) | 10–14 | Sand | Doubtful | | None | |
| Albion | 1,229 | 60–100 | Gravel | Good | (?) | Direct pumping | 1896 |
| Amo | | 40–50 | Sand | Fair | | None | |
| Anderson | 10,741 | 35–100 | Gravel | | | See "Surface water" | |
| Angola (M.) | 1,840 | | do | | $35,000 | Direct pumping | 1895 |
| Atwood | 840 | | do | Fair | | None | |
| Auburn | 2,415 | 20–30<br>150 | do<br>do | do<br>Good | | do | |
| Avilla (M.) | 576 | 20–100 | do | Fair | 2,800 | Pumped to tank | 1890 |
| Bloomingdale | 431 | 12–60 | Variable | Fair to good | | None | |
| Brazil | 5,905 | W. W. 20 | Gravel | Fair | 125,000<br>Ex. 3,500 | Direct pumping | 1875 |
| Bremen (M.) | 1,076 | 40± | do | Good | 15,500 | Pumped to tank | 1892 |
| Brownstown | 1,422 | 20 | Sand | Doubtful | | None | |
| Butler | 2,521 | 20–35<br>85–150 | Gravel<br>do | Fair<br>Good | 16,000<br>Ex. 2,500 | Direct pumping | 1890 |
| Cambridge City (M.) | 1,782 | (?) | do | (?) | ? 25,000 | Direct pumping; also reservoir | 1895 |
| Chambersburg | (?) | 30–35 | do | Fair | | None | |
| Charlestown | 888 | 15–35 | Sand | Good | | do | |
| Chesterton | 931 | 18–33 | do | Doubtful | | do | |
| Claypool | (?) | 25 | do | Fair | | do | |
| Clayton | (? | 10–25 | Variable | do | | do | |
| Coatsville | (?) | 25–30 | do | do | | do | |
| Colfax | 730 | 15–30 | do | do | | do | |
| Collins | (?) | 75–80 | Gravel | Good | | do | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages in Indiana using wells in glacial drift*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *a* | System. | When put in. |
| | | *Feet.* | | | | | |
| Columbia City | 3,500 | 30–75 | Gravel | Fair to good | | See "Wells in rock" | |
| Converse or Xenia | 921 | 10–20 | do | do | | do | |
| Crown Point | 1,907 | 50–70 | do | Good | $39,000 | Pumped to standpipe | 1896 |
| Danville | 1,569 | 110 | do | do | 25,000<br>Ex. 1,000 | do | 1892 |
| Darlington (M.) | 461 | (?) | (?) | (?) | 4,000 | Direct pumping | 1895 |
| Etna Green | 411 | 25–30 | Sand | Fair | | None | |
| Fairfield | (?) | 50 | Gravel | Good | | do | |
| Fairland | 513 | 25–35 | do | Fair | | do | |
| Fort Wayne W. W (part) | 35,393 | 40–60 | do | Good | 550,000<br>Ex. 15,000 | See "Wells in rock." Pumped to standpipe. | 1879 |
| Fowler | 1,285 | 20–30 | do | Doubtful | | See "Wells in rock" | |
| Frankfort | 5,919 | 18–25<br>55–90 | Sand<br>Gravel | do<br>Good | 100,000 | Direct pumping | 1885 |
| Franklin | 3,781 | 40–60 | do | do | 160,000<br>Ex. 2,000 | Pumped to standpipe | 1890 |
| Galveston | (?) | 20± | do | Fair | | None | |
| Garrett | 2,767 | 35<br>75 | Sand<br>Gravel | Doubtful<br>Good | 45,000 | Direct pumping | 1896 |
| Gas City | (?) | 60 | do | do | | None | |
| Geneva | 748 | 35 | do | Fair | | do | |
| Greensburg | 3,596 | 18–50 | do | do | | See "Wells in rock" | |
| Greentown | 721 | 20–25<br>35–45 | do<br>do | do<br>Good | | None | |
| Greenwood | 862 | 12–30<br>190± | do<br>do | Fair<br>Good | | do | |
| Hageman | 641 | 12–16 | Sand | Doubtful | | do | |

*a* "Ex." in this column means running expenses per annum.

*Cities and villages in Indiana using wells in glacial drift*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Haskell | (?) | 10–20 | Gravel | Doubtful | | None | |
| Hebron | 689 | 35–40 | Sand | Good | | do | |
| Inwood | (?) | 20–50 | Gravel | Fair to good | | do | |
| Jonesboro | 687 | 10–45 | do | do | | do | |
| Kempton | (?) | 30–40 | do | Good | | do | |
| Kendallville (M.) | 2,960 | 25–200 | do | Fair to good | $60,000 | Direct pumping | 1887 |
| Kentland | 918 | 10–30<br>60–100 | do<br>do | Doubtful<br>Good | | See "Wells in rock" | |
| Kokomo | 8,261 | 35–45 | do | Fair | | do | |
| Kosciusko | (?) | 15–35 | do | do | | None | |
| Lafayette | 16,243 | 10–60 | Variable | Doubtful | | See "Surface water" | |
| Lagrange | 1,784 | 40–110<br>W. W. 90–110 | do | Good | 20,000<br>Ex. 3,600 | Direct pumping | 1893 |
| Lebanon | 3,682 | 12–25<br>W. W. 53 | do | Doubtful to good | 52,000 | Pumped to standpipe and direct | 1894 |
| Liberty | 1,314 | 20–45<br>W. W. 21 | Gravel | Doubtful to fair | 14,000 | Direct pumping | 1894 |
| Marion (part) | 8,769 | W. W. 70 | do | Good | Ex. 5,000 | do | 1877 |
| Mechanicsburg | (?) | 15–20 | do | Fair | | None | |
| Middletown (M.) | 851 | 100± | do | Good | 16,000 | Pumped to reservoir | 1896 |
| Milford | 677 | 20 | do | Fair | | None | |
| Monrovia | (?) | 10–25<br>118 | Sand<br>Gravel | do<br>Good | | do | |
| Monticello | 1,518 | 20–140 | Variable | do | 38,000<br>Ex. 1,100 | Pumped to standpipe | 1896 |
| Morgantown | (?) | 25–50 | Gravel | do | | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages in Indiana using wells in glacial drift*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Nappanee | 1,493 | W. W. 140 | Gravel | Good | $10,000 Ex. 500 | Pumped to tank | 1892 |
| New Carlisle (M.) | 607 | (?) | do | (?) | (?) | do | 1879 |
| New Haven | 1,079 | 25–35 | do | Fair | | See "Wells in rock" | |
| Newport | 551 | 12–88 | Variable | Fair to good | | None | |
| North Manchester | 2,384 | 10–100 W. W. 100 | do | Doubtful to good | 35,000 | Pumped to standpipe | 1894 |
| Osgood | 841 | 9–15 | Sand | Fair | | None | |
| Oxford | 808 | 14–20 55 | do Gravel | Doubtful Good | | do | |
| Parker | (?) | 20–60 | do | Fair to good | | do | |
| Plainfield | 909 | 35–40 | do | Good | | do | |
| Philadelphia | (?) | 20± | do | Fair | | do | |
| Portland (part) | 3,725 | 14–30 | do | Doubtful | | See "Wells in rock" | |
| Princeton | 3,676 | 20–25 | do | Fair | | See "Surface water" | |
| Red Key (part) | 922 | 10–15 | do | Doubtful | | None | |
| Remington (part) | 940 | 12–20 | do | do | | do | |
| Rensselaer (part) | 1,455 | 75–120 | do | Good | | do | |
| Reynolds | 348 | 10–25 75–120 | Sand Gravel | Doubtful Good | | do | |
| Richmond | 16,608 | 12–40 | Variable | Doubtful | | See "Surface water" | |
| Roann | 582 | 30± | Gravel | Fair | | None | |
| Rockville | 1,689 | 15–75 | Variable | Fair to good | | See "Wells in rock" | |
| Rockfield | (?) | 15–25 50–60 | do | do | | None | |
| Royal Center | 521 | 15–110 | do | do | | do | |
| Rushville | 3,475 | 14–75 | do | Fair | 85,000 | Direct pumping and reservoir | 1896 |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages in Indiana using wells in glacial drift*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Scottsburg | 618 | 15–35 | Sand | Fair | | | |
| Shelbyville | 5,451 | W. W. 35 | Gravel | Fair | $225,000 | Pumped to standpipe | 1890 |
| Sheridan | 1,134 | 15–50 | Variable | Fair to good | | None | |
| St. Paul | (?) | 15–90 | do | do | | do | |
| South Whitley (M.) | 720 | 65 | Gravel | Fair | 15,000 | Direct pumping | 1895 |
| Sullivan | 2,224 | 15–35 | Variable | Doubtful to good | | See "Surface water" | |
| Templeton | (?) | 20–30 | Gravel | Fair | | None | |
| Thorntown | 1,530 | 14–60 | Variable | Fair to good | | do | |
| Tipton | 2,697 | 12–30<br>100–140 | do<br>Sand | Doubtful<br>Good | 35,000<br>Ex. 3,000 | Direct pumping | 1894 |
| Union City | 2,681 | 6–40<br>W. W. 32 | Variable<br>Gravel | Fair<br>Good | 60,000<br>Ex. 3,500 | do | 1873 |
| Upland | *c* 1,000 | 20–30 | do | Fair | 6,000<br>Ex. 125 | Pumped to tank | 1895 |
| Valparaiso | 5,090 | 15–200 | Variable | Doubtful to fair | | See "Surface water" | |
| Veedersburg | 930 | 20–70 | do | Fair | | None | |
| Wabash | 5,105 | W. W. 42–55 | Gravel | Good | 200,000 | Pumped to standpipe | 1886 |
| Warsaw (part) | 3,574 | 10–40<br>W. W. 140 | Variable<br>Gravel | Doubtful<br>Good | 60,000 | Pumped to standpipe and direct | 1886 |
| Washington | 6,064 | 12–30 | Sand | Fair | | See "Surface water" | |
| Waterloo | 1,473 | 20–30<br>60–90 | Gravel<br>do | do<br>Good | | None | |
| Winamac | 1,215 | 25–80 | Variable | Fair | | do | |
| Winchester | 3,014 | 10–25 | Gravel | Doubtful | | do | |
| Westville | 522 | 15–20 | do | do | | do | |

*a* "W. W." in this column means that the well is a waterworks well. *b* "Ex." in this column means running expenses per annum. *c* Estimated.

*Cities and villages of Ohio using wells from glacial drift.*

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Ada | 2,079 | 25–40 | Gravel or rock | Fair | | None | |
| Akron | 27,601 | 60–40 | Gravel | do | $200,000 | Pumped to reservoir | 1880 |
| Andover (part) | 733 | 12–20 | do | do | | None | |
| Ansonia | 676 | 9–18 | do | do | | do | |
| Archbold (part) | 780 | 12–16 | Variable | do | | do | |
| Arlington Heights (M.) | 222 | | | | | Supplied from Reading waterworks | |
| Attica | 682 | 6–20 | Gravel | Doubtful | 15,000 | Pumped to standpipe | 1895 |
| Bond Hill (M.) | 399 | (?) | (?) | (?) | (?) | Supplied from St. Bernard waterworks | |
| Berea (part) | 2,533 | 10–15 | Variable | Doubtful | | None | |
| Blanchester | 1,196 | 10–30 | do | Fair | 20,000 | Pumped to standpipe | 1897 |
| Bluffton | 1,290 | 12–30 | Gravel | do | | See "Wells in rock" | |
| Bryan (M.) | 3,068 | (?) | (?) | (?) | 39,000 | Direct pumping | 1893 |
| Bucyrus (part) | 5,974 | 10–50 | Gravel | Fair | 60,000<br>Ex. 5,180 | do | 1884 |
| Canfield | 675 | 10–25 | Sand | do | | None | |
| Cardington | 1,428 | 13–25 | Gravel | Doubtful | | do | |
| Carthage (M.) | 2,257 | 100± | Sand | Fair | 25,000 | Direct pumping | 1890 |
| Celina (part) | 2,702 | 20 | Gravel | do | | See "Wells in rock" | |
| Chicago Junction | 1,299 | 60–100 | do | Good | | None | |
| Clyde (part) | 2,327 | 8–20 | Sand | Imperfect | | See "Wells in rock" | |
| Columbus (part) | 88,150 | 10–15<br>W. W. 45± | do<br>Gravel | Doubtful<br>Good | 3,000,000 | See "Surface water" | 1870 |
| Delaware | 8,224 | 20–30 | do | Fair | 175,000<br>Ex. 5,000 | Pumped to standpipe and direct | 1889 |
| Delphos (part) | 4,516 | 14 | Sand | Doubtful | | See "Wells in rock" | |
| Edgerton | 967 | 20–60 | Gravel | Fair to good | | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio using wells from glacial drift*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Fort Recovery | 1,186 | 10–18 | Gravel | Fair | | None | |
| Galion | 6,326 | 20–90 | Variable | Good | $100,000 | Pumped to standpipe | 1884 |
| Geneva | 2,194 | 10–15 | Gravel | Doubtful | | None | |
| | | 30–40 | do | Good | | | |
| Glendale | 1,444 | 175 | Sand | do | 35,000 | Pumped to standpipe | 1892 |
| Greenfield (part) | 2,460 | 12–30 | Variable | Fair | | See "Surface water" | |
| Greenville | 5,473 | 52–62 | Gravel | Good | 82,000<br>Ex. 2,500 | Pumped to standpipe and direct | 1893 |
| Greenwich (M.) | 881 | W. W. 24 | do | Fair | 12,000 | Pumped to standpipe | 1896 |
| Hartwell | 1,507 | 100± | Sand | Good | | do | 1893 |
| Hicksville | 2,141 | 18–30 | Gravel | Doubtful | 22,000<br>Ex. 800 | Direct pumping | 1890 |
| Hudson (part) | 1,143 | 10–15 | do | Imperfect | | None | |
| Kent | 3,501 | 25 | do | Doubtful | | See "Surface water" | |
| Lebanon | 3,050 | 20–90 | Variable | Fair | 50,000 | Pumped to standpipe and direct | 1896 |
| Linwood (M.) | | 100± | Sand | Good | 54,000 | Pumped to high and low service reservoirs | 1894 |
| London | 3,313 | 70–180 | Variable | do | (?) | Pumped to standpipe and direct | 1890 |
| Lockland (M.) | 2,447 | | | | | Supplied from Reading waterworks | |
| Leesburg | 617 | 20–35 | Variable | Fair | | None | |
| Loudonville | 1,444 | 20 | Gravel | Doubtful | | do | |
| | | 110 | do | Good | | | |
| Leipsic | 1,353 | 8–15 | Sand | do | | do | |
| | | 90–115 | Rock (?) | Doubtful | | | |
| Madisonville | 2,214 | 18–25 | Sand | do | 35,000<br>Ex. 1,500 | Direct pumping | 1892 |
| | | 140–150 | do | Good | | | |
| Marysville | 2,810 | 15–30 | Gravel | Fair | | See "Wells in rock" | |
| Martinsville | 336 | 30–65 | Variable | do | | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio using wells from glacial drift*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). | System. | When put in. |
| | | *Feet.* | | | | | |
| Mechanicsburg | 1,459 | 10–20<br>60–100 | Sand<br>Gravel | Doubtful<br>Good | | None | |
| Montpelier (M.) | 1,293 | (?) | (?) | (?) | $26,000 | Pumped to standpipe | 1895 |
| Mount Gilead (part) | 1,329 | 10–30 | Variable | Fair | (?) | Under construction | 1897 |
| New Bremen (part) | 1,239 | 12–15 | Sand | do | | None | |
| New London | 1,036 | 25<br>75–100 | Gravel<br>Variable | do<br>Good | | do | |
| New Madison | 478 | 20–25 | Sand | Fair | | do | |
| New Paris | 842 | 12–30 | Gravel | Doubtful | | do | |
| New Washington | 704 | 20–30 | Sand | Fair | | do | |
| Norwood (M.) | 845± | 200± | Sand (?) | Good | 133,152 | Pumped to standpipe | 1894 |
| Oak Hill | 637 | 20 | Sand | Doubtful | | None | |
| Oberlin (part) | 4,376 | 10–30 | Variable | Fair | | See "Surface water" | |
| Orrville (M.) | 1,765 | (?) | (?) | (?) | 25,000 | Direct pumping | 1894 |
| Ottawa (part) | 1,717 | 7–32 | Variable | Fair | | None | |
| Painesville (part) | 4,755 | 10–25 | Gravel | Doubtful | | See "Surface water" | |
| Pataskala | 568 | 12–40 | Variable | Fair | | None | |
| Paulding | 1,879 | 40 | Sand | do | | do | |
| Pemberville | 843 | 30 | Gravel | Good | | do | |
| Plain City (part) | 1,245 | 7–13 | Sand | Doubtful | | See "Wells in rock" | |
| Plymouth | 1,133 | 15–20 | do | do | | None | |
| Ravenna (part) | 3,417 | 15–30 | Variable | Fair | | See "Surface water" | |
| Reading *a* | 3,021 | 155–160 | Gravel | Good | 45,000 | Pumped to reservoir | (?) |
| Richwood | 1,415 | 20–35 | do | Fair | | None | |
| St. Bernard (M.) | 1,779 | 100± | Sand | Good | 64,320 | Pumped to standpipe | 1894 |
| Shelby | 1,977 | 10–40 | Gravel | Fair | | See "Surface water" | |

*a* Including Lockland and Arlington Heights in water supply.

*Cities and villages of Ohio using wells from glacial drift*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Cover. | Waterworks. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | | | |
| Sidney (part) | 4,850 | 12–30 | Gravel | Fair | | See "Surface water" | |
| South Charleston | 1,041 | 15–35 | Variable | do | | None | |
| Spencerville | 1,266 | 10–25 | do | Doubtful | | do | |
| Springfield (part) | 31,895 | 35–45 | do | Fair | | See "Wells in valleys" | |
| St. Marys (part) | 3,000 | 8–12 | Gravel | Doubtful | | See "Wells in rock" | |
| St. Paris | 1,140 | 20–30 | Variable | Fair | | None | |
| Stryker (part) | 1,017 | 10–25 | do | do | | do | |
| Swanton | 508 | 10–12 / 60 | Sand / Gravel | Imperfect / Good | | do | |
| Sylvania | 545 | 15–75 | Variable | Fair | | do | |
| Toledo (part) | 81,434 | 18–30 | Sand | Doubtful | | See "Surface water" | |
| Urbana | 6,510 | 15–65 / W. W. 21 | Variable | Fair | $175,000 / Ex. 4,000 | Direct pumping | 1878 |
| Utica | 763 | 20–35 | do | do | | None | |
| Van Wert (part) | 5,512 | 20 | Sand | do | | See "Wells in rock" | |
| Versailles | 1,385 | 14–40 | Variable | do | | None | |
| Wauseon | 2,060 | 15 | Sand | Imperfect | | do | |
| Wapakoneta | 3,616 | 15–40 / W.W.70–143 | Gravel / do | Fair / Good | 57,000 | Pumped to standpipe and direct | 1895 |
| Washington | 5,742 | 15–30 | do | Fair | 125,000 | do | 1889 |
| Wellington | 2,067 | 15–35 | Variable | do | | None | |
| West Carrollton (M.) | 360 | 60 | (?) | (?) | 7,800 | Direct pumping (?) | 1895 |
| Weston | 845 | 60 | Gravel | Good | | None | |
| West Unity | 872 | 100± | do | do | | do | |
| Wilmington | 3,079 | 15–35 | Variable | Fair | | do | |
| Wyoming | 1,454 | 130–160 | Sand | Good | 43,000 / Ex. 2,400 | Pumped through mains to reservoir | 1889 |
| Xenia (part) | 7,301 | 10–80 | Variable | Fair to good | | See "Surface water" | |
| Yellow Springs | 1,375 | 25± | do | Fair | | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

## WELLS IN ROCK.

A large number of cities and villages, both in Indiana and in Ohio, obtain part of their water supply from wells in rock. In the unglaciated portions of these States, except along the principal river valleys, the wells are almost entirely obtained in rock. As the writer's study was confined mainly to the glaciated portions of these States, the data from the unglaciated portions are rather meager. In the unglaciated districts cisterns are largely used, as it is less expensive to collect water in this way than to drill wells, and the abundant rainfall makes this a reliable means for obtaining water.

In the following table such data concerning wells in rock as are available have been grouped under several heads. These data are made up in part from notes gathered when in the field and in part from the schedules for city water supply, which were filled out by city officials or other competent residents.

The depth of wells here given usually indicates the horizon at which the water is most abundant, but in some cases where water is found at various levels the range in the depth of wells is indicated. It will be observed that in some cities the waterworks supply is from a lower horizon than that of the private wells, but in many cases the public and private wells are from the same horizon.

The water bed and quality of water, it will be observed, bear a definite relationship, water found in limestone being always hard and in sandstone usually soft. A few chemical analyses have been made which furnish definite information concerning the quality of water. These appear on another page. In the absence of analyses the popular estimate of the quality of the water is given, which, though not very definite, has considerable value.

The capacity of the wells is usually estimated by city officials. When numbers are given there have in some cases been accurate measurements, but as a rule only estimates or rude measurements. Some effort was made to determine the size of wells, in order to learn their relation to the capacity, but very little information could be obtained. It may be stated, however, that wells drilled in the rock are usually not less than 4 inches and not more than 12 inches in diameter. The majority of which the size was reported are 6 to 8 inches in diameter.

In the table showing the head from the surface the numerals indicate the distance below the surface, except where + is prefixed, when it is above the surface. Where water stands within a foot or two of the well mouth the word "surface" is used to designate the head. Where wells overflow and the height to which water will rise is not known the word "overflow" is used. It is probable that most of the numerals indicate the average head of the wells, especially in cases where the wells can be lowered by pumping or where the head decreases in seasons of drought.

*Cities and villages of Indiana obtaining part of water supply from wells in rock.*

| Place. | Population in 1890. | Depth. | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *a* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Alexandria | 715 | 60 | Limestone | Hard | (?) | 30 | $46,000 | Pumped to standpipe | 1895 |
| Anderson (part) (1 well at waterworks). | 10,741 | 800 | (?) | Hard, iron | Unlimited | Overflows. | 150,000 | Direct pumping. (See "Surface water.") | 1886 |
| Andrews | 1,320 | 60–150 | Limestone | Analysis | Unlimited. | +5 to —14 | | None | |
| Bedford | 3,351 | 90–100 | do | Hard | Strong. | 50 | | See "Surface water" | |
| Bloomfield | 1,229 | 20–25<br>150–160 | Sandstone | Soft | Strong. | | | None | |
| Bloomington | 4,018 | 10–50 | Limestone | Hard | Weak. | (?) | | See "Surface water" | |
| Bluffton, waterworks (10 wells). | 3,589 | 100–500 | do | do | (?) | (?) | | Direct pumping | 1886 |
| Butler, gas boring | 2,521 | 600 | do | Hard, pleasant | (?) | (?) | | See "Wells in glacial drift" | |
| Charlestown | 888 | 20–35 | do | Hard | Weak. | 5–15 | | None | |
| Columbia City, waterworks (3 wells). | 3,027 | 280 | do | Analysis | 230 | +5 | 30,000 | Direct pumping | 1893 |
| Converse, waterworks | 921 | 230 | do | Hard | (?) | 4 | 10,000 | Pumped to tank | 1895 |
| Converse and vicinity | (?) | 200–400 | do | do | Strong. | Surface. | | | |
| Covington | 1,891 | 350± | (?) | Sulphurous | Strong. | (?) | | See "Surface water" | |
| Decatur, waterworks (8 wells). | 3,142 | 250 | Limestone | Hard | (?) | 15 | 65,000 | Storage well with direct pumping | 1895 |
| Dunkirk, waterworks | 1,024 | 65–100 | do | do | 20 | 45 | 17,000<br>Ex. 1,100 | Direct pumping | 1894 |
| Elwood, waterworks | 2,284 | 75–150 | do | Analysis | 175 | 15–25 | 100,000 | do | 1892 |
| Fairmount | 1,462 | 15–30 | do | Hard | (?) | 6 | | See "Surface water" | |
| Fort Wayne, waterworks (about 30 wells). | 35,393 | 250–430 | do | do | 90 | Variable. | 550,000<br>Ex. 13,000 | Pumped to reservoir and direct.<br>See "Wells in glacial drift" | 1879 |
| Fowler | 1,285 | 175 | do | do | 150 | 25 | 36,500 | Pumped to reservoir and direct | 1895 |

*a* "Ex." in this column means running expenses per annum.

*Cities and villages of Indiana obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *a* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Francesville | 403 | 40 | Limestone | Hard | (?) | (?) | | None | |
| Geneva | 748 | 80 | do | do | (?) | (?) | | do | |
| Gosport | | 926 | (?) | Sulphurous | Strong. | Overflows. | | do | |
| Greenfield, waterworks | 3,100 | 176 | Limestone | Hard | 150 | Overflows. | $50,000<br>Ex. 2,500 | Direct pumping | (?) |
| Greenwood (sanitarium) | 862 | 1,725<br>600 | do<br>do | Sulpho-saline<br>(?) | (?)<br>(?) | 240<br>45 | | None | |
| Greencastle (M.) | 4,390 | (?) | do | Hard | (?) | Overflows. | 303,000 | Pumped to standpipe | 1886 |
| Greensburg, waterworks | 3,596 | 75 | do | Analysis | 200+ | 20 | (?) | Direct pumping | 1889 |
| Harrodsburg | (?) | 20-30<br>111-130 | do<br>do | Hard<br>do | Weak.<br>Strong. | Variable.<br>30 | | None | |
| Hartford | 2,287 | 125-250 | do | Sulphurous, hard | 8 | 10-20 | 50,000<br>Ex. 1,000 | Direct pumping | 1894 |
| Huntington, waterworks (11 wells). | 7,328 | 100± | do | Hard | 2 each. | 10 | 100,000 | Direct pumping. (See "Surface water.") | 1890 |
| Indianapolis, waterworks (small part). | 105,436 | Various | do | Hard, iron | (?) | +5 | 2,500,000 | Direct pumping. (See "Surface water" and "shallow wells.") | 1870 |
| Jasper | 1,281 | 20-130 | Sandstone | Variable | 4 | Surface. | | See "Surface water" | |
| Jeffersonville | 10,666 | 60± | Limestone | Hard | (?) | 55 | | do | |
| Kentland (M.) | 918 | (?) | do | do | 45 | (?) | 6,325 | Pumped to tank | 1896 |
| Knightstown, waterworks (5 wells). | 1,867 | 55-60 | do | Iron, hard | 15 | 14 | 28,000 | Pumped to standpipe | 1894 |
| Kokomo, waterworks | 8,261 | 100-150 | do | Hard, sulphurous | (?) | Surface. | | Direct pumping | 1887 |
| Near Kokomo (Wolf well) | | 1,000± | (?) | (?) | 500 | Overflows. | (?) | Used in irrigation | |
| Lafayette | 16,243 | 235<br>1,000 | Limestone<br>do | Sulphurous<br>Sulphosaline | (?) | Overflows. | | See "Surface water" | |
| Lodi | (?) | 35±<br>1,155 | do<br>do | Analysis | Strong. | Overflows. | | | |

*a* "Ex." in this column means running expenses per annum.

*Cities and villages of Indiana obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *a* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Logansport (small part) | 13,328 | 70–80 | Limestone | Hard, sulphurous. | (?) | 4–8 | ..... | Direct pumping. (See "Surface water.") | 1875 |
| Marion, waterworks | 8,769 | 240 | do | Hard | 100 | Overflows. | Ex. $5,000 | Direct pumping | 1877 |
| Martinsville (sanitariums) | 2,680 | 675<br>1,490 | Variable | Analysis | 30–85 | Overflows. | ..... | See "Shallow wells" | ..... |
| Michigan City (3 wells) | 10,776 | 541<br>819<br>833 | Limestone | Hard, sulphurous. | 300± | Overflow. | ..... | ..... | ..... |
| Mitchell | 1,583 | 30–100<br>1,200 | do<br>(?) | Hard<br>Saline | (?)<br>(?) | (?)<br>Surface. | ..... | None<br>Drawn for street sprinkling | ..... |
| Montpelier (M.) | 808 | (?) | (?) | Hard | (?) | Overflows. | 41,000 | Pumped direct from collecting basins. | 1896 |
| Monon | 1,064 | 20–200 | Limestone | Sulphurous and hard. | (?) | (?) | ..... | None | ..... |
| Montezuma (Riverside Hotel). | 658 | 1,675 | do | Analysis | Strong. | +115 | ..... | ..... | ..... |
| Muncie (M.) | 11,345 | (?) | do | Hard | 500 | + 10 | ..... | Direct pumping | 1885 |
| New Haven, waterworks | 1,079 | 300± | do | Analysis | Strong. | + 10 | 9,000 | do | 1893 |
| Noblesville | 3,054 | 65–80 | do | Hard | Strong. | 6 | Ex. 1,000 | See "Wells in valleys" | 1893 |
| North Vernon | 2,012 | 12–35 | do | do | Weak. | 2–15 | ..... | See "Surface water" | ..... |
| Near North Vernon | (?) | 66 | do | do | Strong. | Overflows. | ..... | ..... | ..... |
| Oakland City | 1,524 | 20–60 | Sandstone or shale. | Iron sulphate | (?) | 10–0 | ..... | None | ..... |
| Paxton | ..... | 25–30 | Sandstone | Sulphurous | (?) | (?) | ..... | do | ..... |
| Portland | 3,725 | 25–150 | Limestone | Hard, sulphurous. | 250 | 10–15 | 45,000 | Direct pumping | 1892 |
| Red Key | 922 | 70–100 | do | Hard | (?) | 20 | ..... | None | ..... |
| Remington | 940 | 75–125 | do | Sulphurous, hard | 3 | 20± | ..... | do | ..... |
| Rensselaer | 1,455 | 30–200 | do | do | Strong. | Surface. | ..... | do | ..... |
| Richmond | 16,608 | 12–40 | do | Sulphates, hard | 1–5 | Variable. | ..... | See "Surface water" | ..... |

*a* "Ex." in this column means running expenses per annum.

*Cities and villages of Indiana obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Ridgeville | 922 | 30–40 | Limestone | Hard | 10–15 | 10± | | None | |
| Rockport | 2,314 | 20–100 | Sandstone | Soft | (?) | (?) | | See "Surface water" | |
| Rockville, waterworks (4 wells). | 1,689 | 100–208 | (?) | | Weak. | (?) | $20,000 | Under construction | 1897 |
| Salem | 1,975 | 20–60 | Limestone | Hard | (?) | 10–40 | | See "Surface water" | |
| St. Paul | | 75–90 | do | Sulphurous | (?) | (?) | | None | |
| Seymour (gas boring) | 5,337 | 1,194 | do | Sulphurous, hard, saline. | (?) | Overflows. | | See "Surface water" | |
| Shoals | 738 | 960 | (?) | Analysis | Weak. | Overflows. | | None | |
| Spencer (3 wells) | 1,868 | 1,150± | Limestone | do | Strong. | Overflow. | | do | |
| Sullivan and vicinity | 2,222 | 100–400 | Sandstone | Pleasant | (?) | (?) | | See "Surface water" | |
| Sullivan (gas well) | | 1,000± | (?) | Saline | (?) | 15 | | Pumped for street sprinkling | |
| Versailles | 421 | 18–25 | Limestone | Hard | 1–5 | | | None | |
| Wabash (artesian well) | 5,105 | 2,270 | do | do | (?) | 85 | | See "Wells in glacial drift" | |
| Williamsport | 1,027 | 65 | (?) | Fresh | (?) | (?) | | None | |
| Williamsport (gas boring) | | 1,200 | (?) | Saline | (?) | (?) | | do | |
| Winamac (gas well) | 1,215 | 1,200 | Sandstone | Saline, iron | 45 | (?) | | do | |
| Winchester | 3,014 | 100± | Limestone | Hard | Strong. | 10 | | do | |
| Worthington | 1,448 | 1,445 | (?) | Sulphurous | Strong. | Overflows. | | do | |

*Cities and villages of Ohio obtaining part of water supply from wells in rock.*

| Place. | Population in 1890. | Depth. *a* | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Ada (part) | 2,079 | 25–40 | Limestone | Hard | (?) | 8–15 | | None | |
| Andover | 733 | 40–60 | Berea grit | Soft | 360 | 16 | | do | |
| Archbold | 780 | 160–175 | Limestone | Hard | Strong. | 10 | | do | |
| Ashland | 3,566 | 30–90 | Sandy shale. | Soft | (?) | (?) | $45,000<br>Ex. 2,400 | Pumped to standpipe and direct. | 1895 |
| Athens (part) | 2,620 | 20–50 | Sandstone | do | (?) | (?) | | See "Surface water" | |
| Bellefontaine (2 wells) | 4,245 | 164 | (?) | Analysis | 350 | +4 | 128,000<br>Ex. 5,000 | Pumped to reservoir | 1883 |
| Belmore | 414 | 60–70 | Limestone | Hard, sulphurous. | (?) | 10–20 | | None | |
| Berea | 2,533 | 60± | Berea grit | Iron | Variable. | 50 | | do | |
| Blanchester | 1,196 | 30± | Limestone | Hard | (?) | 10–15 | 20,000 | Pumped to standpipe | |
| Bluffton | 1,290 | 12–33 | do | do | Variable. | 10–20 | 18,000 | Pumped to standpipe and direct. | 1896 |
| Bowerstown | (?) | 16–65 | Sandstone | Hard and soft | (?) | (?) | | do | |
| Bowling Green | 3,467 | 70–200 | Limestone | Hard, sulphurous. | Strong. | 15 | 70,000<br>Ex. 4,000 | do | 1893 |
| Cadiz | 1,716 | W. W. 200<br>20–40 | Sandstone<br>Limestone | (?)<br>Hard | Strong.<br>(?) | (?)<br>(?) | 35,000<br>Ex. 2,000 | Direct pumping | 1895 |
| Cambridge | 4,361 | 30± | Soft sandstone. | Soft, sulphurous. | (?) | 20 | | See "Surface water" | |
| Canfield | 675 | 50–75+ | Sandstone | Sulphurous | (?) | (?) | | None | |
| Canton (part) (36 wells) | 26,189 | 275–385 | Limestone and sandstone. | Hard | 50 | Overflow. | 450,000<br>Ex. 24,000 | Direct pumping | 1869 |
| Carey (M.) | 1,605 | W. W. 60 | Limestone | do | (?) | (?) | 28,000 | Pumped to standpipe | 1895 |
| Castalia | (?) | 30–60 | do | Sulphurous | 3 | 30 | (?) | Tank and hose for fire | (?) |
| Carrollton (M.) | 1,228 | W. W. 100 | (?) | Hard | (?) | (?) | 25,500 | Pumped to standpipe | 1896 |
| Cedarville | 1,355 | 25–30 | Limestone | Sulphurous | Variable. | 15 | Ex. 600 | None | |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth.[a] | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895).[b] | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Celina | 2,702 | 250± | Limestone | Fresh, hard | 40 | Near surface. | $50,000<br>Ex. 1,200 | Pumped to standpipe and direct. | 1895 |
| Celina (deep wells) | | 1,100<br>1,700 | (?)<br>(?) | Saline<br>Sulphurous | (?)<br>(?) | | | | |
| Clyde | 2,327 | 65 | Limestone | Hard | 3–6 | 6 | 37,000<br>Ex. 2,000 | Direct pumping | 1883 |
| Near Clyde | | 50–75 | do | Hard, iron, sulphur. | 5–15 | Overflows. | | | |
| Corning (M.) | 1,551 | 25–45 | Sandstone | (?) | (?) | (?) | 10,000 | Pumped to tanks for fire protection. | (?) |
| Columbiana | 1,112 | 20–30<br>W. W. 30 by 35. | do | Not hard | Variable. | Surface. | 30,000<br>Ex. 1,200 | Direct pumping | 1895 |
| Continental (M.) | 895 | (?) | Limestone | Hard | (?) | (?) | 4,000 | Pumped to tank | 1894 |
| Covington | 1,778 | 10–50 | do | do | (?) | 6–12 | | None | |
| Cuyahoga Falls | 2,614 | 50± | Sandstone | Soft | Variable. | 25 | | | |
| Delaware (artesian well) | 8,224 | 2,250 | Several | Hard, saline, sulphurous. | 10 | Overflows. | | See "Wells in glacial drift" | |
| Delphos | 4,516 | 35–50 | Limestone | Hard | Variable. | 4–5 | 65,000 | Pumped to standpipe | 1896 |
| Deshler | 1,114 | 70–95 | do | do | Strong. | 20 | | None | |
| Doylestown | 1,131 | 10–50 | Sandstone | Soft | (?) | 6–8 | | do | |
| Dunkirk | 1,220 | 100± | Limestone | Hard | Strong. | Near surface. | | do | |
| East Palestine (M.) | 1,816 | (?) | Sandstone | Soft | Strong. | (?) | 23,500 | Pumped through mains to reservoir. | 1890 |
| Elyria | 5,611 | 60–90 | do | "Alum" water | Strong. | 16 | | See "Surface water" | |
| Findlay | 18,553 | 30–100 | Limestone | Hard, sulphurous. | (?) | 5–15 | | do | |
| Forest | 1,126 | 90± | do | Hard | (?) | 5–15 | | None | |
| Forest (3 miles southwest of). | | 480 | do | "White sulphur". | Strong. | Overflows. | | Forced to tank for domestic and stock use. | |
| Fostoria | 7,070 | 30–50 | do | Hard | (?) | 20 | | See "Surface water" | |

[a] "W. W." in this column means that the well is a waterworks well.

[b] "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *a* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Fremont | 7,141 | 40–60 | Limestone | Hard, sulphur | 15–20 | 25 | | See "Surface water" | |
| Galion | 6,326 | 90± | Sandstone | (?) | 35 | 5–13 | | Pumped to standpipe | 1882 |
| Gambier | 660 | 17–90 | Freestone | Soft and hard | | 6± | | None | |
| Grand Rapids | 572 | 40–60 | Limestone | Hard, sulphurous | (?) | 10–15 | | do | |
| Greenfield | 2,460 | 25–30+ | (?) | Hard | (?) | 8–12 | | See "Surface water" | |
| Hanoverton | 366 | 14–35 | Sandstone | Soft, sulphurous | 15–20 | 4–12 | | None | |
| Hillsboro | 3,620 | 10–50 | Limestone | Hard | (?) | Variable. | | See "Shallow wells in valleys" | |
| Jackson | 4,320 | 18–25 | Sandstone | (?) | Weak. | 6–10 | | None | |
| Kent | 3,501 | 75–100 | do | Soft | (?) | (?) | | See "Surface water" | |
| Kenton, waterworks | 5,557 | 100 | Limestone | Hard | Strong. | 15 | $90,000 | Direct pumping | 1881 |
| Larue | 948 | 50–100 | do | Hard, sulphurous | Strong. | 10–20 | | Railway pumps from Scioto River | |
| Lima | 15,987 | 140–148 | do | do | 550 | Overflow. | 338,000<br>Ex. 12,000 | Direct pumping | 1885 |
| Louisville (M) | 1,323 | (?) | (?) | (?) | (?) | (?) | 15,000 | Pumped to standpipe | 1895 |
| Mansfield | 13,473 | 100–140 | Sandstone | | Strong. | Overflow. | 125,000 | Direct pumping | 1870 |
| Marion | 8,327 | 50–75 | Limestone | Hard | 15 | 10–40 | | See "Surface water" | |
| Martinsville | 336 | 350± | do | Pure | (?) | Near surface. | | None | |
| Marysville | 2,810 | 18–80 | do | Hard | | 6–10 | 80,000 | Direct pumping | 1890 |
| Massillon | 10,092 | 100–200 | Sandstone | Analysis | 350 | Overflow. | 200,000 | Pumped to standpipe and direct. | 1854<br>1885<br>1891 |
| Medina | 2,073 | 30–100 | Limestone | Hard, sulphur | Weak. | (?) | 5,000<br>Ex. 600 | Pumped to standpipe | |
| Mendon | 400 | 50± | do | Hard, sulphurous | Variable. | 2–20 | | None | |
| Morrow | 842 | 50 | do | Hard | Strong. | 35 | | do | |
| Mount Sterling (M) | 752 | (?) | do | do | (?) | (?) | 12,000 | Pumped to reservoir and direct | 1896 |
| Mount Gilead | 1,329 | 140± | Sandstone | Unpleasant | (?) | 40 | (?) | Under construction | 1897 |

*a* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *b* | System. | When put in |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Napoleon | 2,764 | 114–130<br>1,600–1,800 | Limestone ..<br>(?) | Sulphurous<br>.....do | Variable.<br>(?) | 20<br>+3 | ..... | See "Surface water" | ..... |
| New Bremen | 1,239 | 70–100 | Limestone .. | Hard | (?) | 10–15 | ..... | None | ..... |
| New Lisbon, waterworks (25 per cent). | 2,278 | 50–80 | Sandstone .. | Soft | 30 | 20 | $25,000 | Pumped to reservoir. (See "Surface water)". | 1840<br>1888 |
| New London | 1,036 | 150± | Berea grit .. | Saline | ..... | ..... | ..... | None | ..... |
| New Paris | 842 | 20–30 | Limestone .. | Hard | (?) | 2–5 | ..... | .....do | ..... |
| New Straitsville | 2,782 | 20–30 | Variable.... | Hard, sulphurous. | (?) | 10–12 | ..... | Cisterns for fire; impounded water for mining industries, etc. | ..... |
| North Baltimore | 2,854 | 50–60 | Limestone .. | Hard | (?) | (?) | 75,000 | Pumped to standpipe | 1892 |
| Oak Harbor | 1,681 | 30–40 | .....do | .....do | (?) | 20–30 | ..... | None | ..... |
| Oak Hill | 657 | 50 | (?) | Hard, iron | (?) | 5–10 | ..... | .....do | ..... |
| Ohio City | 666 | 75 | Limestone .. | Hard | Strong. | 25 | ..... | .....do | ..... |
| Ottawa | 1,717 | 130± | .....do | Hard, sulphurous. | Strong. | 14 | ..... | Public wells | ..... |
| Paulding | 1,879 | 40? | .....do | Hard | 10–25 | 8–10 | ..... | None | ..... |
| Perrysville (M) | 522 | 92 | (?) | (?) | (?) | (?) | 6,000 | Pumped to reservoir | 1895 |
| Perrysburg | 1,747 | 80 | (?) | Hard | Strong. | 40 | ..... | None | ..... |
| Plain City (2 wells) | 1,245 | 500± | (?) | Hard, sulphurous. | Strong. | +12 | 23,000<br>Ex. 1,584 | Direct pumping | 1894 |
| Republic | 584 | 60–90 | Limestone .. | Hard, iron | (?) | 30–40 | ..... | None | ..... |
| Richwood | 1,415 | 35 | .....do | Hard | (?) | 15 | ..... | .....do | ..... |
| Ripley | 2,483 | 615 | Sandstone (?) | Analysis | Weak. | Overflows. | ..... | See "Surface water" | ..... |
| Rockford (M) | (?) | (?) | (?) | (?) | (?) | (?) | 13,500 | Pumped to standpipe | 1862 |
| Salem, waterworks | 5,780 | 100–110 | (?) | Hard | (?) | 18 | 150,000 | Pumped to standpipe and direct. (See "Surface water"). | 1887 |
| Salineville | 2,369 | 40–60<br>W. W. 100± | Sandstone .. | (?) | (?) | 10–25 | 40,000<br>Ex. 1,200 | Pumped to reservoir | 1892 |

*a* "W. W." in this column means that the well is a waterworks well.

*b* "Ex." in this column means running expenses per annum.

*Cities and villages of Ohio obtaining part of water supply from wells in rock*—Continued.

| Place. | Population in 1890. | Depth. *a* | Water bed. | Quality of water. | Capacity per minute. | Head from surface. | Waterworks. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cost (to 1895). *b* | System. | When put in. |
| | | *Feet.* | | | *Gallons.* | *Feet.* | | | |
| Shreve, waterworks | 1 012 | 140± | (?) | (?) | 60 | 100 | $8,000 Ex. 600 | do | 1893 |
| Sidney | 4,850 | 120 to 200± | Limestone | Hard | (?) | Overflow. | | See "Surface water" | |
| Springfield | 31,895 | 35–45 | do | do | Variable. | Variable. | | See "Wells in valleys" | |
| Stryker | 1,017 | 100–160 | Shale (?) | do | (?) | 2–20 | | None | |
| St. Clairsville | 1,191 | 50–100 | Limestone | do | 10 | (?) | | do | |
| St. Marys | 3,000 | W. W. 280 | do | do | 150–500 | Overflows. | 50,000 | Direct pumping | 1895 |
| Swanton | 508 | 60 | Top of rock. | do | Strong. | Surface. | | None | |
| Sylvania | 545 | 75± | Limestone | do | (?) | 12 | | do | |
| Tiffin, waterworks (part) (7 wells). | 10,801 | 70–150± | do | do | 80 each. | Surface. | | Direct pumping | 1878 |
| Upper Sandusky | 3,572 | 65–70 | do | Hard, sulphur | (?) | 15–20 | | See "Surface water" | |
| Urbana, gas well | 6,510 | 275 | do | Hard | 70–100 | +33 | | See "Wells in glacial drift" | |
| Van Wert, waterworks (6 wells). | 5,512 | 127–175 | do | Hard, sulphurous. | 150± | 5–9 | 125,000 Ex. 4,000 | Direct pumping | 1890 |
| Wadsworth | 1,574 | 40–50 | Sandstone | Soft | (?) | (?) | | See "Surface water" | |
| Wauseon | 2,060 | 150 | Top of rock. | Soft (?) | 50 | Overflows. | | None | |
| Waynesville | 704 | 20–30+ | Limestone | Hard | (?) | (?) | | do | |
| West Union | 825 | 10–30 | do | do | Weak. | 10± | | do | |
| West Unity | 872 | 100–200 | (?) | Sulphurous | 40 | Overflows to −28. | | do | |
| Wilmington | 3,079 | 60–100 | Limestone | Hard | (?) | Overflow. | | do | |
| Winchester | (?) | 25 | do | do | (?) | 7–10 | | do | |
| Wooster | 5,901 | 80–140 | Shale | Hard, saline | (?) | (?) | | See "Surface water" | |
| Xenia, waterworks (part) (2 wells). | 7,301 | 57–100 | Limestone | Hard | Weak. | (?) | | do | |
| Yellow Springs | 1,375 | 25–100 | do | do | (?) | (?) | | None | |

*a*. "W. W." in this column means that the well is a waterworks well.

*b*. "Ex." in this column means running expenses per annum.

## DETAILED OBSERVATIONS.

In many cases the conditions for obtaining water supplies can not well be stated in tabular form. It therefore seems necessary to supplement the tables by explanations covering such cases. The cities or villages thus discussed are taken in alphabetical order, first in Indiana and then in Ohio, and are not grouped as in the above tables.

### INDIANA CITIES AND TOWNS.

*Anderson, Indiana.*—This city stands on the bluffs of White River, the part near the river being broken or rolling land, standing 75 to 100 feet above the stream, while the part back from the bluff is nearly level. In the central and eastern portions of the city water is found in gravel beds at an average depth of 35 feet, and has very little impervious clay above it. In the south and west parts of the city much blue bowlder clay is penetrated, and water is found at various depths, ranging from 50 to 100 feet or more. An artesian well located near the waterworks pumping station in White River Valley is discussed above (p. 487). (Information furnished by James T. Knowland, clerk of waterworks.)

*Bloomington, Indiana.*—This city obtains its supply for the waterworks from two large springs, the larger of which is called Stone spring. The water is collected in a reservoir, which receives more or less drainage from the surrounding country. The waterworks supply is not used for culinary purposes, the residences being furnished with cisterns and in a few instances with wells or springs. Situated as the city is on a driftless upland, these are its only resources. An artesian well drilled to a depth of 2,730 feet failed to obtain a suitable quantity or quality of water for city use. (Information obtained from C. E. Siebenthal and from State geological reports.)

*Bluffton, Indiana.*—There are about ten wells drawn upon by the waterworks, the majority of which are 100 to 200 feet in depth, but one well is 300 and another 500 feet. The water is very hard, but is otherwise unobjectionable. In seasons of drought the Wabash River is drawn upon to meet the extra demands for watering lawns, etc.

*Brookville, Indiana.*—The waterworks supply is obtained from two large open wells sunk in gravel within 30 feet of the edge of Whitewater River, about one-third of a mile above the corporate limits of the town. The wells are 24 feet in diameter and are sunk 12 feet below the lowest water in the river. The present consumption occasionally reaches 300,000 gallons per day. The sanitary analysis, made by Prof. H. A. Huston, State chemist, is as follows:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.0106 |
| Albuminoid ammonia | 0.0888 |
| Nitrogen in nitrates | None. |
| Nitrogen in nitrites | Trace. |
| Phosphates | Trace. |
| Bromine | None. |

Hardness (Clark's scale) { Temporary, 5 degrees. Permanent, 9 degrees.

An analysis of the mineral ingredients is presented on another page. (Information furnished by John Burkhart, superintendent of waterworks.)

*Columbia City, Indiana.*—This city finds excellent water in gravel at a depth of about 75 feet, which supplies many private wells. At the waterworks there are three 8-inch wells 280 feet in depth, which enter limestone and have a united capacity of about 1,000,000 gallons per day. Temperature of water, 50.5° F. Chem-

ical analysis appears on another page. (Information furnished by J. M. Harrison, mayor.)

*Covington, Indiana.*—In the vicinity of this city there are numerous springs, both from gravel beds and underlying sandstone, some of which furnish the city water supply. There is also a well over 300 feet in depth, known as the "Artesian well," but which does not overflow. This yields an abundance of "sulphur water," and the city is taking steps toward bringing it into extensive use. (Information furnished by A. T. Livengood, mayor.)

*Danville, Indiana.*—This city obtains its water supply from four 2-inch and two 3-inch wells driven to a depth of 110 feet in the glacial drift. The water obtained is of medium hardness, with a little iron and sulphur, and has a head 26½ feet above the surface. The average flow of each well is about 2,000 barrels per day. (Information by C. C. Hadley, president town board.)

*Elkhart, Indiana.*—A large well 34 feet in depth and 27 feet in diameter, excavated in the glacial drift, will yield 2,000,000 gallons per day. There is a thin bed of clay overlying the water-bearing gravel which is thought to protect it from contamination. Many driven wells in the city obtain water at from 25 to 100 feet without entering rock. In these wells the head ranges from 3 feet above to 7 feet below the surface.

*Evansville, Indiana.*—The city water supply is obtained from the Ohio River by direct pumping. A new waterworks plant is being constructed and a general reconstruction of the system is being made. There are several deep borings in the city and vicinity, some of which supply water to parks and a natatorium. (Information furnished by August Pfafflin, city engineer.)

*Fort Wayne, Indiana.*—The public water supply is from 54 wells, about one-half in gravel, at a depth of 40 to 60 feet, and one-half in rock, at a depth of 250 to 450 feet. Capacity of wells 7,000,000 gallons per day. Pumping capacity 11,000,000 gallons per day. Probably 28,000 persons, or two-thirds of the population, are supplied from these wells. The remainder use private wells and cisterns. A sanitary analysis made by the city chemist, L. P. Drayer, is as follows:

| | Parts in 100,000. |
|---|---|
| Total solids | 9.32 |
| Free ammonia | Trace. |
| Albuminoid ammonia | Trace. |
| Chlorides | 0.35 |
| Nitrogen in nitrates and nitrites | Trace. |

Iron in minute quantities.

Bacteria per cubic centimeter, 210.

Occasionally a turbidity exists, due to particles of finely divided clay, but the water is generally clear. The wells in the drift have at least 7 feet of blue clay just above the gravel, which is thought to protect them from surface contamination. Several deep borings have been made in the city and vicinity in prospecting for natural gas, and one well was sunk for artesian water at the court-house square in 1875, but without obtaining a flow, though a depth of 3,000 feet was reached. The water furnished by these wells is not considered preferable to that now in use, and the expense of boring may be considered a total loss. One boring, near the bank of the Maumee River, in White's addition, overflows at the rate of 400 gallons a minute. The water is of excellent quality, but it is not utilized. (Information furnished by Prof. C. R. Dryer.)

*Frankfort, Indiana.*—The public water supply is obtained from six 8-inch wells, bored in the bottom of a reservoir sunk 28 feet in depth. The wells extend about 30 feet below the bottom of the reservoir. The capacity of the wells is found to be about 6,000,000 gallons per day. Three sanitary analyses of water were made by Prof. T. C. Van Nuys, of the State University, one specimen being taken from an

old well, another from a faucet in the engine house, and another from a new well. They show very little difference, and the average of the analyses is as follows:

| | Parts in 100,000. |
|---|---|
| Total solids | 34.64 |
| Calcium oxide | 8.55 |
| Magnesium oxide | 5.08 |
| Organic matter | 5.66 |
| Chlorine | 0.77 |
| Ammonia | 0.23 |
| Nitric acid | 0.15 |

*Garrett, Indiana.*—The following analysis of water at the wells of the Baltimore and Ohio Railway headquarters were furnished by E. J. Hughes, M. D.:

| | Parts in 100,000. | |
|---|---|---|
| | 35-foot well. | 75-foot well. |
| Total solids | 36.30 | 55.38 |
| Chlorine | 0.40 | 1.16 |
| Free ammonia | 0.071 | 0.003 |
| Albuminoid ammonia | 0.009 | 0.0029 |
| Reaction | Alkaline. | Alkaline. |
| Turbidity | Turbid. | Clear. |

This analysis apparently indicates contamination of the shallow well, and Dr. Hughes writes that the overlying beds are probably not sufficiently impervious to prevent contamination. The larger amount of chlorine in the deeper well is, perhaps, derived from mineral substances in the drift and is probably not due to surface contamination. The Manual of American Waterworks reports that waterworks constructed in 1896 obtain supply from four 8-inch wells; depth not noted.

*Greensburg, Indiana.*—The entire waterworks supply is from one well 75 feet deep and 12 inches in diameter, 50 feet in the drift and 25 feet in underlying limestone The main supply of water was struck at 21 feet in the rock. Here the drill dropped 10 inches, and drillings below this depth could not be pumped out. The average daily consumption from this well by the city and railway companies is estimated to be 7,500 barrels of 40 gallons. The well has been pumped at the rate of 2,000,000 gallons per day without any appreciable exhaustion, and it is thought that the well may be depended upon for this amount. The following sanitary analysis was made by Prof. E. G. Smith, of Beloit, Wisconsin:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.066 |
| Albuminoid ammonia | 0.004 |
| Chlorine | 0.62 |
| Nitrites | None. |
| Nitrates | Trace. |
| Hardness { Temporary, 11.5 degrees. | |
| Hardness { Permanent, 8.0 degrees. | |
| Hardness { Total, 19.5 degrees. | |

An analysis of the mineral matter is given on another page, and shows calcium and magnesium carbonate to constitute the bulk of the mineral material. (Above data furnished by Prof. W. P. Shannon, of Greensburg, and Mr. William F. Ross, of Rochester, New York.)

*Hammond, Indiana.*—The public water supply for the city of Hammond is obtained

from pipes extended out beneath Lake Michigan. A 16-inch pipe, running about 1,600 feet into the lake, leads to a well or settling basin 10 feet in diameter and 30 feet deep. Another pipe, 24 inches in diameter, is extended 2,000 feet into Lake Michigan. This leads to a well 20 feet in diameter and 20 feet deep. The two wells are properly screened from surface contamination. This water has displaced the use of artesian wells, and supplies the locomotives for several railroads as well as the engines for several large factories, all of which had found the use of artesian water unsatisfactory. The private wells of Hammond are often obtained without passing through any impervious stratum, and it is thought much danger may arise from their use. The use of such water is being abandoned as the superior character of the public water supply comes to be recognized. (Information furnished by W. F. Bridge, city engineer.)

*Huntington, Indiana.*—Eleven wells have been sunk near the waterworks station to a depth of about 100 feet, but the supply being inadequate, water is also pumped from the Wabash River. A large part of the population still depend upon private wells, and the water thus obtained seems to be pure. (Information furnished by S. T. Cast, mayor.)

*Indianapolis, Indiana.*—The Indianapolis Water Company supplies also the suburbs West Indianapolis, Haughville, and Brightwood. It obtains about three-fourths of its supply from wells and one-fourth by filtration from White River. Both the well water and the river water are hard, and the well water is slightly sulphurous and chalybeate. Water is found most abundantly at a depth of 30 to 50 feet near the base of the gravels of the river valley. Such water is liable to contamination, being unprotected by beds of clay or other impervious stratum. For this reason the water company have sunk to lower horizons, obtaining some water from near the bottom of the glacial drift after passing through a bed of blue bowlder clay, and some from the rock. Numerous private wells have been sunk in the city to the water bed near the base of the glacial drift, and these supply a limited quantity but excellent quality of water. The use of river water by the city is highly objectionable, because of the location of gas wells along the stream a few miles above the city, from which there is more or less leakage. (Information furnished by Mr. F. A. W. Davis, superintendent of Indianapolis Water Company.)

*Knox, Indiana.*—In the vicinity of Knox and throughout much of Stark County water is obtained in the surface sand, it being difficult to case it out and reach a lower water horizon. There is some uncertainty also in the supply from lower horizons. The use of such wells necessitates much care in the prevention of surface contamination.

*Kokomo, Indiana.*—The public water supply of Kokomo was obtained by drilling several small wells in the bottom of two large excavated wells. There are also wells drilled in the vicinity of the water-works station from which water is piped into the large open wells. The water, being from a pyritiferous limestone, contains sufficient iron sulphate formed by decomposition of the pyrites to be detectable, but not, as a rule, objectionable. Deep wells are discussed on another page.

*Lafayette, Indiana.*—The public supply for the city of Lafayette is from a bed of gravel underneath the Wabash River at a level about 40 feet below the bottom of the stream. Prof. H. A. Huston, State chemist of Indiana, reports that since this source of supply was substituted for the ordinary water of the river in 1892, there has been a decided improvement in the health of the city, which he attributes to the better quality of the water. Professor Huston has furnished the following analysis of this water:

| | Parts in 100,000. |
|---|---|
| Chlorine | 0.85 |
| Nitrogen in ammonia salts | 0.0005 |
| Nitrogen in albuminoids | 0.0018 |
| Nitrogen in nitrites | None. |
| Nitrogen in nitrates | 0.4610 |

| | Parts in 100,000. |
|---|---|
| Phosphoric acid | None. |
| Sulphur trioxide | 2.28 |
| Silica | 1.08 |
| Iron and aluminium oxides | 0.32 |
| Calcium oxide | 10.82 |
| Magnesium oxide | 4.42 |
| Potash ($K_2O$) | 0.82 |
| Soda ($Na_2O$) | 2.64 |
| Hardness { Permanent, 6 degrees (Clark). Temporary, 6 degrees (Clark). | |

Professor Huston states that the water is hard for boilers and a great soap consumer, but that from a sanitary standpoint no better has been found in the State. He considers the well water obtained on the slopes of the Wabash bluffs an unsafe supply.

An artesian well in this city, made some years since, obtains a flow of sulphurous water from a depth of 235 feet and a gas-well boring obtains a salt sulphur water at a lower depth, the boring being 1,000 feet. These are discussed on another page.

*Logansport, Indiana.*—The public water supply is mainly pumped from Eel River, but several springs in the bluff north of Eel River are collected in wells and supplied by the waterworks to the city for drinking. The water power from a race connected with Eel River is used in pumping, and has supplanted the use of an engine. The private wells in the city are found in gravel near the level of the Wabash and Eel rivers. In some cases they penetrate a bed of clay, but are usually entirely through loose sand and gravel and are thought to be liable to contamination. (Information given by W. B. Ray, city engineer.)

*Marion, Indiana.*—The city of Marion draws its public water supply from two sources—wells in the drift about 70 feet deep and wells in limestone about 240 feet deep. The water flows from both classes of wells, but the flow is not sufficiently rapid to furnish what is needed, hence a compressed-air lift is used. The water is very hard and is slightly chalybeate. An 8-inch well furnishes ordinarily about 4,000 barrels a day. (Information furnished by Louis Von Behren, mayor.)

*Martinsville, Indiana.*—There are three classes of wells in this city: (1) Wells 20 to 30 feet in depth, driven or excavated in the gravel of the White River Valley; (2) flowing wells 40 to 60 and occasionally 90 to 120 feet in depth, obtained in beds of gravel beneath glacial clay; (3) deep wells sunk for use at the sanitariums, 675 to 1,490 feet in depth, the majority being about 700 feet. The water is sulphurous and moderately saline, as well as hard. Analyses are given on another page, and also other statistics concerning the use of this water by the sanitariums.

The city water supply is obtained from one large open well 30 feet in diameter and 30 feet in depth, together with nine driven wells of similar depth. No grounds for suspecting its contamination are known, though the cover is apparently rather imperfect. (Information furnished by Henry Shereman, jr., postmaster, and by C. S. Cunningham, esq.)

*Michigan City, Indiana.*—The public water supply is obtained from several 6-inch driven wells, supplemented in seasons of drought by water from Trail Creek. Water from the drift is preferred to a sulphurous artesian-well water, which may be obtained by sinking wells into the underlying Niagara limestone. (Information furnished by A. W. Frehse, superintendent of waterworks.)

*Mitchell, Indiana.*—Wells are usually obtained in the vicinity of Mitchell at a depth of 30 to 50 feet, the greater part of which depth is through a decomposed limestone. A few wells have been sunk to a depth of 100 feet in order to obtain a greater supply. A gas-well boring was sunk to a depth of 1,200 feet and obtained a supply of salt water, which rises nearly to the level of the well mouth. This water is used for street sprinkling, but is thought to be too salt for domestic use or for sprinkling lawns.

*New Albany, Indiana.*—The city of New Albany obtains its waterworks supply from the Ohio River, but several public wells and a large number of private wells are obtained from the gravel of the terrace on which the city stands. Numerous analyses of the water from public wells have been made by J. F. Elsom, of New Albany. At the request of the mayor, Mr. T. W. Armstrong, Mr. Elsom furnished the following statement concerning the average of water from the city wells. In all cases the selections were made when the water in the wells was extremely low and suspicion of contamination strong.

| | Parts in 100,000. |
|---|---|
| Total solids | 80.02 |
| Organic carbon | 0.739 |
| Organic nitrogen | 0.093 |
| Ammonia | 0.740 |
| Sewage contamination | 32.850 |

Hardness: Temporary, 22.090. Permanent, 26.210.

*Newcastle, Indiana.*—The public water supply is from flowing wells sunk about 90 feet in the glacial deposits. A large supply of excellent water can be obtained in the drift of this vicinity at depths ranging from 20 to 250 feet or more. Analyses of the water from the waterworks wells are presented in the table of analyses on another page.

*Plymouth, Indiana.*—The public water supply for Plymouth is obtained from a series of flowing wells sunk in the glacial drift to a depth of 40 to 50 feet. The water is hard and chalybeate, and the supply is apparently inexhaustible. Wells of this class are found along Yellow River and other streams in Marshall County, and water rises to a corresponding level in extensive districts between streams.

*Richmond, Indiana.*—The public supply for the city of Richmond is obtained from spring water. An analysis made by Prof. D. W. Dennis shows the water to be free from nitrites and free ammonia and saline ammonia, and there is only a trace of albuminoid ammonia. A comparison with wells in the city leads Professor Dennis to the conclusion that more or less malaria exists where these wells are used, but none has been traced to the use of the water from the waterworks. The shallow wells in the city are considered less safe than the water from the springs or of Whitewater River, and their use should be discontinued wherever practicable. The hardness of the water varies slightly with the season. It averages about 27 parts of carbonate of lime in 100,000.

*Rochester, Indiana.*—The city of Rochester obtains its public supply from springs which are run into a well and filtered before the water is pumped into the tank. It is thought to be uncontaminated, although the works are located within the city limits. An artesian well at the public square obtains a supply of water at a depth of about 500 feet, which is sulphurous and chalybeate as well as hard. (Information furnished by William Jay Shields, postmaster.)

*Rockville, Indiana.*—The city of Rockville has thus far been unsuccessful in obtaining an adequate water supply for public use. Three prospective wells have been drilled to depths of about 200 feet each and a fourth to a depth of about 100 feet without finding an adequate supply. The completion of the waterworks is therefore suspended for the present. Private wells within the city range from 15 to 75 feet in depth in glacial drift, the depth varying greatly on adjoining blocks. There appears to be no well-defined water horizon within easy access. An unsuccessful gas-well boring was sunk some years ago to a depth of 2,300 feet. It obtained water, but the water failed to reach the surface, and no use was made of the boring. (Information furnished by Capt. John T. Campbell.)

*South Bend, Indiana.*—The public water supply for the city of South Bend is obtained from about thirty flowing wells driven to a depth of 100 to 125 feet in the glacial drift. A compact calcareous clay nearly free from pebbles and having a thickness of 20 to 40 feet rests upon the water-bearing gravel and prevents surface contamination. The head was originally about 15 feet above the surface in wells located

on the low ground along the river bottom. The greater part of the city stands upon a terrace 20 to 30 feet above this bottom, and consequently above the level to which water will rise. The following analysis was made by Prof. Albert Prescott, of the University of Michigan:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.010 |
| Albuminoid ammonia | 0.008 |
| Nitrates | None. |
| Nitrogen in nitrites | 0.007 |
| Chlorine of chlorides | 0.600 |

Hardness (Clark's scale), 13 degrees.

Professor Prescott states that in the sanitary relations the water is better than the average of good city water supplies. (Information furnished by William M. Whitten, city engineer.)

*Sullivan, Indiana.*—The private wells in this village usually obtain abundant supply in glacial drift at 25 to 35 feet. In the surrounding country wells are often sunk to a depth of 200 to 300 feet, obtaining a supply of fresh water in the sandstone. A gas-well boring made by the city reached a depth of about 1,000 feet and struck a strong flow of salt water, which rises within 15 feet of the surface. This water is being used for street sprinkling, but is so salt as to leave a white incrustation when evaporated. The city waterworks, recently constructed, obtain a supply from Busseron Creek. The water is filtered before it is pumped to the standpipe.

*Terre Haute, Indiana.*—The city of Terre Haute is supplied chiefly by water pumped from the Wabash River, there being but few private wells. The danger of contamination of the water of the wells is so great that frequent analyses are made, and where contamination is known to exist further use is prohibited by the city authorities. The following table of analyses, made by Prof. W. A. Noyes, of the Rose Polytechnic Institute, in 1891, includes water from several wells, in addition to that from the city hydrants, and illustrates the nature of the supplies:

[Parts in 100,000.]

| | Hydrant water. | Deep well at Terre Haute House. | Well at 610 Eagle street. | Well at Fourteenth and Poplar streets. | Well at Thirteenth street and College avenue. | Well at Twelfth and Wabash streets. | Well in front of 519 North Fourth street. | Well at Third street and Washington avenue. |
|---|---|---|---|---|---|---|---|---|
| Total solids | 280 | 404 | 730 | 375 | 373 | 421 | 644 | 332 |
| Chlorine | 12.9 | 11.7 | 41.7 | 7.4 | 10.6 | 12.4 | 20.8 | 4.6 |
| Nitrogen in nitrates | 1.4 | 9.6 | 22.6 | 9.1 | 11.1 | 10.6 | 16.0 | 8.2 |
| Nitrogen in nitrites | None. | None. | 0.05 | 0.002 | 0.001 | 0.002 | 0.002 | None. |
| Free ammonia | None. | None. | 0.10 | None. | 0.002 | None. | 0.004 | None. |
| Albuminoid ammonia | 0.08 | 0.003 | 0.12 | 0.004 | 0.004 | 0.008 | 0.044 | 0.020 |
| Oxygen consumed by organic matter | 1.25 | 0.24 | 0.72 | 0.28 | 0.24 | 0.26 | 0.44 | 0.24 |

"With the exception of the wells at 610 Eagle street and in front of 519 North Fourth street, th contamination is less than in the well waters examined the previous year (1890). Whether this is because most of the wells are located in the less thickly populated parts of the city, or because, on account of the small amount of rain, the surface drainage forms a smaller part of the water in the wells, can only be determined by new analyses of some of the wells examined last year. In any

case, however, the analyses show that a part of the water in each of these wells has at some time in its history been contaminated with organic matter."—W. A. Noyes.

*Union City, Indiana.*—The supply for the Union City waterworks is obtained from two wells, each 30 feet in diameter and 32 feet deep. The water stands at an average depth of about 25 feet in each well, or within 7 feet of the surface. The wells are dug through a tough, bluish clay to a dark sand, which, when reached, supplies water in such quantities as to preclude further progress. The water is thought to be very pure and healthful. In twenty-three years no case of typhoid fever or diphtheria has originated in a family using it exclusively, nor has deleterious matter been detected in it. (Information furnished by William Commons, M. D., health officer.)

*Valparaiso, Indiana.*—The public water supply for this city is obtained from Flint Lake, situated about 3 miles north of the city. As there are no streams leading into this lake, its water is supplied from direct rainfall and from percolation through surrounding gravel beds. In dry seasons it shrinks to such an extent that the supply is scarcely sufficient to meet the demands of the city, and plans are under way for connecting the waterworks system with other small lakes in that vicinity. Private wells and cisterns are used extensively. The wells range in depth from 15 feet to about 200, and obtain their supply from gravel beds in the glacial drift. (Information furnished by J. C. B. Suman, mayor.)

*Wabash, Indiana.*—The public water supply for the city of Wabash is obtained from flowing wells sunk in the valley of Treaty Creek, about a half mile south from the Wabash River bluff. The wells range in depth from 42 to 55 feet, and are 6 inches in diameter. Only a small part of the water goes into the reservoir, and yet an adequate amount is obtained for the use of the city.

Many wells have been drilled into limestone within the city, but the present waterworks supply has largely supplanted them because of its superior quality. A deep artesian well made many years ago has also nearly gone out of use. (Information furnished by James E. McHenry, mayor.)

*Warsaw, Indiana.*—The public supply is obtained from sixteen 2-inch wells 138 feet deep, one 8-inch well 141 feet deep, and one 6-inch well 140 feet deep. The head in these wells is sufficient to cause them to flow 1 to 2 feet above the surface. In addition to the wells, water is pumped from one of the lakes situated on the borders of the city.

*Whiting, Indiana.*—Part of the town is supplied from Lake Michigan by the private pumps of the Standard Oil Company's plant, but a part of the town still use well water obtained in the surface sand.

## OHIO CITIES AND TOWNS.

*Akron, Ohio.*—Several wells driven in gravel to depths ranging from 60 to 125 feet furnish the public water supply. This is supplemented by pumping from a small lake. The wells each have an average yield of about 100,000 gallons per day. The average daily consumption is about 3,000,000 gallons. A portion of the city is underlain at slight depth by sandstone in which water is readily obtained for many private wells. A few families on the west side are supplied from springs.

*Ashland, Ohio.*—Water supply from wells at pumping station is abundant at 30 feet or less, but one of the best wells is 90 feet. Average daily consumption about 50,000 gallons. Daily capacity of a well averages about 50 barrels, but some wells are much stronger. Analysis of water given in tables on later page.

*Ashtabula, Ohio.*—The public supply is from a series of tubes and infiltration wells, 6 to 14 feet deep, in gravel on the shore of Lake Erie.

*Athens, Ohio.*—Waterworks supply is from a large well, 23 feet deep and 30 feet in diameter, situated just above the city in the Hocking River bottom, at a distance of

1,700 feet from the river. Water enters through coarse gravel and is probably fed by the river, its bottom being below river level. In dry seasons 750,000 gallons per day is pumped without lowering the well, and occasionally twice that amount. Average daily consumption nearly 200,000 gallons. (Information furnished by William S. Wilson, mayor.)

*Attica, Ohio.*—The public supply is from a large well, 28 by 25 feet, fed by tile leading through a gravel bed 6 to 11 feet from surface of ground. This well will furnish 750 gallons per minute in ordinary seasons, or far more than the demands of the village. The private wells obtain water at about 20 feet. (Information furnished by A. F. Lepper, postmaster.)

*Bellaire, Ohio.*—Public supply pumped from Ohio River is considered unsafe because of the situation just below the city of Wheeling, but is used by a large part of the population. Private wells obtain supply at level of river, except in a few instances where rock is penetrated. Rock water is often slightly saline. A 6-inch well in the river alluvium will ordinarily supply 50 gallons per minute. Such wells are considered safer than the river water. (Information furnished by James Kenney, jr.)

*Bellefontaine, Ohio.*—The public supply is from two flowing wells, 164 feet in depth, located on ground about 13 feet lower than the Cleveland, Cincinnati, Chicago and St. Louis Railway station. The water is pumped to a reservoir. The combined capacity by pumping is about 1,000,000 gallons per day. Average daily consumption about 750,000 gallons. The analysis shows it to be an alum water, there being nearly 3 grains per gallon of sulphate of alumina. (Information furnished by W. T. Haviland, postmaster.)

*Bellevue, Ohio.*—Several wells in the city appear to have an inexhaustible supply of water from limestone at depths of 40 to 75 feet, but the majority have a limited capacity. The strong wells are supposed by the residents to be located in a "subterranean stream." The public supply is impounded water pumped to standpipe.

*Berea, Ohio.*—The wells are partly in drift at depths of 15 to 20 feet, partly in shale at similar depths, and partly in Berea grit at 60 to 75 feet. There is but little rise of water in the wells. Strength of wells varies greatly. (Information by Dr. D. T. Gould.)

*Bucyrus, Ohio.*—Public water supply partly from a large well, 50 by 20 feet, and partly from Sandusky River. Private wells, 10 to 40 feet in depth, are mainly through bowlder clay and obtain water in glacial gravel. (Information furnished by Charles Donnenwirth, mayor.) The Waterworks Manual reports average daily consumption 550,000 gallons.

*Canton, Ohio.*—The public water supply is about equally divided between Nimishillen Creek and 36 flowing wells, there being pumped from each source about 1,500,000 gallons daily. The flowing wells are 275 to 385 feet in depth and obtain supply from sandstone. Such wells overflow only on low ground along the creek. (Information by A. M. True, superintendent of waterworks.)

*Celina, Ohio.*—Very large supplies of fresh water may be obtained from the drift gravels at 50 or 60 feet or less and from limestone at about 250 feet. The average capacity of a drilled well is estimated to be 1,500 barrels per day. The drift near Celina in places is fully 300 feet, but ordinarily is scarcely 100 feet in depth.

*Cincinnati, Ohio, and suburbs.*—The city of Cincinnati is supplied with water pumped from the Ohio River to reservoirs for both low service and high service. The suburban towns of Madisonville, Linwood, Norwood, Carthage, St. Bernard, Bond Hill, Lockland, Hartwell, Reading, Wyoming, and Glendale are all located in an abandoned valley connecting the Ohio with the Great Miami. This valley is filled with a fine sand, which yields an abundance of good water for the use of these towns. The wells are 100 to 235 feet in depth, the deepest being at Norwood. Dr. John B. Porter, of Glendale, estimates that these suburban towns have an average daily summer consumption by public and private wells of not less than 4,000,000 gallons and occasionally pump 10,000,000 gallons. The wells at Glendale pumping station

penetrate 97 feet of clayey drift before entering the water-bearing sand and are sunk 78 feet into the sand. The water there shows a trace of free ammonia, but no albuminoids. It is hard, fully 75 per cent of its mineral matter being carbonate of lime. Dr. Charles L. Metz, of Madisonville, reports that the three wells at the waterworks of that village are on the lowest ground in that vicinity (along Duck Creek), and are 140, 145, and 150 feet in depth. At 16 feet sand was entered which continues to bottom. Water is hard and incrusts standpipe. A sanitary analysis shows the following:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.0062 |
| Albuminoid ammonia | 0.0050 |
| Nitrates and nitrites | 0.0443 |
| Chlorine | 0.45 |
| Volatile organic solids | 4.50 |
| Inorganic solids | 30.75 |
| Total solids | 35.25 |

*Cleveland, Ohio.*—The public supply is from Lake Erie, the water being taken at a crib 1 mile from the shore. Very few private wells are in use. Two reservoirs are constructed, a low service 170 and a high service 315 feet above the lake. Miles of pipe connected with low service, 390; with high service, 43. Total, 433 miles. Manual of American Waterworks reports 462 miles in June, 1896. Average daily consumption of water nearly 40,000,000 gallons. (Information by Mr. Warren Upham.)

*Clyde, Ohio.*—In the vicinity of this village are flowing wells 50 to 75 feet in depth. The rate ranges from 10 barrels to fully 500 barrels per day. The public supply is from limestone, and water is sulphurous as well as hard. (Information by D. Beamer.)

*Columbus, Ohio.*—The city of Columbus embraces within its limits three valleys and tracts of upland in which water horizons are variable. In places drift deposits exceed 100 feet; in places the drift is thin. Some water is obtained at 10 to 15 feet, but a better supply is found at 30 feet or more, the depth to strong water veins varying greatly within narrow limits. Some shallow wells may be subject to contamination, but clay strata usually protect such wells. The public supply is from Scioto River and impounded water at main station and from wells at East Side station. Average daily consumption, 14,000,000 gallons. Few wells, either for public or private supply, enter rock. The water is hard and contains a small amount of iron and sometimes is sulphurous. (Information by Dr. Edward Orton, State geologist.)

*Conneaut, Ohio.*—Public supply chiefly from eight 5-inch wells on the shore of Lake Erie, with a daily combined capacity of 1,000,000 gallons. Dug wells for private use are being supplanted by driven wells.

*Coshocton, Ohio.*—The public supply is from eighteen 6-inch wells 32 feet in depth, which reach about the level of the Tuscarawas River and obtain the supply from gravel.

*Dayton, Ohio.*—The public water supply is from about eighty 8-inch wells driven to a depth of 50 to 60 feet through alluvial and glacial sand and clays in Mad River Valley to a bed of gravel. The daily consumption in summer averages about 6,500,000 gallons, and for the year about 4,000,000 gallons. Length of mains about 100 miles. Chemical analyses are given in the tables on another page, and show the water to be rather hard. A bacteriological examination made by Dr. S. E. Allen, of Miami Medical College, showed no pathogenic germs, the varieties isolated being the perfectly harmless forms which exist in all water not artificially sterilized. The number of germs is exceedingly low, being but 48 per cubic centimeter.

*Defiance, Ohio.*—The public water supply is pumped mainly from Maumee River. Private wells are from two horizons, the shallow ones being but 10 to 15 feet and the deeper ones 40 to 50 feet in depth. Some of the former having shown evidence of

contamination, this class is regarded with suspicion. An analysis of a deep salt-water well appears on another page. The shallow wells have fresh water.

*Delaware, Ohio.*—The city water supply is from large wells located about 3 miles north of the city and excavated in gravel to a depth of 30 feet. In the city there are a number of springs of sulphur water. There is also a deep well, bored for natural gas, which furnishes water for a bath house under the direction of Dr. S. W. Fowler. Analyses of water from two of the springs are presented in the tables on another page. They show the samples to be a highly saline sulphureted water. The sulphureted hydrogen in Odovene spring, amounting to nearly 3 cubic inches per gallon, is entirely free, no sulphides occurring in the water except a minute trace of sulphide of iron in suspension. (Information furnished by C. W. Wiles, superintendent of waterworks, and by Dr. S. W. Fowler.)

*Dennison, Ohio.*—Dennison and Uhrichsville are practically one town, standing in the valley at the junction of Stillwater and Tuscarawas rivers. In Dennison the wells are 12 to 20 feet in depth, obtaining water from sand beneath yellow clay. In Uhrichsville the wells are usually deeper. Very few wells have been sunk since the waterworks were put in operation in 1888. The waterworks pumping station is on Big Stillwater River, above the towns, and the reservoir stands on a hill 265 feet above the level of the valley bottom. (Information given by E. Eckfeld.)

*Eaton, Ohio.*—The waterworks are located in a creek bottom one-half mile northwest of the corporation line. Ten 6-inch wells 75 to 85 feet deep are connected with the pumps. These furnish only 100,000 gallons per day, which is insufficient for the demands of the city. Recourse is had to spring water issuing at the foot of the bluff, which supplies about 100,000 gallons per day. The spring water has a temperature of 49°, while the well water stands at 56°. An analysis of the combined water is presented in the table of analyses. (Information furnished by W. C. Dove, superintendent of waterworks.)

*Elyria, Ohio.*—The public supply is pumped from Black River and is not satisfactory on account of the large amount of sediment. Private wells are of two classes: (1) Shallow wells in the drift, 10 to 30 feet in depth; (2) wells in sandstone, 60 to 90 feet in depth. The water in the former is not above suspicion, but from the latter source it is excellent, and the supply is abundant for private purposes. Whether a public supply could be obtained from this source has not been determined. (Information furnished by M. H. Levagood, mayor.)

*Findlay, Ohio.*—The public supply is pumped from Blanchard River, which runs through the city. The glacial drift is seldom of sufficient thickness to afford a supply for private wells, but water is often found in the underlying limestone at a depth of but 12 to 15 feet. In some cases the water is sulphurous, but is usually of pleasant taste. In some localities much discomfort is experienced on account of the saturation with oil, which escapes into the drift gravel from the oil wells.

*Franklin, Ohio.*—The public supply is from six 6-inch wells driven into the glacial drift of the Great Miami Valley. Prior to the introduction of this public supply, in 1887, shallow wells 20 to 30 feet deep were in use, which, it was thought, led to the prevalence of typhoid fever, but since the utilization of the deeper wells the town has experienced no run of typhoid fever. The following sanitary analysis of the waterworks supply was made by Prof. O. R. Stuntz, in April, 1887:

| | Parts in 100,000. |
|---|---|
| Total residue | 45.94 |
| Organic and volatile | 17.92 |
| Inorganic and nonvolatile | 28.02 |
| Free ammonia | 0.0016 |
| Albuminoid ammonia | 0.0021 |
| Chlorine | 1.04 |
| Hardness: Temporary, 8.51. | |
| Hardness: Permanent, 14.38. | |
| Hardness: Total, 22.89. | |

*Fremont, Ohio.*—The public water supply is mainly from the Sandusky River. Private wells are obtained in the drift at convenient depths, but there is suspicion of their contamination in many instances. An excellent quality of water may be obtained at a depth of 40 to 60 feet in the limestone. It is estimated that drilled wells of this class yield, in some cases, nearly 1,000 barrels per day. (Information furnished by Charles F. Reiff, superintendent of waterworks.)

*Gallipolis, Ohio.*—The public water supply is from wells sunk in the bed of the Ohio River. Four wells, 6 feet deep and 4 feet in diameter, extend down about 5 feet below extreme low water in a bar at the head of Gallipolis Island. The wells are cemented at top, so that when the river overflows them no water enters except that which comes up from beneath. The water is thus comparatively clear at times when the river carries much sediment. Water is pumped to a reservoir 314 feet above low water in the Ohio. The average daily consumption in summer is 300,000 gallons.

*Greenville, Ohio.*—The public supply is from nine 6-inch wells 52 to 62 feet in depth, which obtain their supply from glacial gravel at the base of the drift, there being limestone at the bottom of each of the wells. The average capacity of each well is about 5,000 barrels per day. A sanitary analysis made by Prof. C. R. Stuntz, of Cincinnati, in December, 1892, reports a large amount of free ammonia, as well as much organic matter. The organic matter is largely composed of peat, and it is recommended that the water should be filtered. One analysis is from a sample of the waterworks water, and the other from Greenville Creek, and the results are as follows:

| | Parts in 100,000 by weight. | |
|---|---|---|
| | Well water. | Creek water. |
| Total solids | 54.02 | 40.46 |
| Organic and volatile solids | 19.56 | 15.46 |
| Inorganic | 34.46 | 25.00 |
| Free ammonia | 0.1012 | 0.0034 |
| Albuminoid ammonia | 0.0034 | 0.072 |
| Chlorine | 0.45 | 0.19 |
| Temporary hardness (grains per United States gallon) | 16.61 | 5.39 |
| Permanent hardness (grains per United States gallon) | 12.76 | 11.95 |

(Information furnished by John P. Lucas, superintendent of waterworks.)

*Hamilton, Ohio.*—The city of Hamilton is supplied by a series of filter wells obtained at about the level of the Miami River in glacial gravel, the average depth being 45 feet. The capacity of the wells is practically inexhaustible, but they are pumped at a rate of about 3 barrels each per minute.

*Hillsboro, Ohio.*—The public supply is from gravel beds reached by twelve driven wells in the valley of Clear Creek, about 2½ miles north of the village. The supply is rather scanty, but probably sufficient if carefully husbanded. The town has a hilly situation, the Niagara limestone cropping out in places on the slope. The irregular surface is filled in by drift deposits from which some well water may be obtained. The source of supply, however, is looked upon with suspicion, as it may easily become contaminated. Wells in the rock range in depth from 10 to 50 feet. (Information furnished by Judge H. M. Huggins.)

*Hudson, Ohio.*—Hon. M. C. Read has published a paper upon the water supply of

Hudson and vicinity, in which it is shown that many shallow wells are obtained at the junction of the yellow and blue till at depths of 10 to 15 feet or less. This source of supply he considers dangerous, for the reason that the yellow clay in seasons of drought opens a series of fissures which readily admit the washings of the surface in showers following such droughts. As in underdraining clay lands the fissures will be opened more rapidly near the drains, on account of the earlier desiccation along them, so they will open up more rapidly for the same cause around the wells, and these will be put in complete communication with the network of openings reaching to the surface. In examining such wells Mr. Read has found centipedes, sow bugs, and earthworms by hundreds brought up in the first drawings of water after copious summer showers. They had sought moisture in the fissures of the clay, and the fact that they were uniformly carried in great numbers into the well when a dashing rain succeeded a long-continued drought shows how directly these fissures connected with the well. In view of these studies made by Mr. Read it can not be too strongly urged that in districts such as that around Hudson, where a drought may open fissures in the clay to the depth of the water-bearing stratum, special pains should be taken to guard against the use of such wells. Over much of northern and northwestern Ohio, where the surface is largely a compact clay, the dangers from this source are as great as at the village of Hudson, where the observations were made. Mr. Read has devised a double cistern, one apartment receiving the water and allowing it to filter through charcoal and gravel into the other apartment, from which the water is pumped. By occasional renewal of the filtering material and washing of the cistern he has been able at slight expense to obtain a supply of water as clear and sweet as the best spring water. In localities where pure well water can not be readily obtained this simple device may be easily employed for obtaining a pure quality of rain water.

*Ironton, Ohio.*—The city of Ironton obtains its supply by direct pumping from the Ohio River, and no private wells are in use. Because of the sediment carried by the river at certain seasons of the year many large cisterns have been constructed which are filled from the waterworks before the spring rise, while the water is clear. (Information furnished by John M. Corns, mayor.)

*Jackson, Ohio.*—The city of Jackson is very unfortunately situated for obtaining an adequate supply for waterworks. The nearest available supply appears to be Raccoon Creek, several miles distant, and the water of this stream is somewhat objectionable. The wells within the city usually obtain water at 18 to 25 feet, but a good well is estimated to have an average capacity of but 3 or 4 barrels per day. (Information furnished by Andrew Leach, mayor.)

*Kenton, Ohio.*—This city is supplied from a large well about 25 feet in diameter and 100 feet deep. With the exception of about 20 feet of drift, it was blasted from solid rock. The water stands at about the level of the top of the rock, and can be lowered only by excessive pumping. (Information furnished by Elmer G. Derr.)

*Lancaster, Ohio.*—The public supply is from springs, a sanitary analysis of which was furnished by Professor Welsh:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.003 |
| Albuminoid ammonia | 0.007 |
| Nitrous acid | 0.001 |
| Nitric acid | 0.108 |
| Chlorine | 1.840 |
| Total solids | 44.500 |

*Lima, Ohio.*—The public supply is from several wells drilled to a depth of 140 to 148 feet in limestone. The best well is pumping 800,000 gallons daily. Average daily consumption exceeds 1,000,000 gallons. Private wells furnish only a small portion of the domestic supply, for it is usually necessary to drill into the rock, and thus incur much expense, to obtain a good supply of water. (Information furnished by H. B. Hackedon, superintendent of waterworks.)

*London, Ohio.*—The city of London obtains a large supply of excellent water from flowing wells at about 150 feet in the glacial drift. There are three 6-inch and two 8-inch wells, with a united capacity of about 800,000 gallons per day. Many strong wells are obtained at shallower depths, but the head is not so great as in the deeper ones. (Information furnished by J. M. Boyer.)

*Lynchburg, Ohio.*—Through the village of Lynchburg there is a gravelly belt, estimated to have an average width of about one-fifth mile, in which an abundance of water may be obtained at depths of 15 to 20 feet. On either side of this belt limestone is struck at slight depth and only weak wells are obtained. The waterworks obtain a supply from this gravel belt. Its well is 16 by 20 feet, and reaches rock. (Information furnished by Manual of American Waterworks and by Daniel Murphy, county surveyor.)

*Mansfield, Ohio.*—The public supply is from a series of flowing wells 100 to 140 feet in depth, located in a valley adjoining the city, and which discharge water into a reservoir. It is thought that an adequate supply may be obtained by increasing the number of these wells. It is proposed to sink a sufficient number to afford 2,000,000 gallons per day. (Information furnished by R. B. McCrary, mayor.)

*Marietta, Ohio.*—Although the waterworks supply is obtained from the Ohio River, many wells, both public and private, are in use which obtain water in gravel at depths of 30 to 90 feet. There is a suspicion of considerable contamination, and the use of such wells is decreasing. (Information furnished by J. B. West, superintendent of waterworks.)

*Marion, Ohio.*—The public water supply is obtained from a gravel pit in Little Scioto Valley, about 2 miles west of the city, at a level about 65 feet below the general level of the city. About 2 acres of ground were excavated to a sufficient depth to form a pool. Test borings indicate that the gravel extends 50 or 60 feet below this level and is filled with an excellent quality of water. The water is used satisfactorily by the railways for locomotives, there being less than 14 grains of carbonate of lime per gallon. (Information furnished by H. C. Stillwell, superintendent of waterworks.)

*Massillon, Ohio.*—The city of Massillon is chiefly supplied from a series of flowing wells drilled into the sandstone, some of which are 100 to 150 feet in depth. Water for domestic use is also obtained from Sippo Lake. The wells have an average capacity of about 500,000 gallons each per day. The water is remarkably hard, considering its derivation from a sandstone rock, there being, as shown by the analysis in the tables, 12.65 grains of carbonate of lime per gallon. (Information furnished by A. W. Inman, superintendent of waterworks.)

*Mechanicsburg, Ohio.*—The village of Mechanicsburg depended entirely upon open wells for domestic supply until 1892, when wells were driven to a bed of gravel below the bowlder clay. The greater part of the supply is still obtained from open wells, and an epidemic of typhus which prevailed in 1894 is thought to have resulted from the use of such wells. (Information furnished by T. E. Burnham.)

*Mount Vernon, Ohio,*—The waterworks supply is obtained from twenty-four flowing wells, 2 to 6 inches in diameter, driven to depths of 63 to 97 feet in the glacial drift. A 6-inch well is estimated to have an average capacity of about 100 gallons per minute, or nearly 150,000 gallons per day. The water is chalybeate as well as hard. A well drilled into the rock at Mount Vernon obtained a flow of brackish water unsuitable for use by the waterworks. The following sanitary analysis of water from the wells in the drift was made by Professor Lord, of the State University:

Free ammonia, 0.017 parts in 100,000.
Albuminoid ammonia, traces.
Chlorine, 0.35 grains per United States gallon.
Total solids, 16.0 grains per United States gallon.
Combustibles, 2.0 grains per United States gallon.
Hardness, 11.5.

*Napoleon, Ohio.*—In the portion of the town lying between the Maumee River and Canal water is obtained at a depth of 15 to 30 feet. In the remainder of the town wells are usually obtained in the rock at a depth of 110 to 130 feet. Many of the wells in rock have a sulphurous water which is not pleasant for drinking. For this reason filtered cistern water is used by a large per cent of the people. The waterworks and electric lighting are in one plant, run by the same machinery and a single set of employees. The cost of the plant was $60,000, but how much of this should be charged to water supply is not known. (Information furnished by Charles Evens.)

*Nelsonville, Ohio.*—The public water supply is obtained from a large well sunk to a depth of 25 feet in the gravel of the Hocking River Valley at a distance of 200 yards from the stream. There is very free movement of water through this gravel, and the supply is inexhaustible. Private wells are largely abandoned since the construction of the waterworks.

*Newark, Ohio.*—The public water supply is from large wells excavated at the bank of the north fork of Licking River, in the northern part of the city. The water is considered very pure and wholesome. It is rather hard, there being about 20 grains of carbonate of lime per gallon. (Information furnished by William A. Veach, receiver for company.)

*New Lisbon, Ohio.*—The public water supply is from two sources, about 25 per cent being pumped from wells drilled into the sandstone rock and the remainder stream water. The water from the stream is carried by gravitation into a large cistern into which also the well water is pumped. The entire supply is then forced to a reservoir on a hill standing about 200 feet above the pumping station. One pump is arranged to force water direct from the pumping station through the mains. The wells have an average capacity of about 40,000 gallons each per day. (Information furnished by I. M. Dickenson, mayor.)

*New Philadelphia, Ohio.*—The public water supply is from a series of wells in the Tuscarawas River bottom, driven about to the level of the river bed. A few wells have been sunk to a depth of 25 or 30 feet below the river bed, and it is thought that the supply from this source is not so hard as that found at the level of low-water mark. The water is pumped to a reservoir on a hill adjacent to the town. Private wells are obtained at about the level of the river and vary from 20 up to 50 feet, according to the elevation of the surface. (Information furnished by Joseph Welty.)

*New Straitsville, Ohio.*—This village is built upon the slope of a hill about 150 feet in height, and the wells are obtained from several different horizons. In some cases the water is strongly impregnated with iron and sulphur, especially that found below "Coal No. VI." Surface water is collected in reservoirs for mining industries and iron furnaces, and in cisterns for fire purposes.

*Niles, Ohio.*—This city obtains its public water supply from nine wells sunk to a depth of 50 feet in glacial deposits. The combined capacity is about 500,000 gallons per day.

*Oberlin, Ohio.*—The public water supply is pumped from the east branch of Vermilion River, at Kipton, six miles distant. An analysis of the river water made at the end of a dry season, September, 1886, gave the following results:

Total solids, 35.35 grains per gallon.
Hardness, 32.66 degrees.
Hardness after a rain, 12 degrees.
Free ammonia, 0.0094 parts in 1,000,000.
Albuminoid ammonia, 0.02 parts in 1,000,000.

Many private wells are in use which obtain water from sandy layers between the yellow and blue till, at depths of 8 to 12 feet, and in the gravel beds at lower depths in the drift. Near the west part of the town the Berea grit is within 3 to 6 feet of the surface, and wells are there drilled some distance into the rock. The well water has occasionally been found to show contamination in the series of

analyses made by Professor Jewett. In one case contamination by a cesspool was certain. In thirteen analyses of water suspected to be bad, made by Professor Jewett, the amount of free ammonia was found to vary from 0.001 part in 100,000 to 0.033 parts. The albuminoid ammonia ranged from 0.005 to 0.027 parts in 100,000. The amount of chlorine in grains per gallon ranged from 0.80 to 16.10, the latter being the amount in a well known to be contaminated by a cesspool. The average amount of chlorine in the thirteen analyses is 6.43 grains per gallon. As all these waters were selected for their known badness they can scarcely be considered representative, but they serve to indicate that there is danger arising from the use of the shallow wells. (Information furnished by Prof. A. A. Wright.)

*Ottawa, Ohio.*—No public water supply is yet introduced, but the city has a system of fire cisterns supplied from Blanchard River. There are also a few "town wells" which contain water from limestone at a depth of about 130 feet. The private wells are often obtained at depths of 10 to 35 feet, from gravel beds in the glacial drift. Quite a number of private wells are drilled into the rock, which is entered at about 70 feet from the surface. (Information furnished by T. J. Sweeney, mayor.)

*Plain City, Ohio.*—The public water supply is obtained from two artesian wells 500 feet in depth, which yield an unlimited amount of slightly sulphurous water, not unpleasant for drinking. This water is rapidly displacing the use of private wells, which were obtained at depths of 7 to 13 feet and are liable to surface contamination. (Information furnished by G. M. Russell, postmaster.)

*Piqua, Ohio.*—The public water supply is obtained through a somewhat expensive canal and basin system, supplied by Miami River, the cost of the system of canals and basins being $260,000. The canal is 6 miles in length, and the basins are of different sizes, one basin containing 40 acres, another 11, and another 3, and there are smaller ones. The quality of water is thought to be excellent. Private wells are obtained at depths of 10 to 24 feet, in beds of gravel. In some cases these wells are thought to be liable to contamination. An artesian well boring demonstrates that water will rise to about the level of the Miami Canal, but the head is scarcely sufficient to cause a flow at the general level of the city. (Information furnished by James Ward Keyt, mayor.)

*Pomeroy, Ohio.*—This city has no public water supply, principally because of the great indebtedness. A few wells, 60 to 65 feet in depth, are in use, but the greater part of the water supply is from cisterns filled from roofs of buildings. (Information furnished by E. R. Davenport, city engineer.)

*Portsmouth, Ohio.*—The public water supply of the city is obtained by direct pumping from the Ohio River. Very few private wells are in use, it being necessary to sink usually to a depth of 60 to 100 feet to obtain a supply.

*Ravenna, Ohio.*—The greater portion of the public water supply is pumped from a lake having an area of about 30 acres. This being inadequate, a system of wells have been sunk on the margin of the lake, which obtain an excellent quality of water, at a depth of about 150 feet in a bed of gravel at the base of the glacial drift. (Information furnished by D. C. Coolman, postmaster.)

*Ripley, Ohio.*—A system of waterworks was put in in 1896, which will obtain its supply from the Ohio River. The water is first pumped to two settling basins and from these to a reservoir on the bluff, about 300 feet above the river. Several private wells in Ripley reach depths of 85 to 90 feet without entering rock. An artesian well, made near the base of the bluff, obtains a salt water containing a considerable amount of lithium carbonate. The analysis is given in the tables. (Information furnished by Dr. W. A. Dixon.)

*St. Marys, Ohio.*—The public water supply is from four 8-inch wells about 280 feet in depth, sunk into the limestone, and which have a combined average daily capacity of 2,000,000 gallons. The water will rise to a height of 12 feet above the surface. It is very hard and has a small amount of sulphur and iron, but is of excellent quality. Wells of this class may be obtained over an area of several square miles in the vicinity of St. Marys, and many have been made by the farmers. The water

supply from the drift is of good quality and usually adequate for private wells. (Information furnished by O. E. Dunan.)

*Sandusky, Ohio.*—The public supply is pumped from Sandusky Bay. A private company has springs located about 6 miles west of the city, which furnish a small amount of excellent water. The use of private wells is almost discontinued. (Information furnished by Charles Judson, C. E., superintendent of waterworks.)

*Sidney, Ohio.*—The public water supply is pumped mainly from Great Miami River, and is of excellent quality. There are many private wells which also furnish a good quality of water. The open wells have a depth of 12 to 30 feet, and drilled wells a depth of 100 to 200 feet. (Information furnished by H. S. Ailes, mayor.)

*Springfield, Ohio.*—The public water supply is obtained from wells sunk into glacial gravel. There are also many private wells. The depth of wells in the higher part of the town is about 40 feet, but in the lower part is 15 to 20 feet. Usually water is obtained without entering rock, but in parts of the city the rock stands within 5 feet of the surface and wells there must be drilled. An analysis of the city water is given in the tables. (Information furnished by W. H. Linn, city engineer.)

*Steubenville, Ohio.*—A waterworks plant was put in at this city in 1836 and enlarged in 1865 on the old site. An entire new plant was built in 1894. Two reservoirs are constructed at different elevations. The higher one has a line of pipes connected with it which are used for fire; the lower one is used for domestic purposes. It is probably one of the most complete systems in the State. There is a pumping capacity of 6,000,000 gallons, a reservoir capacity of 7,000,000 gallons, and a daily consumption of about 2,500,000 gallons. (Information furnished by David McGowan.)

*Tiffin, Ohio.*—The public water supply is obtained partly from the Sandusky River, but recently seven 10-inch wells have been sunk into the rock, which furnish a combined average yield of about 800,000 gallons per day. Several factories and many private parties have wells sunk into the rock to depths of 70 to 90 feet. (Information furnished by Mr. M. Scannell, manager Tiffin waterworks.)

*Toledo, Ohio.*—The public water supply is pumped from the Maumee River. For some time after the construction of the waterworks a prejudice against using what was called hydrant water was felt, but it is now rapidly taking the place of all other water supplies, and nearly 50 miles of additional pipe has been laid since 1892, making 128 miles in all. The private wells were largely of shallow depth and as the sewerage system was developed their supply was drained, thus making it necessary either to sink deeper wells or use the hydrant water. The quality of the public water supply is considered to be such that no danger is attached to its use. (Information furnished by T. R. Cook, superintendent of waterworks.)

*Troy, Ohio.*—The public water supply is obtained from two open and five driven wells located in the Miami Valley just above the city. The open wells are 30 feet in depth and the driven wells 40 to 50 feet. The average combined capacity is estimated to be about 2,000,000 gallons per day. The water is of excellent quality, the only objectionable feature being its hardness. (Information furnished by A. T. Beedle, superintendent of waterworks.)

*Urbana, Ohio.*—The public water supply is from an open well 21 feet in depth and 20 feet in diameter, excavated in glacial gravel, and from eight 6-inch driven wells. They are estimated to yield 1,000,000 gallons or more per day. There are several manufactories that use outside supplies. The Artificial Ice Company have three wells 28 feet in depth, which supply about 450,000 gallons per day. The Urbana Strawboard Works have two wells 12 feet in depth and 6 feet in diameter, which supply about 500,000 gallons per day. The Ohio Strawboard Works have wells which supply their daily consumption of about 1,000,000 gallons. Impounded water from springs and brooks in the east part of the city supply the railway locomotives. There are many other wells for domestic and manufacturing purposes whose yield is not estimated.

The city is, therefore, richly supplied with water at shallow depths. A gas-well boring obtains a supply of water from a depth of 275 feet in a limestone formation. The capacity is estimated at 100,000 to 150,000 gallons per day. It has a head 33 feet above the level of the Pan Handle railway station, or about 1,060 feet above tide. (Information furnished by Dr. Thomas F. Moses.)

*Van Wert, Ohio.*—The city water supply is from wells sunk into the limestone to depths of 125 to 175 feet. The head is within 10 feet of the surface, but a pump of 1,500,000 gallons daily capacity has lowered six 6-inch wells 26 feet, continuous pumping ten hours. An analysis of water from these wells is presented in the tables. There are many private wells still in use which obtain water at about 20 feet, in beds of gravel beneath clay. (Information furnished by James F. Higgins, mayor.)

*Wapakoneta, Ohio.*—The public water supply is derived from nine 6-inch wells, varying in depth from 35 to 143 feet. The water from all the wells rises to the surface of the ground. The average capacity of each well is about 200 gallons per minute. The deeper wells reach the bottom of the drift, but do not penetrate the limestone. The following sanitary analysis, made by the State board of health, is from a sample taken from a well 45 feet in depth:

| | Parts 100,000. |
|---|---|
| Oxygen required | 0.10 |
| Free ammonia | 0.041 |
| Albuminoid ammonia | 0.003 |
| Organic ammonia | 0.005 |
| Nitrous acid | None. |
| Nitric acid | 0.024 |
| Chlorine | 0.30 |
| Total solids | 46.40 |
| Hardness { Temporary, 34.40. | |
| Permanent, 6.60. | |
| Total, 41.00. | |

(Information furnished by J. Wilson, jr., trustee waterworks board.)

*Wellington, Ohio.*—The village of Wellington has not been successful in obtaining an adequate supply from wells, although several borings have been sunk in that vicinity to depths of 500 to 1,000 feet. The drift, about 100 feet in depth, furnishes only weak wells. The only recourse for public supply appears to be that of impounding water.

*Wellsville, Ohio.*—The cities of Wellsville and East Liverpool obtain most of their water supply by pumping from the Ohio River, there being only a few wells and cisterns. Wells are obtained usually at a depth of 35 to 45 feet, except on the higher parts of the bottom land, where a depth of 60 to 70 feet or more is necessary to reach the level of the river. (Information furnished by O. C. Sinclair, mayor.)

*West Union, Ohio.*—This town is situated upon a high hill, around the margin of which numerous springs of hard water issue, which are utilized by the residents. Wells are 10 to 30 feet in depth and obtain water in the limestone. A good well is estimated to have an average capacity of 20 barrels per day. (Information furnished by J. H. Connor, postmaster.)

*Wilmington, Ohio.*—Two classes of wells are in use in this city—open wells sunk to a depth of 20 or 30 feet, and bored or drilled wells with a depth of 60 to 100 feet. Some of the latter class of wells overflow. The water is obtained from sand or gravel near the base of the glacial drift or at slight depth in the underlying limestone.

*Wooster, Ohio.*—Several sources of water supply are in use, and the public supply is from two distinct sources. One reservoir is filled by pumping water impounded from a small stream; another is filled from a large well. The private wells are of two classes—open wells dug to a depth of 14 to 20 feet, and drilled wells with a

depth of 80 to 140 feet. The following sanitary analysis is from a sample taken from the pond used to fill one reservoir:

| | Parts in 100,000. |
|---|---|
| Free ammonia | 0.013 |
| Albuminoid ammonia | 0.036 |
| Nitrates | None. |
| Nitrites | None. |
| Chlorine | 0.71 |
| Sulphureted hydrogen | None. |

Turbidity, very marked.
Color, yellowish.
Taste and odor, slight.

Other analyses have been made which vary somewhat from the above, but copies are not at hand. (Information furnished by C. E. Thorn.)

*Xenia, Ohio.*—The public water supply since 1887 has been from a series of springs located on the borders of the city. These for some years yielded about 1,000,000 gallons per day but in the drought of 1894 and 1895 their flow became reduced to one-tenth that amount. Prospect borings for water near the springs failed to develop any adequate supply. The private wells are of various depths, ranging from 10 to 80 feet. They are largely obtained in gravel near the base of the glacial drift. In some cases they are liable to contamination because of insufficient cover. The need of a more adequate public supply is very great.

*Youngstown, Ohio.*—The city obtains its public supply by pumping from the Mahoning River. For high service a standpipe is used, but for low service direct pressure. Many wells have been drilled in the vicinity of this city which obtain a slightly brackish water, unpleasant for drinking. Shallow wells on the uplands often obtain a good quality of water at convenient depths. Those in the valley are in many cases liable to contamination, and their use is largely discontinued. (Information furnished by W. S. Hamilton, superintendent of waterworks.)

*Zanesville, Ohio.*—The public supply is pumped from the Muskingum River to a reservoir on the bluffs. An analysis of the water is given in the tables. Many private wells are in use, which usually obtain water in gravel or sand. The Artificial Ice Company obtains a supply from a well 66 feet in depth. An analysis of its water appears in the tables.

## RAINFALL.

At the close of the year 1895 the State weather service of Indiana maintained twenty-six points of observation of precipitation, so distributed as to represent fairly well all parts of the State. The following summary of available records, prepared under the direction of Prof. H. A. Huston, director of the State weather service, appeared in his monthly report for December, 1895. It includes, with the observations for the State weather service, all the reliable records published prior to the organization of that service.

It will be observed that the normal annual precipitation for the State for an average period of fourteen years is 39.57 inches, and that there is a steady decrease from south to north in the amount of precipitation, there being in the southern part 43.57 inches, in the central part 38.15 inches, while in the northern part there is but 35.49 inches. This decrease in amount of rainfall from south to north affects the neigh-

boring States on the west (Illinois and Iowa) and extends northward beyond the national boundary. As shown below, it is not so perceptible in Ohio.

*Table of precipitation in Indiana.*

[From report of director of State weather service, 1895.]

| Place of observation. | Number of years. | Normal. | Greatest annual amount. | Year. | Least annual amount. | Year. |
|---|---|---|---|---|---|---|
| | | *Inches.* | *Inches.* | | *Inches.* | |
| Mount Vernon | 8 | 44.91 | 57.15 | 1890 | 36.09 | 1894 |
| Princeton | 12 | 39.56 | 56.96 | 1890 | 27.95 | 1887 |
| Marengo | 13 | 64.20 | 97.38 | 1890 | 44.29 | 1886 |
| Vevay | 30 | 44.52 | 60.33 | 1883 | 26.53 | 1895 |
| Butlerville | 10 | 43.41 | 52.69 | 1890 | 32.72 | 1895 |
| Worthington | 13 | 42.21 | 54.78 | 1883 | 32.73 | 1895 |
| Seymour | 8 | 41.97 | 49.88 | 1890 | 33.43 | 1894 |
| Columbus | 12 | 37.77 | 46.07 | 1890 | 27.08 | 1894 |
| Madison | 2 | 37.86 | 40.16 | 1894 | 35.54 | 1895 |
| Terre Haute | 2 | 30.01 | 32.70 | 1895 | 29.32 | 1894 |
| Cambridge City | 3 | 36.57 | 47.87 | 1893 | 28.41 | 1895 |
| Huntington | 2 | 26.22 | 27.61 | 1894 | 24.83 | 1895 |
| Valparaiso | 3 | 33.04 | 35.67 | 1894 | 30.42 | 1895 |
| Kokomo | 3 | 31.33 | 36.15 | 1893 | 27.42 | 1894 |
| Marion | 10 | 31.02 | 36.60 | 1893 | 22.61 | 1895 |
| Jeffersonville | 7 | 43.05 | 58.33 | 1890 | 36.86 | 1895 |
| Connersville | 13 | 39.09 | 50.99 | 1890 | 23.68 | 1895 |
| Indianapolis | 24 | 44.16 | 57.33 | 1876 | 34.13 | 1894 |
| Mauzy | 15 | 41.10 | 57.31 | 1888 | 27.05 | 1895 |
| Logansport | 11 | 38.17 | 43.62 | 1885 | 25.97 | 1895 |
| Rockville | 8 | 37.09 | 43.58 | 1890 | 29.53 | 1894 |
| Farmland | 13 | 39.63 | 51.21 | 1890 | 28.47 | 1894 |
| Lafayette | 16 | 38.05 | 47.21 | 1882 | 27.01 | 1895 |
| Delphi | 10 | 36.83 | 49.98 | 1890 | 26.23 | 1895 |
| Columbia City | 10 | 35.50 | 42.34 | 1890 | 26.26 | 1895 |
| Angola | 11 | 36.57 | 42.20 | 1890 | 31.06 | 1894 |
| Northern portion | 12 | 35.49 | 43.77 | 1892 | 26.60 | 1895 |
| Central portion | 12 | 38.15 | 47.05 | 1890 | 29.38 | 1895 |
| Southern portion | 12 | 43.57 | 60.10 | 1890 | 35.61 | 1894 |
| State | 14 | 39.57 | 50.86 | 1883 | 30.99 | 1895 |

In Ohio at the close of 1895 nearly one hundred and fifty independent observers sent in reports to the State climate and crop service. About one-third of these stations have maintained systematic observations for an average period of eleven years, the length of period varying from five years to twenty-five at the different stations. The normal

annual precipitation for the State for the thirteen years prior to 1896 is 37.87, or 1.7 inches less than in Indiana. The average of greatest annual precipitation for the stations is 42.65 inches, and the average of least precipitation is 31.02 inches, thus giving a range of 11.63 inches in the amount of annual precipitation. The greatest annual precipitation noted at any station is 65.39—at Demos, in Belmont County, in the year 1890. The least annual precipitation noted at any station is 20.50 inches—at Celina, in Mercer County, in 1895.

The following table, taken from the report of the director of the Ohio section of the Weather Bureau for 1895, illustrates the above statements and presents the normal rainfall, the range in rainfall, and years of record for each station where observations have been long maintained. It will be observed that the northern section has on the whole a decidedly lower normal rainfall than the middle and southern sections. But certain stations, such as Canton, Hiram, and Garrettsville, have a rainfall much above the normal for the State. The cause for such exceptionally high rainfall is not apparent, nor is the low rainfall at Dayton, Celina, and Springboro.

*Table of precipitation in Ohio.*

[From report of director of State climate and crop service, 1895.]

| Place of observation. | Number of years. | Normal. | Greatest annual amount. | Year. | Least annual amount. | Year. |
|---|---|---|---|---|---|---|
| *Southern section.* | | *Inches.* | *Inches.* | | *Inches.* | |
| Athens | 6 | 37.80 | 49.10 | 1890 | 32.86 | 1894 |
| Cincinnati | 25 | 39.23 | 54.67 | 1880 | 26.59 | 1894 |
| Circleville | 5 | 33.18 | 39.57 | 1888 | 26.40 | 1895 |
| Clarksville | 9 | 39.00 | 47.70 | 1893 | 31.88 | 1889 |
| Dayton | 13 | 35.77 | 46.97 | 1883 | 26.78 | 1889 |
| Hanging Rock | 13 | 41.99 | 60.22 | 1890 | 32.52 | 1895 |
| Logan | 12 | 42.65 | 58.69 | 1890 | 32.69 | 1895 |
| Marietta | 13 | 41.28 | 60.99 | 1890 | 26.61 | 1895 |
| McConnellsville | 12 | 39.14 | 54.22 | 1890 | 29.35 | 1895 |
| Portsmouth | 11 | 41.54 | 56.08 | 1890 | 31.24 | 1895 |
| Springboro | 5 | 34.14 | 45.92 | 1890 | 25.95 | 1895 |
| Waverly | 12 | 38.69 | 53.58 | 1890 | 25.26 | 1895 |
| Waynesville | 7 | 39.50 | 48.28 | 1893 | 28.27 | 1895 |
| *Middle section.* | | | | | | |
| Celina | 8 | 32.41 | 41.67 | 1890 | 20.58 | 1895 |
| Columbus | 17 | 39.28 | 51.30 | 1882 | 28.50 | 1889 |
| Demos | 6 | 38.03 | 65.39 | 1890 | 27.85 | 1894 |
| Greenville | 10 | 36.58 | 43.71 | 1888 | 22.03 | 1894 |
| Kenton | 7 | 38.59 | 50.65 | 1890 | 26.10 | 1895 |

*Table of precipitation in Ohio*—Continued.

[From report of director of State climate and crop service, 1895.]

| Place of observation. | Number of years. | Normal. | Greatest annual amount. | Year. | Least annual amount. | Year. |
|---|---|---|---|---|---|---|
| *Middle section*—Cont'd. | | *Inches.* | *Inches.* | | *Inches.* | |
| New Alexandria | 11 | 41.89 | 58.53 | 1890 | 31.95 | 1887 |
| New Comerstown | 10 | 41.04 | 62.79 | 1890 | 28.67 | 1895 |
| North Lewisburg | 13 | 40.15 | 49.50 | 1893 | 28.95 | 1895 |
| Ohio State University | 13 | 37.26 | 50.47 | 1890 | 26.95 | 1895 |
| Westerville | 10 | 37.96 | 49.24 | 1890 | 28.80 | 1895 |
| *Northern section.* | | | | | | |
| Akron | 9 | 37.95 | 53.09 | 1890 | 31.05 | 1894 |
| Ashland | 7 | 35.90 | 49.00 | 1890 | 26.97 | 1894 |
| Canton | 12 | 39.30 | 54.52 | 1890 | 31.29 | 1894 |
| Cleveland (W. B.) | 24 | 36.56 | 51.51 | 1878 | 27.09 | 1895 |
| Cleveland (Hyde) | 13 | 37.30 | 49.35 | 1890 | 29.73 | 1895 |
| Ellsworth | 5 | 32.66 | 37.45 | 1888 | 28.18 | 1895 |
| Findlay | 6 | 36.56 | 42.75 | 1890 | 29.28 | 1894 |
| Garrettsville | 7 | 40.03 | 53.81 | 1890 | 33.86 | 1895 |
| Gratiot | 6 | 39.04 | 57.52 | 1890 | 28.69 | 1894 |
| Hiram | 13 | 40.49 | 51.33 | 1890 | 30.34 | 1886 |
| Lordstown | 6 | 34.80 | 49.43 | 1890 | 28.72 | 1895 |
| Oberlin | 13 | 33.27 | 45.91 | 1890 | 25.01 | 1894 |
| Orangeville | 5 | 34.33 | 46.36 | 1890 | 24.97 | 1894 |
| Sandusky | 18 | 34.75 | 46.37 | 1881 | 24.89 | 1889 |
| Tiffin | 7 | 33.65 | 45.57 | 1890 | 27.27 | 1889 |
| Toledo | 25 | 31.02 | 45.91 | 1881 | 21.33 | 1894 |
| Upper Sandusky | 12 | 36.74 | 48.03 | 1890 | 31.67 | 1886 |
| Wauseon | 23 | 36.86 | 52.55 | 1892 | 28.49 | 1888 |
| Wooster | 11 | 34.49 | 54.21 | 1890 | 31.32 | 1894 |
| Youngstown | 11 | 33.52 | 50.93 | 1890 | 26.20 | 1887 |
| Southern section | 13 | 38.53 | ..... | ..... | ..... | ..... |
| Middle section | 10.5 | 38.32 | ..... | ..... | ..... | ..... |
| Northern section | 12 | 35.96 | ..... | ..... | ..... | ..... |
| State | ..... | 37.87 | ..... | ..... | ..... | ..... |

There is a sufficient amount of precipitation, and the precipitation is so well distributed throughout the year, both in Indiana and Ohio, that droughts of disastrous effect are rare. Usually the soil is sufficiently pervious to absorb a large portion of the precipitation and yield it at the needed times to the growing crops. There are, however, portions of both States where a compact white clay soil prevents the absorption

of moisture. In such localities the surface also is usually very level and the tracts are poorly drained. As a consequence the land is flooded in rainy seasons and baked in seasons of drought. The portion of Indiana most seriously affected in this way lies outside the limits of the newer drift, in the southeastern corner of the State. It embraces southwestern Franklin, southeastern Decatur, Jennings, Ripley, Dearborn, and Jefferson counties, and the water partings in Ohio and Switzerland counties. A smaller district is found on the western border of the State in Clay, Vigo, and Sullivan counties. In Ohio the most extensive district is found in Clermont, Brown, Clinton, and portions of border counties in the southern part of the State. The problem of opening these soils and rendering them permeable to moisture and air is one of great agricultural importance.

There are small areas where the soil allows the water to pass downward beyond the extent of vegetation. Such are the gravel and sand plains which border many of the valleys in the northern and western parts of Indiana and the southern part of Ohio. The situation of these tracts is usually favorable for irrigation, as they are found on the lowlands. It is thought that by the use of irrigation in seasons of drought the value of such lands may be greatly increased, and that the returns will more than meet the expense.

# NEW DEVELOPMENTS IN WELL BORING AND IRRIGATION IN EASTERN SOUTH DAKOTA, 1896.

BY

NELSON HORATIO DARTON.

# CONTENTS.


| | Page. |
|---|---|
| Introduction | 567 |
| Progress in well sinking in 1896 | 568 |
| Brule County | 568 |
| Charles Mix County | 570 |
| Aurora County | 572 |
| Buffalo County | 573 |
| Jerauld County | 573 |
| Sanborn County | 574 |
| Davison County | 575 |
| Hanson County | 579 |
| Hutchinson County | 580 |
| Bonhomme County | 586 |
| Yankton County | 587 |
| West of the Missouri River | 587 |
| New light on extent of artesian basin | 590 |
| New light on pressure and head | 591 |
| New light on location of bed rock | 592 |
| Irrigation by artesian waters in 1896 | 597 |
| Aurora County | 597 |
| Beadle County | 598 |
| Bonhomme County | 598 |
| Brule County | 598 |
| Davison County | 600 |
| Douglas County | 602 |
| Hanson County | 602 |
| Hutchinson County | 603 |
| Jerauld County | 604 |
| Sanborn County | 604 |
| Spink County | 605 |
| Yankton County | 606 |
| Temperature of the deeper artesian waters | 606 |
| Chemical analyses | 611 |
| Volume of flow | 613 |

# ILLUSTRATIONS.


| | | Page. |
|---|---|---|
| PLATE XXXVIII. | Logs of artesian wells in Charles Mix County | 570 |
| XXXIX. | Lake supplied by artesian well at Newark, South Dakota | 572 |
| XL. | Logs of artesian wells in Aurora County, South Dakota | 574 |
| XLI. | Logs of artesian wells in Davison County, South Dakota | 576 |
| XLII. | Logs of artesian wells in Hutchinson County, South Dakota | 584 |
| XLIII. | Boring outfit at well on Rosebud Indian Reservation, Meyer County, South Dakota | 590 |
| XLIV. | Map showing rates of increase of underground temperatures in deep wells in eastern South Dakota and North Dakota | 608 |
| XLV. | Contour map of bed-rock surface in a portion of the Dakota artesian basin | 610 |
| XLVI. | Bed-rock surface at Deadwood, South Dakota, showing Potsdam sandstone lying on pre-Cambrian schists | 612 |
| XLVII. | Map of portion of Dakota artesian basin showing relative volume of flows from wells now flowing | 614 |
| FIG. 78. | Log of well on Carpenter farm near Pukwana, South Dakota | 568 |
| 79. | Outline map of Brule County, South Dakota, showing location of artesian wells, with their depths and yield in gallons per minute | 569 |
| 80. | Log of artesian well at Crow Creek Agency, on the Missouri River, Buffalo County, South Dakota | 573 |
| 81. | Log of well on farm of H. K. and E. O. Ashmore, near Artesian, South Dakota | 575 |
| 82. | Logs of artesian wells at Hutterische Colony and at Scotland, Bonhomme County, South Dakota | 587 |
| 83. | Log of artesian well at Cheyenne Agency, Dewey County, South Dakota | 588 |
| 84. | Log of boring on Rosebud Reservation | 589 |
| 85. | Log of boring at De Smet, South Dakota | 595 |

# NEW DEVELOPMENTS IN WELL BORING AND IRRIGATION IN EASTERN SOUTH DAKOTA, 1896.

By NELSON HORATIO DARTON.

## INTRODUCTION.

During the year 1896 there was considerable progress in the sinking of wells and the application of well waters to irrigation in South Dakota. In a preliminary report issued last year[1] an account was given of all available data obtained up to the end of 1895. For some counties it was not possible to obtain complete lists of wells, nor to give full accounts of irrigation operations. In the present report an endeavor will be made to place on record the greater part of the supplemental information. A large part of the data was obtained by correspondence with well-owners and well-drillers, but Maj. F. F. B. Coffin also made a partial canvass of some of the counties in the southeastern section of the State. In a further scanning of the data from the wells it was found that the temperatures of the waters indicated an underground thermal condition throughout the artesian basin, with rapidly increasing intensity in a portion of the Missouri Valley. This subject is one of so much interest that it has been thought advisable to elaborate the information as fully as possible and set it forth in a chapter and plates in this report.

The question of the volume of the waters is one that was not very fully treated in the Preliminary Report, so that some further consideration has been given to this line of inquiry.

Owing to the relatively rainy season of 1896, interest in irrigation has not been so great as in some of the preceding years, and there has been a corresponding decrease of activity in well-sinking. Nevertheless, quite a large number of farmers have continued to irrigate with marked success. Wells have been sunk, and there are plans for active irrigation in the summer of 1897. The greatest number of wells have been sunk in Davison, Hutchinson, and Brule counties. There are several new wells in Charles Mix, and others in Bonhomme, Sanborn, Hanson, Davison, Aurora, Jerauld, Yankton, and possibly some other counties, and the Government has sunk some remarkable wells along the Missouri River at Cheyenne, Crow Creek, and Yankton Indian agencies. Much progress has been made with the boring on the Rosebud Reservation, but a flow has not yet been reached.

[1] Preliminary report on artesian waters of a portion of the Dakotas: Seventeenth Ann. Rept. U. S Geol. Survey, Part II, Economic Geology and Hydrography, 1896, pp. 1–92, Pls. LXIX–CVII.

## PROGRESS IN WELL SINKING IN 1896.

### BRULE COUNTY.

To the numerous wells in this county others were added in 1896. One of the most remarkable was sunk on the Carpenter farm, near Pukwana, in sec. 35, T. 104, R. 70. Its depth is 907 feet, diameter 10 inches, and flow 1,386¼ gallons per minute. Flows were reported at 546, 845, and 870 feet. The water rises 6 inches above the top of the tubing, and its closed pressure is estimated to be about 60 pounds to the square inch. The water is somewhat saline, but it is no doubt in every way satisfactory for the extensive irrigation operations for which it is intended. The cost of the well was $5,200. Its altitude is about 40 feet above the railroad station. The "log," as given by Mr. J. S. Sanborn, is reproduced in fig. 78.

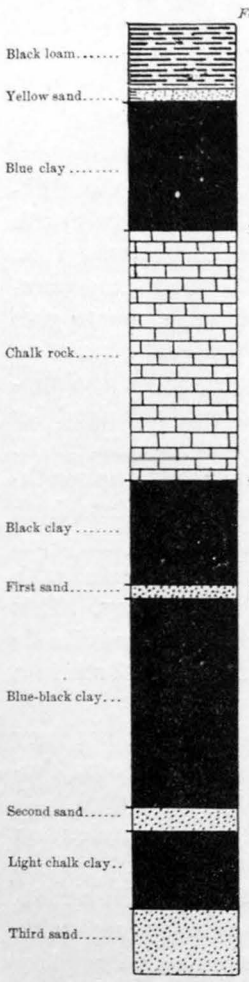



FIG. 78.—Log of well on Carpenter farm, near Pukwana, South Dakota.

The well of Mr. Fred. Shereda, completed in 1896, is in sec. 18, T. 101, R. 68. Its depth is 900 feet, with 800 feet of 3-inch casing. The flow is estimated at 200 gallons per minute, from beds which begin 800 feet below the surface. The well is intended to supply water for irrigation.

At the city mill in Chamberlain a 4-inch well has been sunk to a depth of 660 feet. It obtains a large flow at a depth of about 600 feet, from the stratum that supplies the other wells. The pressure is over 100 pounds and the water rises 7 feet above the mouth of the well. The average horsepower is 10, from a 1⅝-inch nozzle.

In sec. 12, T. 102, R. 68, Mr. M. Marty's well, sunk for irrigation, is 920 feet deep, 4 inches in diameter, and furnishes a large volume of water from the second flow at 850 feet. The water rises 15 inches above the well.

The well of Mr. Martin Smith, also completed in 1896, is in sec. 25, T. 103, R. 69. Its depth is 955 feet, diameter 4 inches, and flow 150 gallons per minute. The water-bearing beds were penetrated at a depth of 830 feet.

The new well of D. N. Kaufman, in sec. 12, T. 103, R. 71, is 1,071 feet deep, 6 inches in diameter, and has a flow of 1,300 gallons. Other flows were at 810 and 955 feet. Chalk was reported from 300 to 500 feet, with shale below.

In the vicinity of Kimball, Messrs. Ochsner & Bro. have continued their boring, in sec. 1, T. 103, R. 68, to a depth of 1,175 feet, but so far have not been able to obtain a larger flow than 40 gallons per minute.[1]

[1] A notice of this well in the Preliminary Report was based on a schedule received early in 1896, which gave figures somewhat different from these, especially as to yield.

The boring is cased with 966 feet of 6-inch pipe and has an inner tubing 4½ inches in diameter. From 1,075 to 1,175 feet the sandrock was very firm and nearly dry. It is thought that more porous water-bearing beds will be found by sinking deeper, and accordingly it is planned to deepen the boring next season. This area of dry sandrock extends for some distance northward and caused the failure of a 1,200-foot boring in sec. 1, T. 104, R. 67, where only a very small flow was obtained. Another well in sec. 34, T. 104, R. 67, found similar conditions. Fig. 79 is a map showing the distribution of wells in Brule County, and this area of dry sandstone is also indicated. It has been suggested that

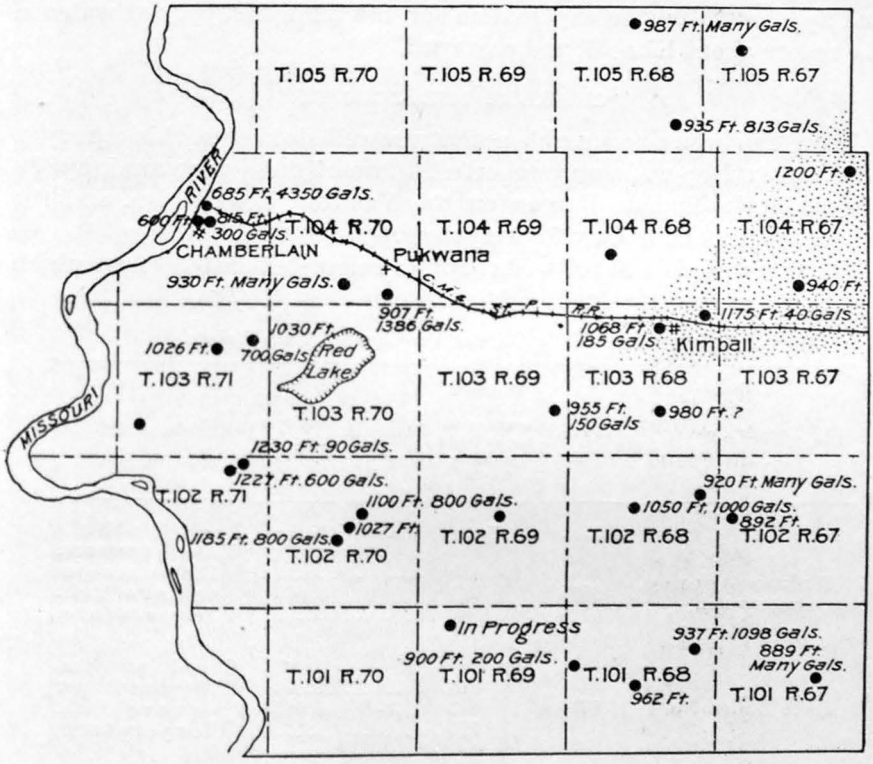



FIG. 79.—Outline map of Brule County, South Dakota, showing location of artesian wells, with their depths and yield in gallons per minute. The dotted area shows the region of scant flows.

this dry rock is the westward extension of the Sioux Falls quartzite, of decreased hardness and without the distinctive pink color. While this of course is possible, it is thought not to be probable, and an attempt to sink deeper in search of more porous beds in the Dakota formation is very desirable.

Mr. Page Guthrie, well driller at Kimball, has given some information in regard to the underground geology of eastern Brule County which is worthy of publication. He states that the drift deposits usually average about 100 feet in thickness, comprising from 15 to 25 feet of yellow clay above and 75 feet of blue clay below. The underlying for-

mation consists of about 700 to 800 feet of light-colored shales and then a series of shales about 100 feet thick with interbedded thin sheets of iron pyrites and three thick beds of sandrock containing water. These sandrock strata vary in thickness, porosity, and amount of contained water. Usually the second and third strata of the sandrock are the thickest. In most areas one stratum is of a more porous texture than the others and yields the principal water supply. In some cases each yields a fairly good supply, and on the other hand there are local areas in which they are all rather firm and the combined flow is not great in volume. This was notably the case in the old city well at Chamberlain, and appears to be the explanation for the limited supply of water in the region about Kimball and eastward.

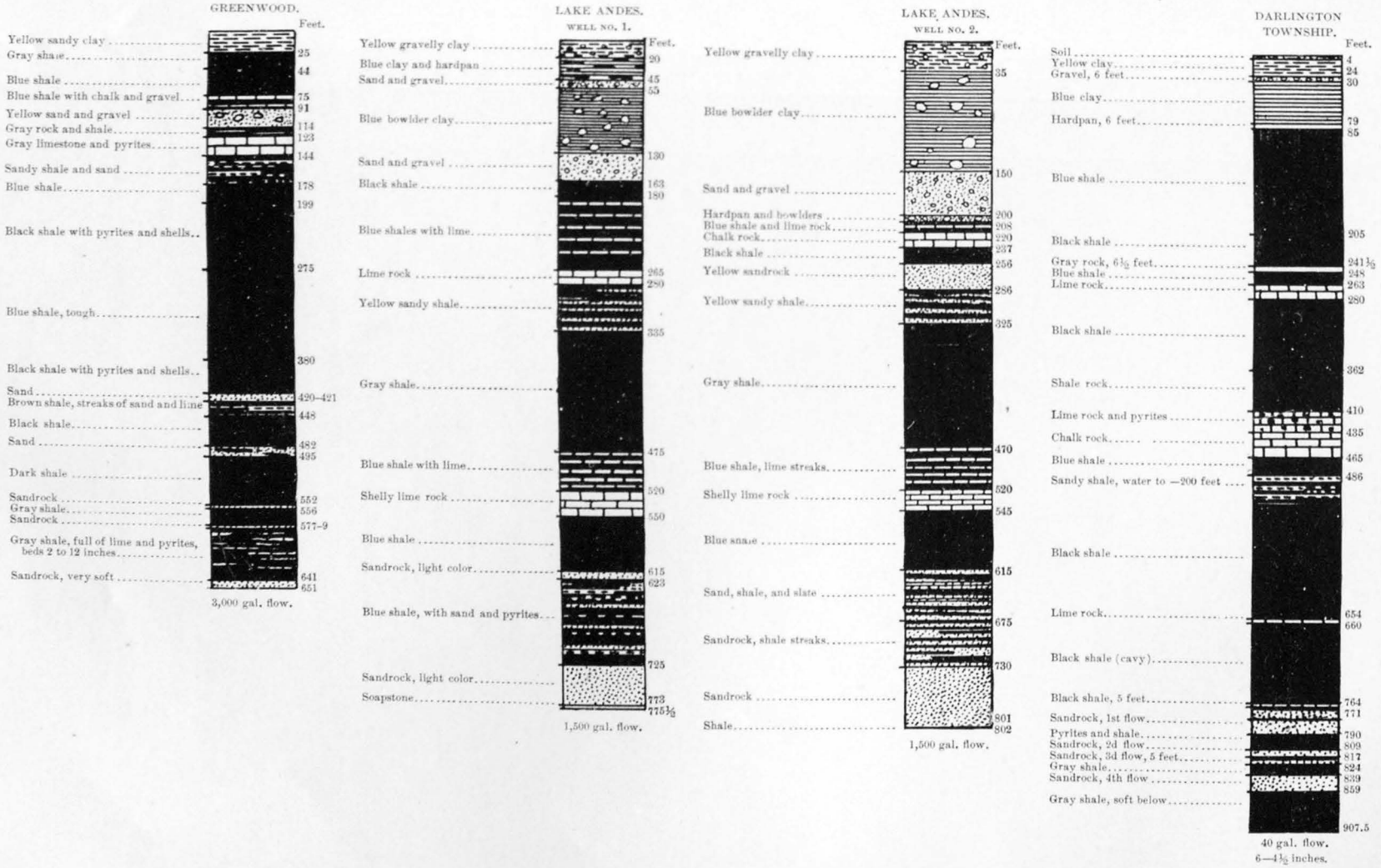
## CHARLES MIX COUNTY.

There has been considerable activity in well sinking in this county in 1896, as six deep wells were reported. Two of these were sunk by the United States Indian Bureau on the Yankton Reservation, and the others by farmers, mainly for irrigating.

The following is a list of wells sunk or completed in 1896 from which returns have been received:

*List of new wells in Charles Mix County, South Dakota.*

| Location, etc. | Depth. | Distance from the surface to top of beds yielding flows. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| Yankton Agency, Greenwood. | 651⅛ | 420<br>482<br>552 | .....<br>6<br>..... | .....<br>3,000<br>..... | Closed pressure, 119 pounds per square inch. Temperature, 70°. |
| Lake Andes, No. 1.. | 775½ | 615<br>623<br>725 | .....<br>8–6<br>..... | .....<br>1,500<br>..... | Closed pressure, 70 pounds per square inch. Temperature, 70°. |
| J. E. Latham, T. 100, R. 68, sec. 9. | 830 | 760<br>808<br>818 | .....<br>2–1½<br>..... | .....<br>7<br>..... | |
| D. H. Harris, T. 99, R. 67, sec. 18. | 769 | 766 | 2–1 | 7½ | Much water at 515 feet. |
| J. M. Pasek, T. 100, R. 69, sec. 9. | 980 | 805<br>840<br>927 | .....<br>3<br>..... | .....<br>125<br>..... | Chalk at 210 feet. |
| Township 99, R. 67, sec. 21. | 907⅝ | 771<br>809<br>819<br>838 | .....<br>.....<br>8–4½<br>..... | .....<br>.....<br>40<br>..... | |
| Lake Andes, No. 2.. | 802 | 590<br>675<br>730 | .....<br>8–6<br>..... | .....<br>1,500<br>..... | Sunk early in 1897. Estimated pressure, 70 pounds. Temperature, 70°. |




LOGS OF NEW ARTESIAN WELLS IN CHARLES MIX COUNTY, SOUTH DAKOTA.

The well at the Yankton Agency, at Greenwood, was sunk for water supply and power, both of which it affords in a most satisfactory manner. With a 3½-inch opening, its pressure is 59 pounds per square inch, and a horsepower of 9.63 is indicated, the greater part of which can be utilized by the Pelton wheel. The log of this well, as given by Mr. L. F. DeKay, is reproduced in Pl. XXXVIII.

Samples were received from depths of 420–448 feet, 448–480 feet, 552–577 feet, 577–603 feet, 608–610 feet, and 611–620 feet.

Above the principal flow which was utilized, several other beds of water-bearing materials were penetrated. There was a large volume of water at 144–150 feet, which rose to within 65 feet of the surface. The first flow at 420–421 feet yielded 10 gallons per hour of soft water, with a temperature of 56° F. There was a flow at 482–492 feet; a 15-gallon per minute flow of soft water at 552–556 feet, and a fourth flow of soft water at 579 feet, yielding 30 gallons per minute, with a temperature of 64° F. The water from the main flow has a temperature of 70° F., and its quality is hard.

It is reported by Mr. D. H. Harris that the Darlington Township well has sufficient head to raise the water 60 feet above the surface. The log of this well, supplied by Mr. J. C. McLain, chairman of the township board, is given in Pl. XXXVIII.

The United States Indian Bureau has sunk two wells at Lake Andes, which have proved very successful. They are intended to fill the lake, and, aided by the heavy rains and deep snow, the water level is rapidly rising. The logs of the wells, as reported by Mr. A. E. Swan, the driller, are given in Pl. XXXVIII. It is reported that in well No. 1 a small flow was encountered at 615–623 feet, and several other small flows at 623–725 feet. The main flow is in beds which extend from 725 to 773 feet. In well No. 2 very similar conditions were found. Water began to dribble over the top of the pipe at 590 feet; the flow increased somewhat from the sand streaks at 615–675 feet, and a flow of 200 gallons per minute was found in the beds at 675–730 feet.

Mr. J. E. C. Wilson, sec. 13, T. 98, R. 68, has deepened the boring on his farm to a depth of 1,220 feet, but without obtaining a flow. A large volume of water, found in a sand bed at about 900 feet, rises to within 28 feet of the surface, and small amounts from water-bearing beds below have raised it to within 15 feet of the surface. It is possible, owing to the high altitude of the land and dip of the beds, that this boring has not yet reached the stratum in which a large volume of flowing water should be expected, but it is much more probable that the land is higher than the head of the waters. Owing to lack of opportunity, it was not possible to visit this boring to determine the altitude of the land and ascertain whether an artesian flow should be expected in this elevated area.

## AURORA COUNTY.

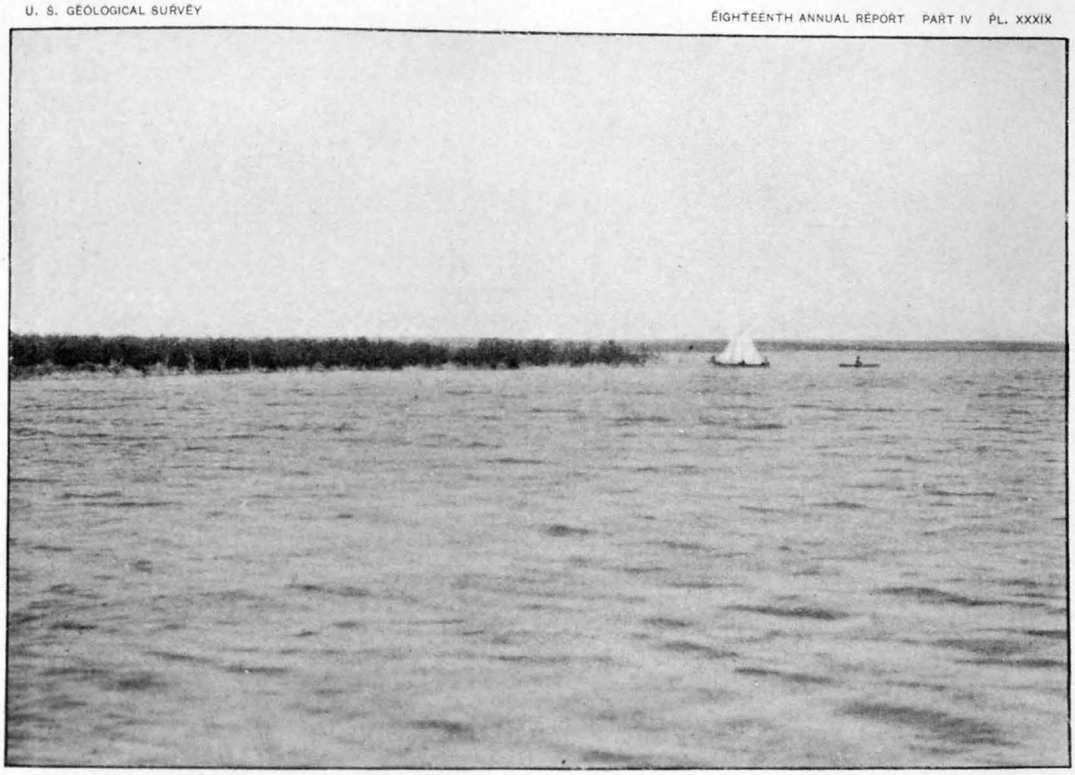
Several wells were sunk in this county in 1896, mainly for water supply for irrigation. Their principal features are given in the following list, which also includes some wells sunk in previous years but not included in the Preliminary Report:

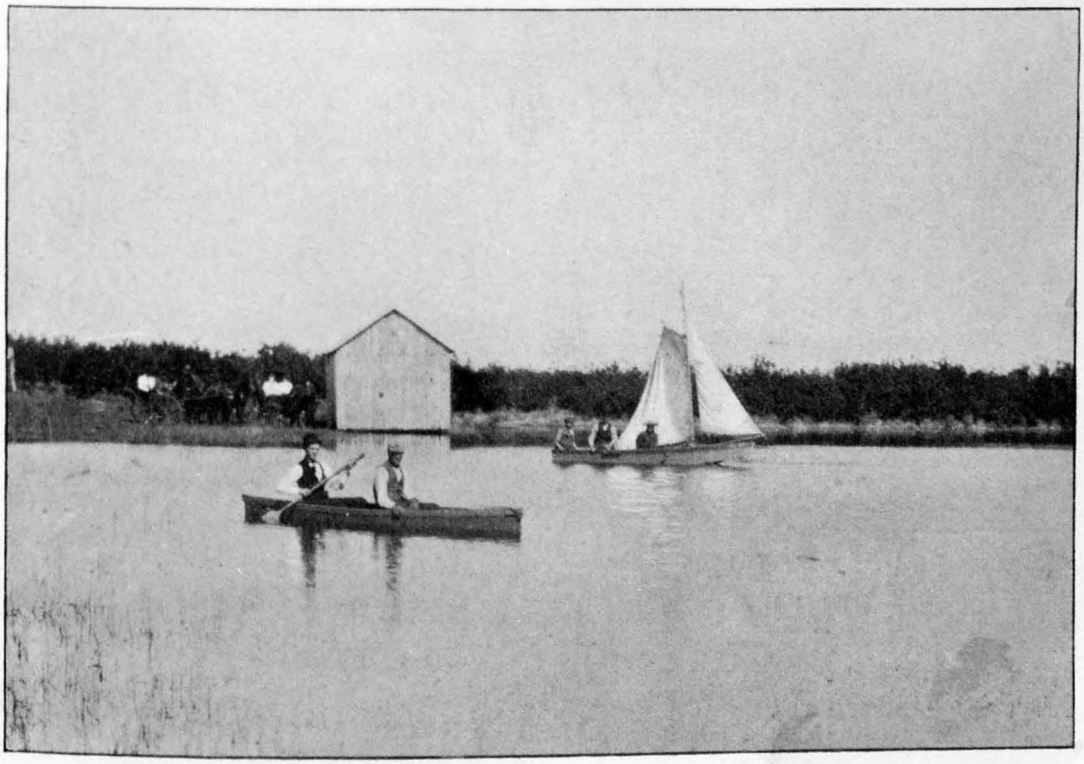
*Supplemental list of artesian wells in Aurora County, South Dakota.*

| Location, etc. | Depth. | Distance from the surface to top of beds yielding flows. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| Philip Eyer, T. 103, R. 63, 5 miles southeast of Plankinton. | 705 | 675 | 3 | 200 | |
| Evon Raesley, T. 103, R. 63, sec. 28. | 716 | 600<br>675 | 3<br>..... | 200<br>..... | |
| Mike Galles, T. 102, R. 66, sec. 17. | 835 | 835 | 4½ | 400 | |
| George Saville (?), T. 103, R. 63. | 530 | ..... | 2 | 30 | |
| Sam. Swenson, T. 103, R. 63, sec. 13. | 420 | 390 | 2 | 30 | |
| J. D. Barton, T. 103, R. 63, SW. ¼ sec. 8. | 755 | 620<br>753 | .....<br>3 | .....<br>100 | Pressure, 80 lbs. per square inch. |
| O. R. Auld, in Plankinton. | 745 | 740 | 4 | 60 | |
| J. R. Mabbot, T. 103, R. 63, sec. 26. | 530 | 500 | 2 | 10 | First flow, chalk, 40–140 feet. |
| L. Mabbott, T. 103, R. 63, sec. 26. | 490 | 440 | 2 | 10 | |
| Leonard Scott, T. 103, R. 63, sec. 35. | 484 | ..... | 4–3 | ..... | |
| James Ryan, T. 104, R. 63, sec. 22. | 525 | ..... | 4½–3 | 168 | |
| George Scott, T. 105, R. 63. | 475 | ..... | 2 | 5 | |
| J. W. Ryan, T. 102, R. 63, sec. 10. | 613 | ..... | 2 | 3 | |
| Crystal Lake Township, SE. ¼ sec. 17. | 850 | 643<br>794 | .....<br>4½ | .....<br>600 | Pressure, 55 lbs. per square inch. |
| Plankinton Township well. | 775 | 755 | 4½ | 200 | Pressure, 55 lbs. per square inch. |
| O. Scott, T. 104, R. 63, sec. 1. | 470 | ..... | 2 | 4 | |

Logs of the wells of Mr. James Ryan and Mr. J. W. Ryan are given in Pl. XL.

On the farm of Mr. H. Brady an attempt has been made to obtain water, but owing to mishaps the boring has been abandoned. The





LAKE SUPPLIED BY ARTESIAN WELL AT NEWARK, SOUTH DAKOTA.

casing was not driven properly and the tools were lost. The depth reached was between 700 and 800 feet, and the first flow was passed near 700 feet. A fairly good volume of water was found at a depth of 530 feet, which came to within 25 feet of the surface.

Mr. S. W. Peas, well driller, has furnished a general section for Aurora County, which is reproduced in Pl. XL. It comprises the results of his observations in a number of borings which he has sunk in recent years. He states that the hard rock underlying the lowest water-bearing sandrock is of the nature of the Sioux Falls granite, being excessively hard. At one locality he drilled into it for 19 feet, but under such difficulties that the expense was $400.

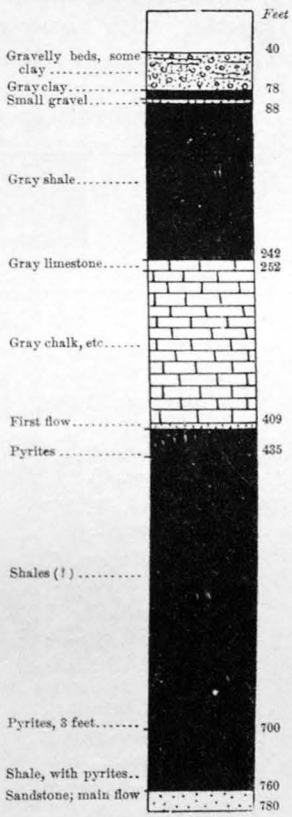



FIG. 80.—Log of artesian well at Crow Creek Agency, on the Missouri River, Buffalo County, South Dakota.

## BUFFALO COUNTY.

The first well in this county of which we have any record was sunk at Crow Creek Agency in 1896 by the United States Indian Bureau. As the locality is somewhat isolated from other wells, it is very interesting to have this boring demonstrate the extension of the water-bearing beds up the Missouri Valley from Chamberlain to Pierre. The well has a depth of about 780 feet, and is 6 inches in diameter. The flow is very large, and it is stated that the column of water rises 5 feet above the surface when the well is wide open. The closed pressure was over 180 pounds, which was as much as the gage would register. With a 1⅝-inch nozzle outlet the pressure is 85 pounds; with a 1⅞-inch nozzle outlet it is 70 pounds, and with a 2-inch nozzle outlet it is 65 pounds. The temperature of the water is 72°, and its specific gravity 1.004. The well at first threw out white sand, but this discontinued after a while, and its subsequent behavior has been entirely satisfactory. The first flow was found at 409 feet, but its head was barely sufficient to bring the water above the surface. The final flow was reached at 760 feet, and the water-bearing sand was penetrated to a depth of 20 feet. In fig. 80 is given an outline of the log of the well, based on a few samples with explanatory notes by the agent.

## JERAULD COUNTY.

Mr. Frank Campbell had a well sunk in this county in 1896, in sec. 6, T. 106, R. 63. Its depth is 760 feet. It contains 696 feet of 3-inch casing, 206 of 2½-inch casing, and 37 feet of 2-inch casing. Water-

bearing beds begin at 737 feet. The flow is 280 gallons per minute; closed pressure, 140 pounds to the square inch; and the well throws a 1-inch stream 55 feet high.

## SANBORN COUNTY.

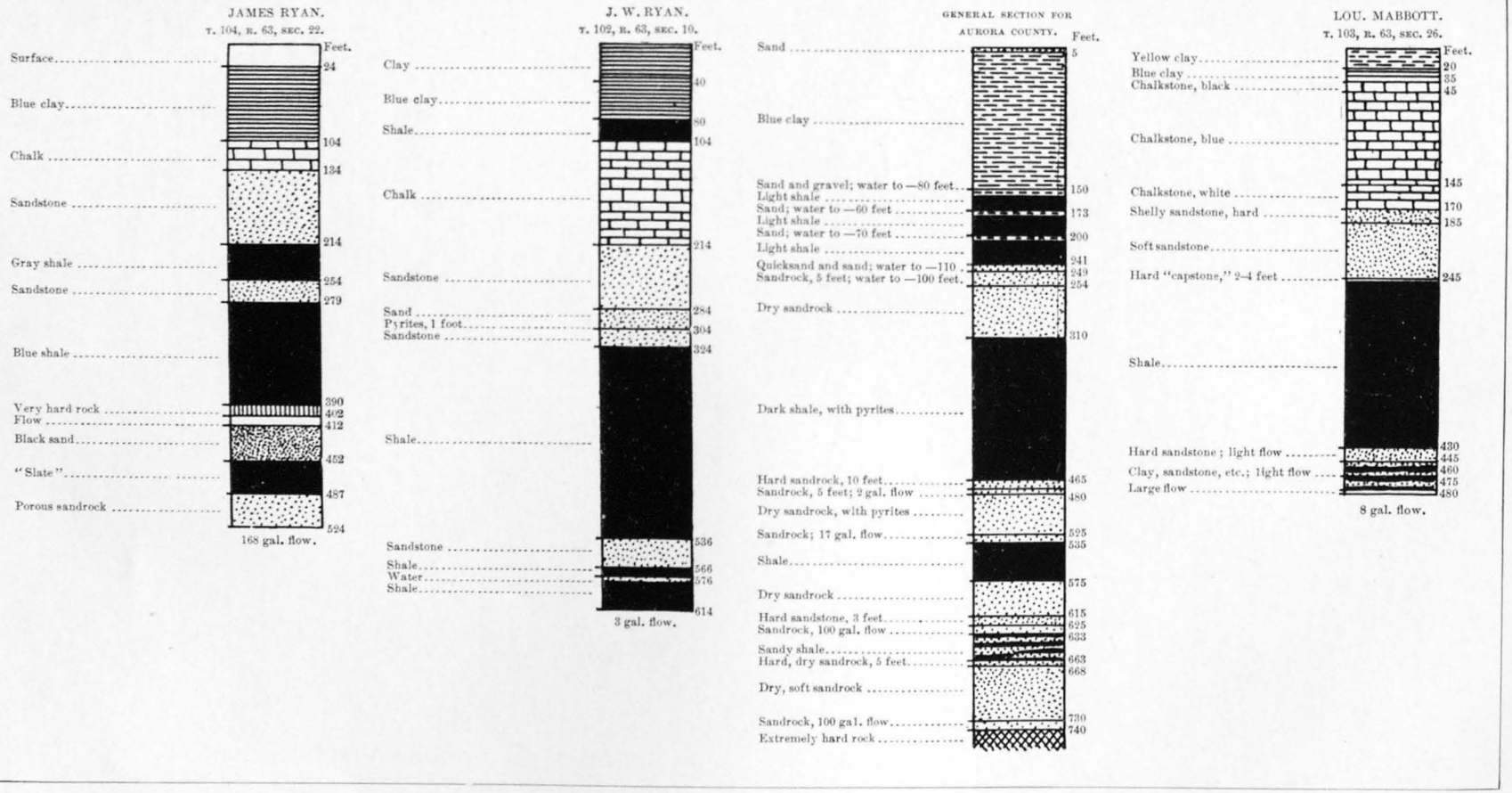
A number of shallow wells were bored in this county in 1896, and two wells which have depths of over 600 feet.

The following is a list of wells from which returns have been received, together with some wells sunk in previous years which were not included in the Preliminary Report:

*Supplemental list of artesian wells in Sanborn County, South Dakota.*

| Location, etc. | Depth. | Distance from the surface to top of beds yielding flows. | Diameter. | Yield per minute. | Remarks |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| H. C. Sprague, T. 105, R. 60, sec. 10. | 625 | 600 | 2 | 30 | |
| A. D. Green, T. 108, R. 60, sec. 35. | 85 | 85 | 2 | 40 | |
| C. Ostrander, T. 106, R. 59, sec. 18. | 82 | 82 | 2 | 6 | |
| C. Wilson, T. 106, R. 58, sec. 7. | 92 | 92 | 2 | 40 | |
| C. W. Winters, T. 106, R. 58, sec. 9. | 140 | 140 | 2 | (*a*) | |
| A. Oversheldt, T. 105, R. 60, sec. 20. | 497 | 447 | 2 | 165 | Sunk in 1892. |
| H. K. and E. O. Ashmore, 1½ miles SW. of Artesian. | 630? | 530<br>630 | 3 | (*b*) | Pressure, 35 lbs. per square inch. |
| H. Helgeson, T. 105, R. 62, sec. 17. *c* | 463 | ..... | 2 | 6 | |
| —— Oswald, T. 105, R. 62, sec. 30. *c* | 500 | ..... | 1¼ | 15 | |
| Peter Lundgren, T. 105, R. 62, sec. 19. *c* | 485 | ..... | 2 | 4 | |

*a* No flow. *b* Satisfactory. *c* Information furnished by Peter Norbeck.




LOGS OF WELLS IN AURORA COUNTY, SOUTH DAKOTA.

The Ashmore well is on a farm 1 mile south and one-half mile west of Artesian. The log is given in fig. 81. The first flow was found at 530 feet and the second at 630 feet. From near the bottom of this well the sand pump brought out a lump of pyrites with some shells adhering to it. They were a Mactra and a Fasciolaria, but are too imperfect for positive specific identification. The horizon of these forms would appear to be the Pierre shale. The rock in which the drilling was discontinued is stated to be only moderately hard, but a sufficient amount of it was not penetrated to determine that it was not bed rock.

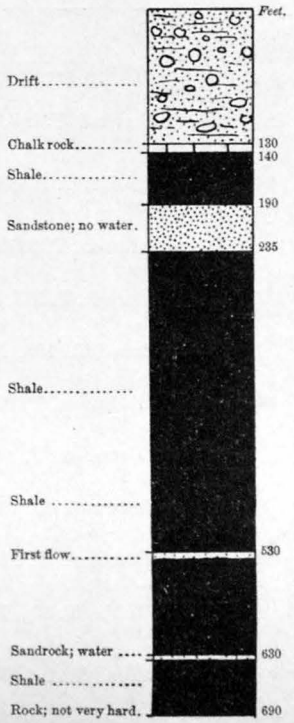



FIG. 81.—Log of well on farm of H. K. and E. O. Ashmore, near Artesian, South Dakota.

## DAVISON COUNTY.

Quite a number of wells were sunk in Davison County in 1896. They have reached the water-bearing strata which supply the abundant flows to many wells sunk in previous years, and throw no important new light on the underground relations. An endeavor has been made to make a more complete list of the new wells of this county than was given in the Preliminary Report, and the additional information, including that relating to wells sunk in 1896, is given in the following list:

*Supplemental list of artesian wells in Davison County, South Dakota.*

| Location, etc. | Depth. | Depth to water. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| Mount Vernon Mill Co., in Mount Vernon. | 350 | 198<br>350 | 5⅝ | 40 | |
| Charles F. Raymond, T. 103, R. 62, sec. 2. *a* | 420 | 270 | 2 | 60 | |
| W. M. Smith, T. 103, R. 62, sec. 14. *a* | 450? | 400 | 2 | 60 | |
| Peter Hogsteadt, T. 103, R. 62, sec. 12. | 315 | ..... | 2 | 20 | |
| J. O. Butler, in Mount Vernon. *a* | 442 | 430 | 2 | 8 | |

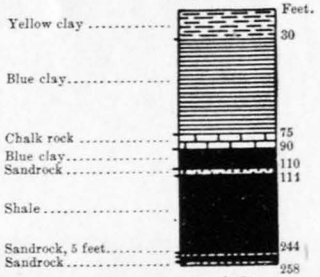
*a* Sunk in 1896.

*Supplemental list of artesian wells in Davison County, South Dakota*—Continued.

| Location, etc. | Depth. | Depth to water. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| F. W. Rowell, T. 103, R. 62, sec. 11. | 408 | 350 | 2 | 45 | |
| Charles Arland, T. 103, R. 62, sec. 15. | 397 | 285 | 4½–3½ | 125 | Sandstone 337–397 feet; very hard bottom. |
| Jake Johnson, T. 103, R. 62, sec. 9. *a* | 385 | 285<br>385 | 2 | 60 | |
| Knute Johnson, T. 103, R. 62, sec. 9. *b* | 380 | ..... | 2 | 30 | |
| Art. Frederick, T. 103, R. 62, sec. 10. | 495 | 360 | 3 | 35 | |
| Hatch Bros., T. 103, R. 62, sec. 15. | 406 | 278 | 2 | 60 | |
| John K. Johnson, T. 103, R. 62, sec. 3. | 646 | 350<br>620 | 4½ | 700 | |
| Edward Brannon, T. 104, R. 62, sec. 21. | 395 | 280<br>395 | 3 | 20 | |
| George Schlund, T. 104, R. 62, sec. 27. *a* | 388 | 270<br>385 | 3 | ..... | |
| B. P. Nicholson, T. 104, R. 62, sec. 9. *a* | 550 | 380<br>545 | 2–1¼ | 130 | |
| Nathan Noble, T. 104, R. 62, sec. 25. | 330 | 276<br>300 | 3 | 75 | |
| H. H. Olson, T. 104, R. 62, sec. 18. | 408 | ..... | 2 | 20 | |
| Edwin Lewis, T. 104, R. 62, sec. 34. | 361 | 345 | 2 | 90 | |
| W. H. Kilborn, T. 104, R. 62, sec. 21. | 424 | ..... | 3 | 156? | |
| Ezra Rice, T. 104, R. 62, sec. 12. | 416 | ..... | 2 | 5 | |
| George Morgan, T. 104, R. 62, sec. 3. *a* | 601 | 601 | 4½–3 | 130 | |
| J. O. Johnson, T. 104, R. 62, sec. 7. | 444 | ..... | 2 | 15 | |
| B. Haljeson, T. 104, R. 62, sec. 28. | 380 | 280<br>275 | 3 | 32 | |
| W. Cornwell, T. 104, R. 62, sec. 35. | 479 | 460 | 5–4½ | Many | |
| Rev. Thormsgaard, T. 104, R. 62, sec. 6. *b* | 458 | 299 | 1¼ | 3 | |
| J. S. Wilson, T. 104, R. 61, sec. 29. | 419 | 350<br>400 | 2 | 50 | |
| J. S. Wilson, T. 104, R. 61, sec. 8. | 577 | 335<br>550 | 2 | 50 | |
| Iowa Investment Company, T. 104, R. 61, sec. 27. | 295 | 100 | 4 | 30 | |

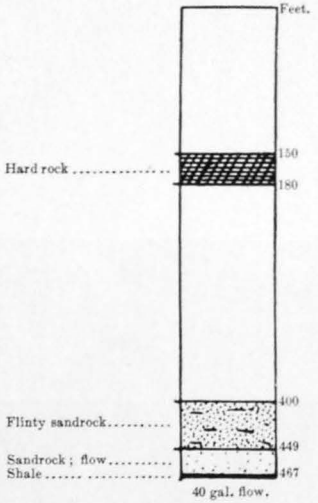
*a* Sunk in 1896. *b* Information supplied by Peter Norbeck.

M. GLEASON.
T. 104, R. 60, SEC. 5.



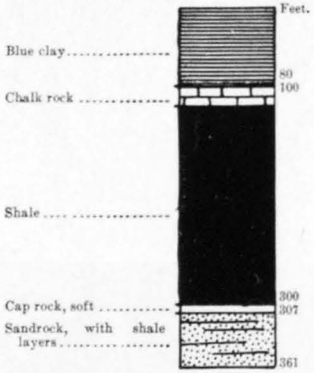

200 gal. flow.

N. DONDELINGER.
T. 104, R. 60, SEC. 17.

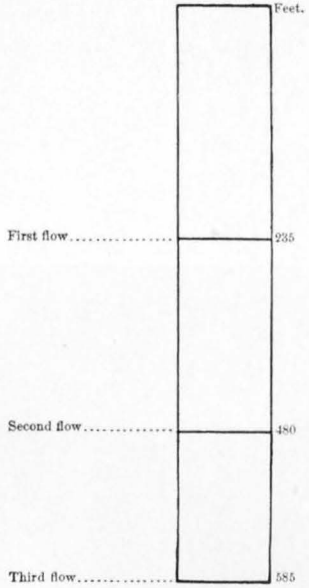



40 gal. flow.

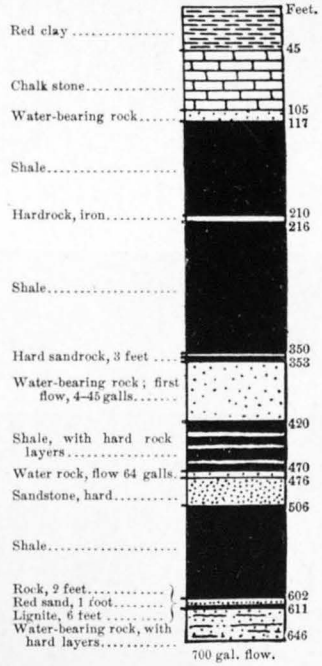
T. 104, R. 60, SEC. 7.




T. 104, R. 61, SEC. 8.

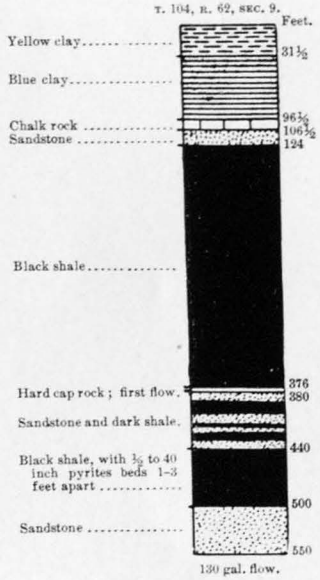



J. K. JOHNSON.
T. 103, R. 62, SEC. 3.




700 gal. flow.

B. P. NICHOLSON.
T. 104, R. 62, SEC. 9.




130 gal. flow.

LOGS OF ARTESIAN WELLS IN DAVISON COUNTY, SOUTH DAKOTA.

*Supplemental list of artesian wells in Davison County, South Dakota*—Continued.

| Location, etc. | Depth. | Depth to water. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| A. M. Logan, T. 104, R. 61, sec. 18. | 653 | ..... | 2-1¼ | 90 | Chalk 50–150 feet. |
| C. C. Young, T. 104, R. 61, sec. ? | 383 | 350 | 2 | 60 | |
| W. A. Fraser, T. 104, R. 61, sec. 33. *a* | 425 | 250<br>420 | 3 | 210 | |
| E. D. Watkins, T. 104, R. 61, sec. 20. | 420 | 418 | 2 | 22 | |
| Everett Smith, T. 104, R. 61, sec. 26. | 265 | ..... | 2 | 20 | Stopped on hard bed. |
| H. N. Cox, T. 104, R. 61, sec. 25 | 307 | 200<br>285 | 3 | 40 | |
| John Titus, T. 104, R. 61, sec. 30. | 375 | ..... | 2 | 120 | |
| Oney Clark, T. 104, R. 61, sec. ? | 415 | ..... | ..... | 30 | Sandstone 380–415 feet. |
| H. L. O'Mealey, T. 104, R. 61, sec. 22. | 344 | 310 | 2 | 60 | |
| S. S. Slade..... | 440 | 355<br>424 | 2 | 10 | |
| Martin Gleason, T. 104, R. 60, sec. 5. *a* | 258 | 256 | 2 | 200 | |
| J. B. Martin, T. 104, R. 60, sec. 17. | 344 | 320 | 2 | 60 | |
| John Gleeson, T. 104, R. 60, sec. 9. | 237 | 237 | 2 | 2 | |
| E. E. Dean, T. 104, R. 60, sec. 11. | 370 | 365 | 2 | 4 | |
| H. J. Timm, T. 104, R. 60 sec. ? | 355 | ..... | ..... | 70 | Sandstone 330–355 feet. |
| N. Dondelinger, T. 104, R. 60, sec. 17. | 456 | ..... | 3 | 70 | Sandstone 438–456 feet. |
| W. M. Dodge, T. 104, R. 60, sec. ? | 323 | ..... | ..... | 100 | Sandstone 288–332 feet. |
| Joseph Gilfillian, T. 104, R. 60, sec. ? | 365 | ..... | ..... | 90 | Sandstone 337–365 feet. |
| M. L. Babb, T. 103, R. 61, sec. 30. *a* | 354 | ..... | 2 | 75 | |
| H. A. Stahl, T. 103, R. 61, sec. 19. *a* | 411 | 370 | 2 | 120 | |
| J. M. Schmidt, T. 103, R. 61?, sec. 8. | 308 | 250 | 2 | 30 | |
| D. H. Musser, T. 103, R. 61, sec. 17. | 288 | 245 | 2 | 30 | |
| John Abraham, T. 103, R. 61, sec. 6. | 216 | 216 | 2 | 60 | |
| Nathan Noble, T. 103, R. 61, sec. 7. | 330? | 276? | 2 | 35 | |

*a* Sunk in 1896.

*Supplemental list of artesian wells in Davison County, South Dakota*—Continued.

| Location, etc. | Depth. | Depth to water. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| John Hoyseth, T. 103, R. 61, sec. 19. *a* | 335 | ..... | 2 | 20 | |
| A. Reitzel, T. 103, R. 61, sec. 25. *a* | 325 | ..... | 2 | 1½ | |
| Oliver Pine, T. 103, R. 61, sec. 19. *a* | 346 | ..... | 2 | 30 | |
| O. Stahl, T. 103, R. 61, sec. 19. *a* | 410 | ..... | 2 | 110 | |
| A. B. Seaton, T. 103, R. 60, sec. 8. | 385 | 280<br>385 | ..... | 35 | |
| M. Spears. In Mitchell..... | 550 | ..... | 2 | 60 | Pressure, 131bs. |
| W. M. Smith, T. 102, R. 62, sec. 9. *b* | 460 | 430 | 2 | 90 | |
| H. Heidinger, T. 102, R. 62, sec. 31. | 642 | 600 | 2–1¼ | 20 | |
| J. Reier, T. 102, R. 62, sec. 29. *b* | 485 | 450 | 2–1¼ | 30 | |
| S. Pound, T. 102, R. 62, sec. 3. *a* | 385 | ..... | 2 | 25 | |
| H. H. Garey, T. 102, R. 62, sec. 6. *a* | 460 | ..... | 2 | 25 | |
| M. Grady, T. 101, R. 61, sec. 25. *b* | 520 | 440<br>516 | 2 | 27 | |
| John Schoenfelder, T. 101, R. 61, sec. 28. | 530 | ..... | 2 | 15 | |
| Jos. Schoenfelder, T. 101, R. 61, sec. 21. | 535 | 530 | 1¼ | 35 | |
| Oscar Warfield, T. 101, R. 61, sec. 2. | 425 | ..... | 2 | 30 | |
| Chas. Drake, T. 101, R. 60, sec. 29. *b* | 413 | ..... | 2 | 35 | |
| L. Lowrie, T. 101, R. 60, sec. 9. *b* | 477 | 385 | 2 | ..... | Very hard rock on bottom. |
| J. Miles, T. 101, R. 60, sec. 13 *c*. | 320 | 318 | 2 | 3 | |
| N. Blackman, T. 101, R. 60, sec. 21. *b* | 320 | 315 | 2 | 45 | |
| B. Portnes, T. 101, R. 60, sec. 32. *b* | 435 | 430 | 2 | 25 | |

*a* Information supplied by Peter Norbeck. *b* Sunk in 1896. *c* Sunk in 1897.

The water horizons in Davison County are very uniform in their relations over wide areas. They have been mostly developed in the northern half of the county, as the wells are quite widely scattered in the southern townships. The depth of the wells varies in greater part from 300 to 450 feet. The wells of Mitchell are from 548 to 586 feet deep, and the wells in the higher lands in the southwestern corner of the county have to go to about the same depth. In portions of the region north of Mitchell and about Mount Vernon there are first-flow waters

at moderate depths which are the source of supply for some of the wells, but in most cases the deeper waters, with their larger yield, are preferred. As the water-bearing strata lie at such moderate depth in this county, the expense of obtaining a flow from the main water-bearing bed is not great.

At the well of Mr. Spears in Mitchell, 60 rods north of the town well, it is reported that 40 feet of hard sandstone was found at the depth of 100 feet, which was not reported in the town well. Another difference was in finding no water at the depth of 260 feet, as in the town well, the beds at this depth being of shale. At 320 feet, and again at from 480 to 505 feet, hard sandstone was reported. The cap rock was entered at 533 feet, overlying a loose sandstone which yielded a good flow with a pressure of 13 pounds per square inch.

## HANSON COUNTY.

Returns have been received from only one new well in Hanson County, that of Mr. W. H. Tripp, in sec. 12, T. 104, R. 58. Information has also been received in regard to a few wells sunk in previous years which were not included in the Preliminary Report. These are given in the following table:

*Supplemental list of artesian wells in Hanson County, South Dakota.*

| Location, etc. | Depth. | Distance from the surface to top of beds yielding flows. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| W. H. Tripp, T. 104, R. 58, sec. 12. | 483 | 465 | 4½ | 35 | Pressure, 20 lbs. |
| Abe Taylor, T. 104, R. 57, sec. 27. | 508 | 508 | 2 | 4 | |
| C. L. Holbrook, T. 104, R. 57, sec. 7. | 510 | 505 | 3÷2 | 16 | |
| Fred Hess, 4 miles north of Farmer. | 260 | ..... | 2 | ..... | |
| Victor Matthews, 3½ miles west and one-half mile north of Farmer. | 150 | ..... | 1¼ | ..... | |

In the W. H. Tripp well the following materials are reported:

| Feet. | |
|---|---|
| 0–200 | yellow and blue clay. |
| 200–250 | sand. |
| 250–468 | shale, with beds of pyrites 2 to 16 inches thick. |
| 468–483 | sandrock, pink. |

Under the sandrock, which was the water-bearing stratum, there lies a very hard substance, which may possibly be the bed rock. It may, however, be pyrites, and Mr. Tripp is of the opinion that it is not the Sioux quartzite. It was penetrated for 3 feet at great expense.

At the Holbrook well the water occurs in a 10-foot bed of red sandrock, which lies on an exceedingly hard rock, into which the workmen were able to drill only a few inches.

## HUTCHINSON COUNTY.

The artesian waters of the Dakota basin are very extensively utilized in the western and northwestern portion of Hutchinson County. There are several hundred wells, mainly of small size, but they yield a very large aggregate outflow of excellent water. Owing to the moderate depth at which the water-bearing stratum lies in this region, a small well is within the means of almost every farmer, so that this important resource has here proved particularly useful.

During the year 1896 a number of additional wells have been sunk, in most cases with complete success. In order to place on record the features of the wells of this county, a somewhat extended canvass was made in 1896, the results of which are set forth in the following list, which also includes the few wells given in the list in the Preliminary Report. The list is not by any means complete, but it gives a sufficient number of wells in each section to indicate the conditions under which the underground waters occur.

*Partial list of artesian wells in Hutchinson County, South Dakota.*

| Name. | Quarter section. | Depth. | Depth to water. | Diameter. | Yield per minute. |
|---|---|---|---|---|---|
| *Township 100, range 61.* | | *Feet.* | *Feet.* | *Inches.* | *Gallons.* |
| Jos. Oberembt | —— 10 | 420 | ..... | 3 | 15 |
| M. Oberembt | NW. 10 | *a* 419 | 419 | 2 | 15 |
| A. Zeier | SW. 14 | 430 | 412 | 3 | 1 |
| J. Nauheizerl | SW. 28 | 525 | 525 | 3 | 30 |
| Matt Korter | NE. 22 | 470 | 400 | 3 | 2 |
| Jos. Schoenfelder | NW. 21 | 502 | 502 | 2 | 60 |
| Paul Schoenfelder | NE. 26 | 504 | 504 | 3 | 90 |
| Nick Mayer | SW. 25 | *a* 473 | 436 | 2 | 1 |
| John Herrmann | SW. 25 | 458 | 404 | 2 | ..... |
| Philip Mayer | NE. 25 | 465 | 460 | 2 | 5 |
| J. P. Puetz | NE. 14 | *a* 450 | ..... | 2 | 30 |
| John Schumacher | SE. 20 | 570 | 480<br>570 | 2 | 16 |
| Theo. Emmery | SE. 33 | 585 | 505<br>580 | 2–1¼ | ..... |
| John Hohn | SW. 27 | 436 | 417 | 2 | 3 |

*Partial list of artesian wells in Hutchinson County, South Dakota*—Continued.

| Name. | Quarter section. | Depth. | Depth to water. | Diameter. | Yield per minute. |
|---|---|---|---|---|---|
| *Township 100, range 61*—Continued. | | *Feet.* | *Feet.* | *Inches.* | *Gallons.* |
| Cooper Ferjen *a* | SE. 28 | 530 | 523 | 2 | 45 |
| Mr. Garrett | NE. 17 | ..... | ..... | ..... | ..... |
| Jos. Hohn | NW. 22 | ..... | ..... | ..... | ..... |
| Matt Bower | NW. 24 | ..... | ..... | ..... | ..... |
| *Township 100, range 60.* | | | | | |
| Jacob Giesen | —— 23 | 370 | ..... | 2 | ..... |
| H. Esser | SE. 13 | 460 | 400 | 2 | 10 |
| L. Bower | SW. 24 | 462 | 426 | 2 | 3 |
| M. J. Schlingen | —— 18 | 370 | 340 | 2 | ..... |
| John Schlimeyer | —— 17 | 370 | 330 | 2 | 7 |
| Matt Schurz | SW. 18 | 420 | 380 | 2 | 4 |
| Jos. Erlocher | SW. 17 | ..... | ..... | ..... | ..... |
| *Township 99, range 61.* | | | | | |
| J. W. Straup | SW. 1 | 503 | 435<br>495 | 2 | 15 |
| G. Winter | SW. 25 | 490 | 485 | 1½ | 25 |
| Frank Fritza | SW. 9 | *a* 530 | 530 | 2 | Many. |
| Henry Bäke | —— 14 | 505 | 505 | 2 | 25 |
| Carl Radke | SE. 24 | 520 | 520 | 1¼ | ..... |
| Mrs. Pope | —— 14 | 140 | 140 | ..... | ..... |
| C. Raugust | NE. 22 | 515 | 508 | 1½ | 20 |
| John L. Schmidt | NW. 20 | 572 | 525 | 2 | 25 |
| Geo. W. Goodling | SE. 2 | 508 | 426 | 2 | 12 |
| John Tiede | NE. 27 | 491 | ..... | 2–1¼ | 8 |
| Frank Kramer | SW. 14 | ..... | ..... | ..... | ..... |
| G. Graumann | 26 | 504 | 490 | 2 | 50 |
| Martin Winter | NW. 35 | 558 | 535 | 1¼ | 15 |
| Frank Hinzes | NW. 21 | ..... | ..... | ..... | ..... |
| J. R. Manwarring | SW. 2 | 560 | 535 | 1¼ | ..... |
| Wm. Harding | NW. 3 | ..... | ..... | ..... | ..... |
| Geo. Heisinger | NE. 12 | 518 | 500 | 1¼ | 20 |
| T. Heisinger | SE. 12 | 531 | 490 | 2 | 30 |
| *Township 99, range 60.* | | | | | |
| G. Hoffman | NE. 19 | 485 | 470 | 2 | 25 |
| Parkston, City | ..... | 522 | 480 | 6 | 5 |
| Christian Fisher | NW. 30 | 500 | 360<br>500 | 2 | Many. |
| Fred. Unger | NW. 7 | 540 | ..... | 2 | 10 |
| F. Hildebrandt | SW. 29 | 485 | 470 | 1¼ | 90 |

*a* Sunk in 1896.

*Partial list of artesian wells in Hutchinson County, South Dakota*—Continued.

| Name. | Quarter section. | Depth. | Depth to water. | Diameter. | Yield per minute. |
|---|---|---|---|---|---|
| *Township 99, range 60*—Continued. | | *Feet.* | *Feet.* | *Inches.* | *Gallons.* |
| Dan Tiede | NW. 31 | 501 | 495 | 1¼ | 25 |
| Aug. Stelzer | NW. 32 | 500 | 500 | 1½ | 8 |
| T. H. Benson | SW. 23 | 443 | 440 | 2 | ..... |
| E. L. Dings | NW. 22 | 420 | 418 | 2 | 5 |
| M. Heizinger | SW. 7 | 522 | 485 | 2 | ..... |
| Aug. Mathiäs | NW. 32 | 470 | ..... | 3 | (*a*) |
| Chas. Fergen, in Parkston | ..... | 510 | 504 | 2 | ..... |
| A. B. Taylor | NE. 22 | 400 | 382 | 2 | 1 |
| Mr Hort | SW. 14 | ..... | ..... | ..... | ..... |
| H. B. Hadin | NW. 13 | ..... | ..... | ..... | ..... |
| Aug. Gross | SE. 24 | ..... | ..... | ..... | ..... |
| H. Benson | —— 34 | 446 | 440 | 2 | Many. |
| W. Henker | NW. 35 | ..... | ..... | ..... | ..... |
| *Township 99, range 59.* | | | | | |
| John Isaac | 34 | 490 | 490 | 2 | ..... |
| Milltown | ..... | 365 | 221<br>250 | 10–6 | ..... |
| *Township 98, range 59.* | | | | | |
| Fred Brandt | SW. 20 | 420 | ..... | 2 | 1½ |
| Jacob Mogck | NW. 7 | 450 | 200 | 1¼ | 15 |
| John Mogck | SW. 5 | ..... | ..... | ..... | ..... |
| Christian Mogck | SE. 6 | ..... | ..... | ..... | ..... |
| Aug. Kern | SE. 7 | ..... | ..... | ..... | ..... |
| John Schlenker | SW. 7 | ..... | ..... | ..... | ..... |
| M. Baltzer | —— 29 | 428 | 418 | 2 | 15 |
| M. Baltzer, jr | NE. 29 | 400 | 395 | 2 | 15 |
| Jacob Mayer | SE. 19 | ..... | ..... | ..... | ..... |
| F. Mehlhaff | SW. 16 | 430 | 426 | 2 | 4 |
| Peter Mehlhaff | SW. 21 | 410 | ..... | ..... | ..... |
| Fred. Mehlhaff, jr | NW. 21 | ..... | ..... | ..... | ..... |
| Martin Baltzer, sr | SE. 21 | 370 | 350 | 2 | 13 |
| Wm. Baltzer | NE. 28 | ..... | ..... | ..... | ..... |
| *Township 98, range 60.* | | | | | |
| C. Pennann | NW. 14 | 495 | 495 | 2 | 25 |
| H. Schnobel | NE. 23 | 189 | 189 | 2 | 21 |
| Jacob Herr | SW. 24 | 174 | 170 | 2 | ..... |
| Fred Schultz | NE. 15 | 160 | ..... | 2 | ..... |
| Jake Stoebner | NE. 30 | 542 | 542 | 3 | 16 |

*a* Two-inch stream.

*Partial list of artesian wells in Hutchinson County, South Dakota*—Continued.

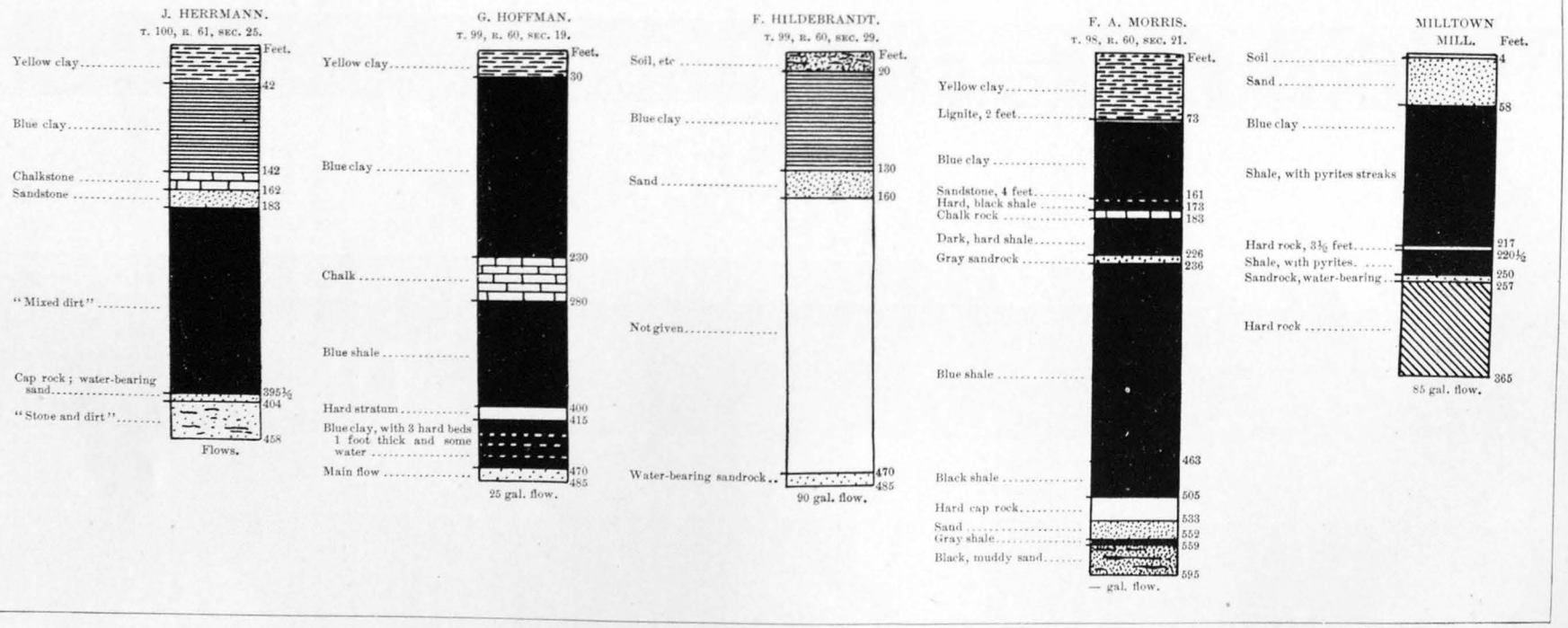
| Name. | Quarter section. | Depth. | Depth to water. | Diameter. | Yield per minute. |
|---|---|---|---|---|---|
| *Township 98, range 60*—Continued. | | *Feet.* | *Feet.* | *Inches.* | *Gallons.* |
| Henry Stoebner | NW. 29 | 577 | 550 | 2 | 50 |
| John Mehlhaff | NE. 24 | 480 | 470 | 2 | 15 |
| Johann Frey | SW. 29 | 580 | 570 | 2 | (*a*) |
| N. V. Morris | NW. 20 | 540 | 538 | 2 | 66 |
| F. A. Morris | NW. 21 | 559 | 531 | 2 | 50 |
| Dan Koth | NE. 11 | 150 | ..... | 2 | 20 |
| E. E. Johnson | NE. 18 | 580 | 560 | 2 | 16 |
| J. Wudel | SE. 3 | 580 | 520 | ..... | 120 |
| John Koenig | NW. 9 | 500 | (*b*) | 5 | (*c*) |
| Gottlieb Koenig | SW. 5 | 500 | 490 | 2 | 10 |
| George Brost | SE. 12 | ..... | ..... | ..... | ..... |
| Jacob Brost | NE. 12 | 129 | 125 | 2 | ..... |
| Jacob Brosz | SE. 13 | ..... | ..... | ..... | ..... |
| Jacob Brosz, jr | SW. 18 | ..... | ..... | ..... | ..... |
| Fred Brosz | SE. 12 | 132 | 125 | 2 | Many. |
| August Mueller | NE. 1 | ..... | ..... | ..... | ..... |
| Christ Schemke | NW. 7 | 550 | 530 | 2 | ..... |
| Nat Tiede | W.½ W.½ 6 | 475 | ..... | 2 | 75 |
| L. Koenig | SW. 8 | 510 | 510 | 2 | 25 |
| A. Kaiser | NE. 4 | ..... | ..... | ..... | ..... |
| M. Wudel | NE. 3 | ..... | ..... | ..... | ..... |
| Martin Tiede | NE. 6 | 500 | 490 | 2 | Many. |
| Nathaniel Koenig | SW. 6 | 520 | 510 | 2 | 15 |
| *Township 98, range 61.* | | | | | |
| Simon Tiede | —— 12 | 560 | ..... | 1¼ | 23 |
| C. Doëring | NW. 13 | 545 | 545 | 1¼ | 13 |
| Wm. Tiede | SE. 1 | 510 | ..... | 3–1½ | ..... |
| G. Winter | SW. 15? | 690 | 680 | 3 | ..... |
| J. Tiede | NW. 1 | 500 | 500 | 1½ | ..... |
| Dan Hartmann | NE. 12 | 555 | 555 | 1½ | 40 |
| John Heinz | SW. 3 | 548 | 548 | 2–1¼ | 36 |
| Gottlieb Sprecher | NW. 2 | 530 | 530 | 1¼ | Many. |
| William Tarl | ..... | ..... | ..... | 1 | ..... |
| Philip Weber *d* | —— 7 | 64 | 60 | 4 | 6 |
| Jos. Lutz | 23 | 798 | 740 | 1 | 13 |
| *Township 97, range 60.* | | | | | |
| Gottleib Kludt | NE. 4 | 560 | 545 | 2 | 45 |
| Town well, Tripp | ..... | 824 | 794 | 4½ | Many. |
| C. Frederich | NE. 23 | 550 | 550 | 1½ | 50 |

*a* Three-inch flow. *b* Second flow. *c* Two-inch stream. *d* Low in valley.

*Partial list of artesian wells in Hutchinson County, South Dakota*—Continued.

| Name. | Quarter section. | Depth. | Depth to water. | Diameter. | Yield per minute. |
|---|---|---|---|---|---|
| *Township 97, range 60*—Continued. | | *Feet.* | *Feet.* | *Inches.* | *Gallons.* |
| Tripp creamery well | NE. 17 | ..... | ..... | ..... | ..... |
| W. Taylor | —— 5 | 614 | 604 | 2 | 40 |
| *Township 97, range 61.* | | | | | |
| J. W. Seaman *a* | NW. 7 | 62 | 59 | 3 | 6 |
| John Moorsey | —— 9 | 945 | ..... | ..... | ..... |
| *Township 97, range 59.* | | | | | |
| Adam Wise | SW. 30 | 550 | 540 | 1¼ | ..... |
| W. T. Schmidt | NE. 30 | 517 | 510 | 2 | 30 |
| *Township 97, range 57.* | | | | | |
| John Baer | SW. 34 | 360 | 315 | 2 | ..... |
| Jacob Schmidt | NW. 15 | 500 | 400 | 2 | 2 |
| Sam Klandt | SW. 23 | 406 | 145<br>406 | 1¼ | ..... |
| Adam Heiboldt | NE. 11 | 154 | 53?<br>154 | 1¼ | ..... |
| F. Heckenlaible | SW. 1 | 73 | 73 | 2 feet | 4 |
| Fred Stryle | NW. 24 | 65 | 65 | 2 | ..... |
| Jacob Gundert | —— 21 | 747 | 630 | 2 | 4 |
| Fred Heiboldt | —— 11 | 154 | 135 | 2 | 5 |
| Heinrich Frash *a* | NW. 34 | 485 | 300<br>400<br>485 | 2–1¼ | 3 |
| *Township 97, range 56.* | | | | | |
| Gottfried Handel | —— 19 | 445 | 445 | 2 | ..... |
| J. Weber | —— 18 | 122 | 122 | 4 | 60 |
| *Township 98, range 57.* | | | | | |
| Peter Wahl *a* | SE. 21 | 64 | 64 | 2½ | 1 |
| George Gross, jr | NE. 1 | ..... | ..... | ..... | ..... |
| *Township 99, range 58.* | | | | | |
| Henry Reiswig | —— 29 | 275 | 130<br>270 | 2 | 1 |
| Conrad Remikee | NW. 21 | 280 | ..... | 2 | ..... |
| John Bombach | —— 29 | 300 | ..... | ..... | 10 |
| *Township 98, range 56.* | | | | | |
| H. Dewald | SW. 17 | 54 | 52 | 3 | 4 |
| Joseph Hoeffer | NW. 6 | 53 | 53 | 2 | 9 |
| *Township 99, range 56.* | | | | | |
| Jacob Walter | SE. 19 | 95 | ..... | 2 | Many. |
| David Wallmann | SW. 19 | ..... | ..... | ..... | ..... |
| Anna Hoeffer | SW. 31 | 75 | 54 | 2 | 12 |

*a* Sunk in 1896.




LOGS OF ARTESIAN WELLS IN HUTCHINSON COUNTY, SOUTH DAKOTA.

It will be seen from this list that the greater number of wells are in the vicinity of Parkston, mainly within a radius of 6 miles and extending southward toward Tripp. There are other deep wells about Tripp. In the center of the county the wells are more widely scattered, and there is another group of them in the vicinity of Menno. No wells have been reported in the northeastern portion of the county except some shallow ones west of Freeman. In the Parkston region the water-bearing stratum lies at a depth of between 475 and 525 feet over quite a wide area. The depth increases in the higher lands westward and southward, and on the high ridge at Tripp the water lies 820 feet below the surface. On the very high land in the extreme southwestern corner of the county the depth is correspondingly greater. During the last season, in sec. 9, T. 97, R. 61, a boring was made to a depth of 945 feet which failed to reach the water-bearing horizon owing to the height of the land. Throughout the artesian area in the western portion of the State there are small flows of water of higher horizon than the Dakota sandstone. These furnish flows to wells from 120 to 160 feet in depth. In the region about Menno the distribution of the underground waters is somewhat irregular. The main artesian horizon lies between 400 and 500 feet below the surface, but at the Gundert well, in sec. 21, T. 97, R. 57, it was found necessary to go to a depth of 747 feet. There are a few wells which obtain water supplies from shallow sources, probably in the drift. There are several such wells in T. 98, Rs. 57 and 58, and in T. 99, R. 56. No wells have been reported in the high range of hills which extend south from Freeman in the southeastern corner of the county. It is probable that on the higher slopes of these hills no flow would be obtained, although undoubtedly the entire region is underlain by the water-bearing strata.

At the Hutterische Colony at Milltown an attempt has been made to obtain water in larger flow and with greater pressure than are found in the water-bearing stratum which supplies the generality of wells in that vicinity. The purpose was to obtain power for the mill. The boring is in the James River bottom, and has reached a depth of 365 feet. The record is given in Pl. XLII. The outer casing, 10 inches in diameter, is down to the hard rock, which begins at 257 feet, and then there is a 6-inch bore for the next 108 feet to the bottom. A small flow was found at a depth of 221 feet, and a flow from 250 to 257 feet, on the surface of hard rock, furnishes a fair supply. The hard rock is stated to be calcareous sandrock, similar to that found by Mr. Ashmore 1 mile south of Artesian and at Scotland. On the table land 40 feet above the level of the mill boring there are flowing wells which obtain good supplies from the porous sandrock lying on the hard rock. The thickness of the water-bearing stratum is there 90 feet.

## BONHOMME COUNTY.

A few shallow wells and one deep well were sunk in this county in 1896. Some of the facts regarding them are given in the following list:

*Supplemental list of artesian wells in Bonhomme County, South Dakota.*

| Location, etc. | Depth. | Distance from the surface to top of beds yielding flows. | Diameter. | Yield per minute. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons.* | |
| Peter Weber, T. 95, R. 57, sec. 8. | 200 | 100<br>200 | 2 | 5 | |
| C. Mehrer, T. 95, R. 57, sec. 8. | 300 | 115<br>250<br>300 | 2 | 5 | |
| Johann Redmann, T. 95, R. 57, sec. 5. | 90 | 90 | 2 | 5 | First flow. |
| John Brown, T. 60, R. 93, sec. 5. | 825 | ..... | 6 | 1,800 | Closed pressure, 76 lbs. per square inch. |
| Thos. Morgan, T. 94, R. 60, sec. 9. | 768 | 690 | 2 | 60 | Sunk in 1895. |
| Hutterische Colony, near Bonhomme. | 645 | 400<br>450<br>580 | 3 | ..... | Pressure, 65 lbs. 50 feet above Missouri River. |
| Hutterische Colony, near Bonhomme, one-fourth mile distant. | 590 | ..... | 7 | 1½ | Pressure, 55 lbs. |
| Hutterische Colony, near Bonhomme, T. 96, R. 59., sec. 15. | 700 | ..... | 2 | ..... | In a ravine. Chalk, 20–120 feet. |

Information has also been received of another well sunk in 1895 on the farm of Thomas Morgan, and in regard to some of the wells of the Hutterische colony, near Bonhomme, which were not described in the Preliminary Report, and which it is desirable to place on record. They are included in the list. The log of the 645-foot well of the Hutterische colony is given in fig. 82.

The driller of the Brown well states that the sandrock is divided by 20 feet of pinkish, putty-like clay, with 30 feet of sandrock above, yielding 600 gallons of water per minute, and 30 feet below, yielding 1,100 gallons per minute.

There is also given in fig. 82 the log of a boring made some years ago near Scotland, kindly furnished by Mr. A. E. Swan. It indicates the presence of a series of pink, sandy deposits under the main water-bearing horizon, lying upon rock thought by the driller to be undoubtedly

Sioux Falls quartzite, which was penetrated with great difficulty for 6 feet at the bottom of the well. The pink sandrocks are said to contain distinctly calcareous streaks.

## YANKTON COUNTY.

Very little progress was made in well boring in this county during 1896. In June an attempt was made to increase the flow at the city well in Yankton by deepening it from 625 to 942 feet, but no material increase of flow was obtained. I am informed by Prof. J. E. Todd that the last 44 feet were in crystalline rock. The driller, Mr. P. F. Kearns,

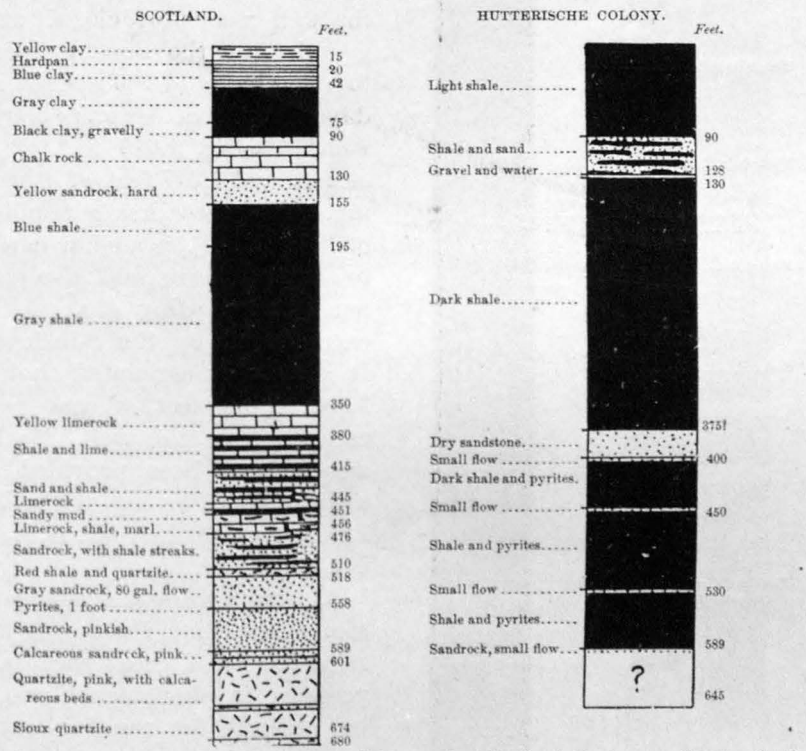



FIG. 82.—Logs of artesian wells at Hutterische Colony and at Scotland, Bonhomme County, South Dakota.

informs me that some years ago at the Asylum, 3 miles north and on the same level, he found the Sioux Falls quartzite at 825 feet.

## WEST OF THE MISSOURI RIVER.

On two of the Indian reservations west of the Missouri River deep borings were in progress in 1896; one at the Cheyenne Agency, about 75 miles above Pierre, which obtained a large flow of water, and the other on the Rosebud Reservation, 22 miles east-northeast of the agency, which has not yet obtained a flow. They were both sunk by

the United States Indian Service Bureau. A well was started in 1897 on the Lower Brule Reservation, near Chamberlain.

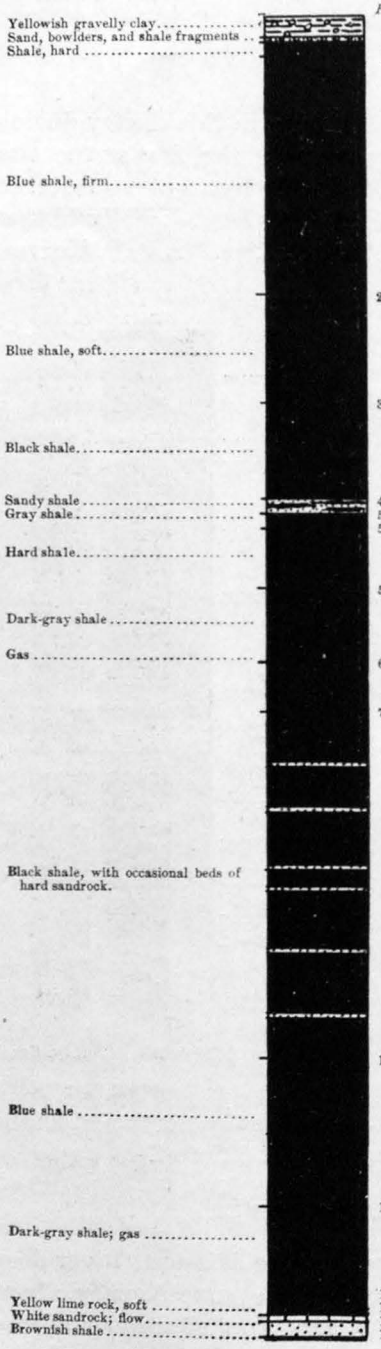



FIG. 83.—Log of artesian well at Cheyenne Agency, Dewey County, South Dakota.

The well at the Cheyenne Agency is in the Missouri River bottom, on a terrace about 40 feet above the river. The flow was found at a depth of 1,317 feet, under a cap rock 1 foot thick. The volume of water is stated to be 500 gallons per minute, and the pressure 205 pounds per square inch. The pressure when the well was first closed was 187 pounds, but the amount increased to a maximum of 205 pounds in four days. The well contains 530 feet of 8-inch casing, 1,015 feet of 6-inch casing, and 1,337 feet of 4-inch casing. The water has a temperature of 79° or 80° F., is similar in salinity to that of Pierre, and also contains much illuminating gas, which was encountered by the 8-inch casing. It is roughly estimated that about 2,400 cubic feet of gas per day escapes from the well. So far no means have been provided for its utilization. The log of the boring, kindly furnished by Mr. A. E. Swan, is given in fig. 83.

Although the water of this well is somewhat saline, the boring is to be regarded as a great success. The pressure is phenomenal, and could be utilized for running extensive machinery if necessary.

The boring on the Rosebud Indian Reservation has been in progress for two years, and had attained a depth of 2,500 feet early in February, 1897. Owing to the exhaustion of funds available for the continuation of the boring the work has been discontinued, but a further appropriation of $3,000 has been made to enable it to be continued entirely through the Dakota sandstone and, it is hoped, into the underlying formations. It will be a very important

experiment and will throw light on the underground water resources for a wide area of the plains country west of the Missouri River. The boring is situated on the high divide at the head of branches of Oak Creek, of White River, and of Keyapaha River, and is intended to supply water to the creeks for the watering of stock belonging to the Indians.

A partial record of the boring, based on samples kindly furnished by the Indian agents, is given in fig. 84. The inner casing of the boring is 6 inches in diameter, the 8-inch casing having stopped at 2,145 feet in a 10-foot bed of soft clay, which caved so badly as to pinch the pipe and render further progress impracticable. At the last, 400 blows were required to move the casing an inch, and then 100 blows every inch to keep it going. It finally stopped at the end of June, 1896. The water in the boring stood at 1,140 feet below the surface at a depth of 1,390 feet in December, 1895. At 1,490 feet more water was found, which rose slightly higher. The first sand found, at 1,880 to 1,885 feet, in a hard layer, yielded water, which rose to within 600 feet of the surface in February, 1896. At 2,165 feet there was a very open sandrock, with a considerable volume of water, which rose an additional 100 feet in the well. In a bed of sand extending from 2,292 to 2,310 feet a still further volume of water was found, mainly at a depth of 2,295 feet, but without increase of head. The calcareous beds at 1,550, 1,660, 1,870, and 1,900 feet appear to be in the Niobrara formation—the chalk rock of the Missouri River

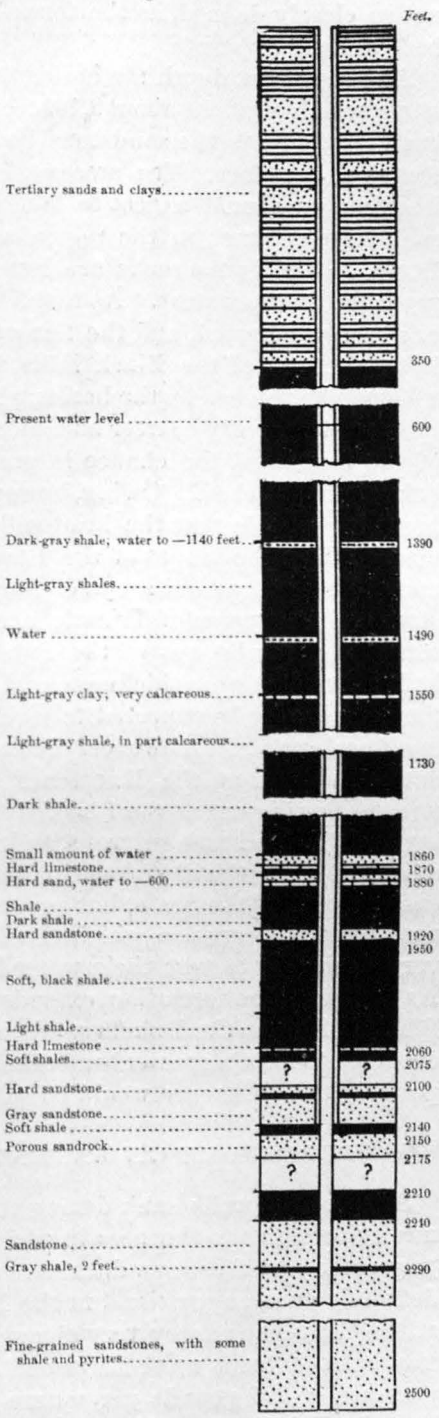


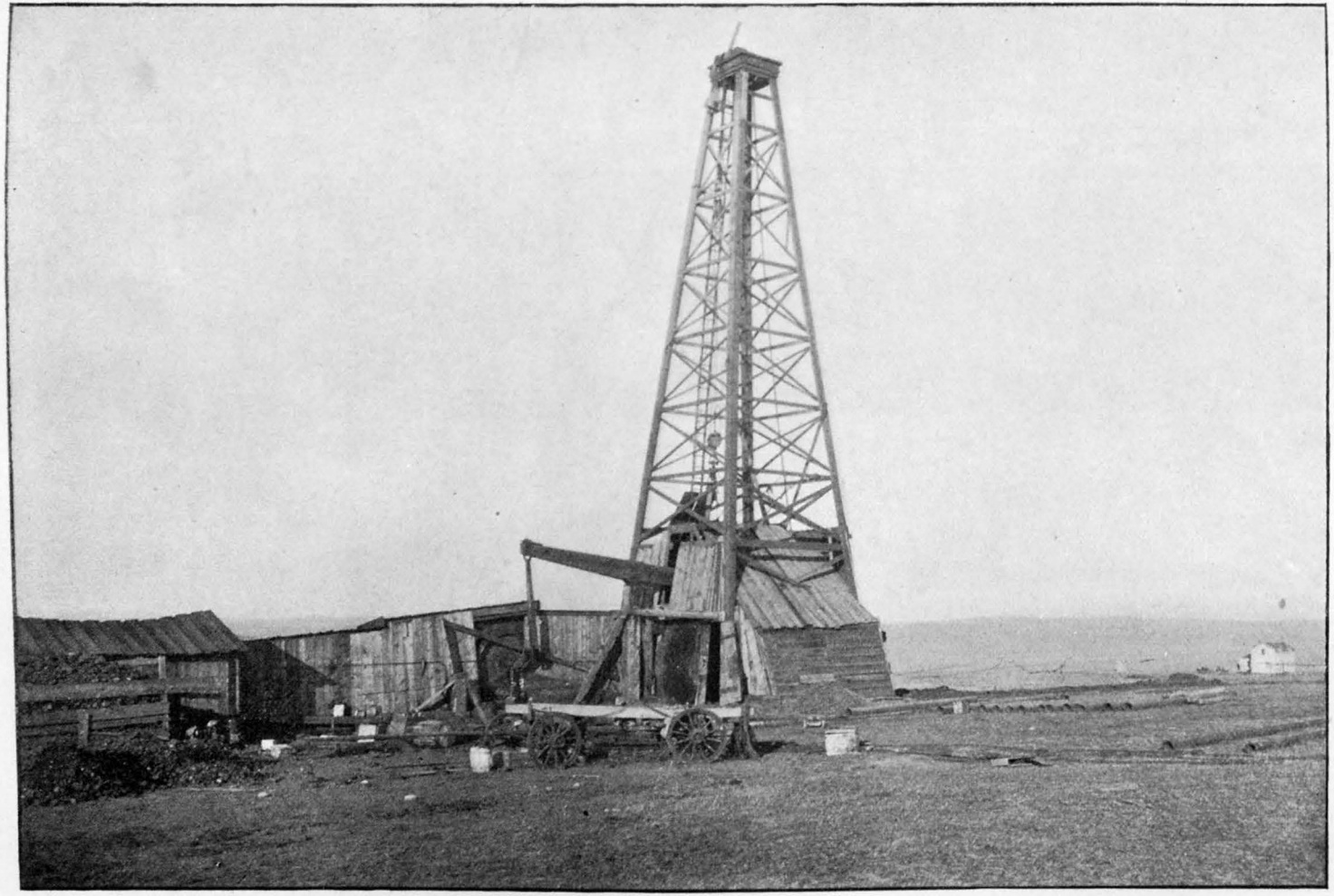

FIG. 84.—Log of boring on Rosebud Reservation.

region. The relations of the underlying Benton shales, however, are not so clearly defined, as the formation appears to include calcareous beds and sandy strata.

At the present depth the boring is quite deep into the Dakota sandstone, which began at about 2,100 feet. A considerable volume of water has been found in the sandstone beds, which rises to within about 500 feet of the surface. The amount, however, appears to be very much less than we should expect to find in this formation, which furnishes such large volumes in the region adjoining and east of the Missouri River. Possibly the rocks are here so fine grained as to be much less pervious to the waters. As a thickness of 400 feet of the sandstone has been penetrated, and the formation is not much thicker than this in the foothills of the Black Hills, it is probable that the basal beds will soon be reached by the boring when it is continued. As these basal beds are frequently coarser and more porous than the upper members of the formation, the chance is greater for a larger volume of water being found in them. Owing, however, to the high altitude of the boring it is probable that the head will not be sufficient to give a surface flow. Along the slopes of the Black Hills the Dakota formation is underlain by clays and sands of Jurassic age, the red clays and sandstones with gypsum of Triassic age, and then a great series of limestones and sandstones of the Paleozoic. The Jurassic and Triassic beds are not of great thickness, and their texture is mainly so fine that they can hardly be expected to yield a water supply. In the underlying limestone series, however, the conditions are very favorable for the flow of waters, as the limestones are porous and cavernous. The streams flowing out of the Black Hills lose much of their water in passing over the limestone outcrops, and this water undoubtedly extends far eastward down the dip of the strata. The limestones thin out in the eastern part of the State, but probably extend with diminished thickness under the area in which the Rosebud boring is situated. It is very desirable to test their water-bearing capabilities at this point. As the limestone formation extends much higher up the flanks of the Black Hills than the Dakota sandstone, the limestone waters should be expected to have a greater head than those of the Dakota sandstone, and possibly this difference would be sufficient to afford a flow at Rosebud.

## NEW LIGHT ON EXTENT OF ARTESIAN BASIN.

Some of the wells sunk during the season of 1896 have added definite evidence as to the area in which artesian flows may be expected. In greater part these new data have verified the prediction made, either definitely or as suggestions, in the Preliminary Report. The fine well at the Cheyenne agency very eloquently verifies the idea that the artesian basin extends up the Missouri Valley above Pierre, and the high pressure of 205 pounds per square inch is indicative of considerable lateral width in the valley, deep as it is, and great extension north-



BORING OUTFIT AT WELL ON ROSEBUD INDIAN RESERVATION, MEYER COUNTY, SOUTH DAKOTA.

ward, doubtless to far beyond Bismarck. The head indicated by the pressure of 205 pounds is not sufficient to render probable the finding of a flow on the adjoining high lands as elevated as Gettysburg, but it affords a basis for predicting flows far up the valleys of the Big Cheyenne and Moreau rivers. It is believed that the artesian basin extends all the way up the Cheyenne River Valley to the vicinity of the Black Hills. The pressures of the very successful flowing wells at Bellefourche certainly indicate a considerable extension of the artesian basin in that vicinity. The success of the Crow Creek and Greenwood wells is in line with the known extent and capabilities of the artesian-water resources in the Missouri Valley.

The deep borings in the vicinity of Kimball indicate that for a considerable area along the eastern margin of Brule County the usual water-bearing horizon consists of sand too dense to yield satisfactory supplies. Further light on the condition of the underlying beds in the vicinity will be afforded when the Ochsner Brothers continue the deepening of their boring.

Information has lately been furnished that a very small flow of water was obtained in the deep boring at Webster, in Day County, which may indicate that flows are obtainable slightly farther up the western slope of the Coteau than would be expected from the pressure at Andover, but this does not widen the limits of the artesian basin more than a few miles in this vicinity. Mr. R. W. Parliman has kindly furnished some additional data regarding this deep boring at Webster, made several years ago. The total depth was 1,400 feet, and a small flow was obtained at 1,100 feet, which is still flowing (August 27, 1896). Water was also found at 600 feet. It is stated that the principal formation underlying the drift was shale, with some beds of pyrites, limestone, and sandstone. The boring was in shale at 1,400 feet. Samples of some of the upper borings were saved and submitted for examination. They are as follows:

| Feet. | |
|---|---|
| 170 | fine sand. |
| 200–260 | moderately coarse, gray sand. |
| 260 | very fine, buff-gray sand. |
| 270–370 | moderately fine, gray sand. |
| 370–400 | moderately coarse, gray sand. |
| 400–470 | gray, very sandy clay. |
| 470–500 | moderately coarse, gray sand. |
| 890 | fine, gray sand bed Thickness not given. |

## NEW LIGHT ON PRESSURE AND HEAD.

The high pressure and elevated head of the waters of the South Dakota basin is one of the most impressive features of the area. Many of the wells have pressures of 150 pounds or more per square inch, which is equivalent to a head of from 350 to 400 feet. This head and pressure decreases rapidly, of course, as the slopes of the higher lands

are ascended, and to the southeastward, where the waters are more or less free to escape in the valleys of the Big Sioux and Missouri rivers. In the new wells sunk in 1896 some remarkable pressures have been recorded, the most noteworthy being at the Cheyenne Agency, where the amount is said to be 205 pounds to the square inch. This is equivalent to a head of 470 feet, and indicates a quite rapid ratio of increase from Pierre, where the pressure was reported as 165 pounds per square inch. In the new well at Crow Creek Agency the closed pressure was over 180 pounds, which was as high as the gage on hand would record. With a 2-inch nozzle outlet the pressure was 65 pounds, with a 1⅞-inch nozzle outlet the pressure was 70 pounds, and with a 1⅝-inch outlet the pressure was 85 pounds. This indicates a somewhat greater pressure and head than would have been predicted from our knowledge of the pressure at Chamberlain and Pierre. At the Yankton Agency the closed pressure of 119 pounds per square inch is in accordance with other wells in the vicinity. It is, however, reported that the well sunk at Fort Randall some years ago had a closed pressure of 210 pounds to the square inch, but this is not authenticated. If the head of the water increases to the westward, as we should expect, the area in which artesian flows may be expected will comprise all of the lower lands in the central plains region as far as the slopes of the Black Hills and northward far up the Missouri. The head of the water in the deep well at Chamberlain was nearly 1,900 feet above sea level; at Pierre about the same; and it is 1,970 feet at the Cheyenne Agency. This rate of increase, if it continues northward, should be sufficient to give a great flow at Bismarck, but to the westward it is not sufficient to give a flow at the boring on the Rosebud Reservation, which is at an altitude of about 2,700 feet, or only 300 feet below the altitude of intake along the foothills of the Black Hills.

## NEW LIGHT ON LOCATION OF BED ROCK.

Several of the wells sunk in 1896 are claimed to have reached bed rock, and they have thrown some new light on its position. Other wells have been sunk to a great depth without finding the bed rock, and thus our knowledge as to its minimum distance from the surface at these points has been enlarged. Some question has been raised as to the identity of the bed rock in the wells, and while there are grounds for uncertainty in some cases, there are others which appear to be well authenticated. In the Preliminary Report there was given all information on this subject that was in hand up to the end of 1895, mainly in the form of a contour map showing the altitude of the bed-rock surface. The new information obtained in 1896 does not materially affect the contours on this map, which is reproduced in Pl. XLV, mainly to illustrate the relations of underground temperature. The lines are, however, extended into the area along the Missouri River from Pierre to

Yankton, and are slightly modified at a few points. The principal modification is in the vicinity of De Smet, where, from information recently furnished, it was learned that the bed rock was at the bottom of the boring at 1,610 feet, instead of comprising the lower 400 feet of the boring, as originally stated. This indicates a somewhat greater eastward extension of the deep underground valley which passes by Huron and Iroquois.

Information has been received from Prof. J. E. Todd, State geologist, that in a well bored at Yankton bed rock was found at a depth of 885 feet and was penetrated to a depth of 929 feet. The material was said to resemble serpentine. The mouth of the well is reported at 1,259 feet above sea level. Further evidence in this connection has recently been furnished by Mr. P. F. Kearns, who states that several years ago he bored a well at the Asylum, 3 miles north of the city well and at about the same altitude, and found "Sioux Falls quartzite" at a depth of 825 feet. These observations are in accord with other evidence of a deep underground valley extending from Yankton toward Menno, and give an important factor in the position and slope of the floor of this valley, as shown in Pl. XLV.

Mr. A. E. Swan has kindly furnished the log of a well which he bored at Scotland some years ago, which throws some light on the relations of bed rock in the northeastern corner of Bonhomme County. This log is given in fig. 82, p. 587. Pink sandrock and quartzite began at a depth of 558 feet and extended to a depth of 670 feet. Much of this material was very hard, but there were included beds of softer character which were said to contain lime. These rocks lie on a very hard pink quartzite at 670 feet below the surface, which was penetrated for 6 feet with great difficulty. It is pronounced by Mr. Swan to be typical "Sioux quartzite."

In the deepest well on record in the southeastern corner of Davison County it is reported that bed rock was found at a depth of 477 feet. This well is on the farm of Mr. L. Lowrie, in sec. 9, T. 101, R. 60, and was sunk in 1896. The altitude of the land is 1,360 feet, so that the bed-rock surface is at an altitude of 883 feet. This is precisely in accord with the contour indicated in the map in the Preliminary Report and reproduced here as Pl. XLV.

In two wells in the northern part of Hanson County, of which information has recently been received, hard rock has been found to underlie the water-bearing sandstone, but its nature has not been definitely proved. One well is in sec. 12, T. 104, R. 58, where the rock lies 483 feet below the surface. It was drilled into for 3 feet at great expense. From some of the statements made regarding the material it is possible that the rock may be pyrites, but it is more probable that it is the dark granite reported last year at a depth of 512 feet in sec. 14 of the same township. It is thought by the drillers not to be the Sioux quartzite.

In the well in sec. 7, T. 104, R. 57, the water-bearing rock was found

to lie on excessively hard rock at a depth of 510 feet. This underlying formation was penetrated only a few inches, but it was thought to be bed rock.

In the same township, about 4 miles north of Farmer, Mr. F. G. Butler, well driller, made a boring 455 feet deep in which the last 40 feet were in a rock supposed to be Sioux quartzite. No water was obtained.

In the adjacent northwestern corner of McCook County the bed rock is reported by Mr. Fred. G. Butler, well driller, at a depth of 125 feet in a well near the center of T. 104, R. 56. The rock was typical Sioux quartzite, and it was penetrated for 10 feet without finding water. This is in accord with the rapid rise of the bed-rock surface in the northeastern corner of Hanson County, as shown in Pl. XLV.

In a well 3 miles northwest of Salem an 8-inch stratum of hard rock was found at a depth of 240 feet, underlain by dry sand. At a point 4 rods distant the hard-rock stratum was 6 inches thick at the same depth, but there were sands and gravels below yielding a good supply of water.

During 1896 two deep borings have been made in the southeastern portion of Sanborn County, one of which appears possibly to have reached bed rock. It is on the Ashmore farm, a mile and a half southwest of Artesian. At a depth of 690 feet a moderately hard rock was found underlying 53 feet of shale, in which boring was discontinued. On the farm of H. C. Sprague, in sec. 10, T. 105, R. 60, 27 inches of very hard rock was penetrated at 497–524 feet, underlying 11 feet of hard shale, but softer beds with water-bearing sands were found below, down to the bottom, at 625 feet below the surface.

In Hutchinson County the only new data in regard to the position of bed rock are from Milltown, where the Hutterische Colony have been attempting to bore through the very hard rock which begins at a depth of 257 feet below the James River bottom, or about 940 feet above sea level. They have bored 108 feet into this rock, and have planned to go deeper in search of a water-bearing stratum that will furnish a large flow and a pressure sufficient to run their mill. The material is stated to be somewhat calcareous and similar to the rock found in the Ashmore well south of Artesian and at Scotland. There is, however, considerable probability that it is a portion of Sioux Falls quartzite, which we should expect to find in about this position in north-central Hutchinson County. If this is the case the prospects are poor for finding water when this boring is continued in the spring, as proposed.

Mr. Jacob Giesen, residing in sec. 23, T. 100, R. 60, reports hard rock at a depth of 350 feet, into which he has drilled 20 feet with the very greatest difficulty. Its altitude above sea level is 875 feet.

It is stated that in the De Smet well the drillers struck hard rock at a depth of 1,610 feet and could make no material progress in it. The log of this boring, kindly furnished by Mr. J. J. Miller, who was chairman of the waterworks committee, is reproduced in fig. 85.

There is some evidence that the wells in the eastern portion of Brule County about Kimball are down nearly to the bed rock, which was thought to have been identified at White Lake, in the adjoining county. The question is, however, still an open one, but probably the deepening of the boring of the Ochsner Brothers will decide the matter one way or the other. The occurrence of hard rock in the Plankinton, White Lake, and other wells in Aurora County, has been supposed to indicate an extension of an underground ridge of the Sioux Falls quartzite westward from Mitchell, and if this is the case it no doubt should be expected to underlie Kimball, probably with somewhat decreased altitude, as shown in Pl. XLV. In this case we may account for the diminished flows in that vicinity by the idea that the beds, which contain abundant water supplies farther west and south, abut against the underground ridge of bed rock and that their edges do not extend to Kimball. On the other hand, the supposed bed rock may be simply an area of Dakota sandstone, locally more compact and less permeable to water than it is in the adjoining region. This is an important practical problem, which can be decided only by further borings in the doubtful area.

If, as is suggested above, the identity of the supposed western extension of the Sioux quartzite in the wells at Plankinton, White Lake, and vicinity, is open to some question, and the hard material be Dakota sandstone, it is evident, nevertheless, that there is a general upward pitch of the beds in this direction, which no doubt indicates a ridge in the underlying floor or an abnormal thickness of the Dakota formation. There can be no question as to the rapid rise of the Sioux quartzite east of Mitchell, for it reaches the surface in distinctive outcrops and has been deeply bored into in several wells. It is very

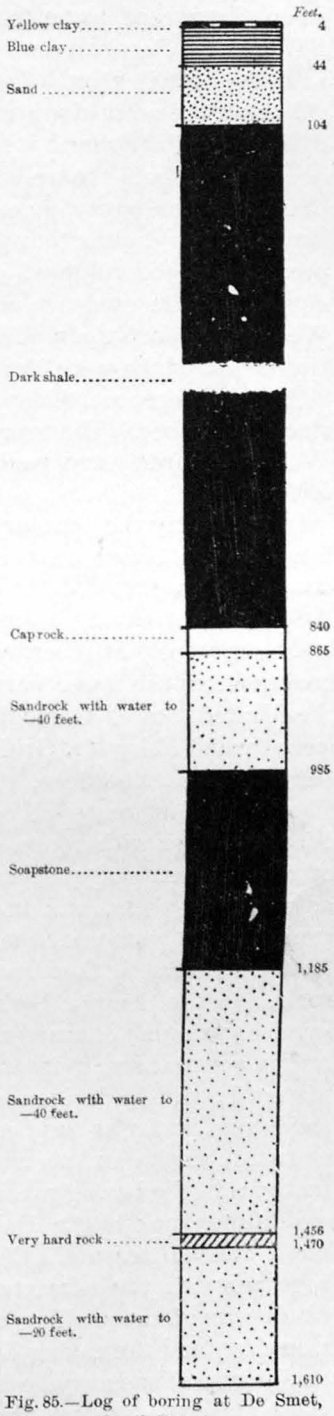



Fig. 85.—Log of boring at De Smet, South Dakota.

evident from the altitudes of the Dakota sandstone that there is a steep downward slope from Chamberlain to Pierre, as shown in Pl. XLV. The Rosebud boring also indicates that to the west and south west the floor lies much lower than about Chamberlain.

I think the most doubtful evidence of the occurrence of bed rock is at Fort Randall, where it rises much nearer to the surface than would be expected from the wells at Greenwood and in the western corner of Charles Mix County, on either side, which failed to reach bed rock at much greater depths than the Fort Randall well. The evidence of the presence of the ridge which extends to Wolsey north of Huron does not rest on the evidence of the reported occurrence of bed rock in the Wolsey well, but upon the materials from the Budlong well north of Hitchcock, which were clearly borings from granite, showing, as stated in last year's report, feldspar, quartzite, and mica in an altogether distinctive manner. The reported presence of the bed rock in the well at Wolsey accords very well with the very definite evidence north of Hitchcock.

In preparing the contour map of the bed-rock surface, all the calculations were based on the known altitude of the mouth of the well above sea level.

Some doubt having been expressed in regard to the identity of the crystalline rock at Aberdeen, a careful examination was made of the borings from the lower part of the well by several of the geologists of the United States Geological Survey in Washington. Two samples were furnished by Mr. Griffith from the section preserved in the High School well at Aberdeen. They were both clearly of a granitic nature. The uppermost material contained fragments of quartz, feldspar, and mica, together with rounded grains of quartz, sand, and shale. Some of the fragments of quartz were sharply crystalline, with some feldspar adhering to them, and in one or two grains mica also. The sand grains which were mixed with this material were undoubtedly derived from a stratum farther up in the boring by the jar or attrition of the tools. In the deepest borings the rock was somewhat harder but of precisely similar character. The angular feldspar was unmistakable, and in some cases it is attached to quartz fragments. This sort of material could be derived only from the bed rock itself. The Dakota sandstone, so far as has been observed, does not contain feldspar, nor angular quartz detritus, and the large amount of the crystalline-rock material in the boring precludes the possibility of a chance bowlder of crystalline rock in the Dakota sandstone, which in itself would be a most unusual feature. The presence of the rounded quartz grains, together with the admixture from above, is to be expected when the conditions of the drilling are considered. Progress in the bed rock was slow, and the casing did not completely shut off a small influx of sand from sedimentary beds of the Dakota sandstone above. Of course these statements do not preclude the possibility of bowlders from the

surface drift having been thrown down the well, but it is believed that there are no good grounds for urging this as a probability.

## IRRIGATION BY ARTESIAN WATERS IN 1896.

In eastern South Dakota interest in irrigation by artesian-well waters is steadily increasing as the great value of this resource is becoming more generally appreciated. A large part of the farming district of the State is underlain by waters which will flow in large volume from wells of moderate depth, but lack of capital and of knowledge of irrigation methods has retarded the utilization of these waters.

The season of 1896 having been comparatively rainy in many sections, there has been less irrigation than in the previous season, but a number of new wells have been sunk and reservoirs and ditches prepared in readiness for the next dry season. At this writing it is probable, from the very heavy snowfalls and rapid thawing in the winter of 1896–97, that the ground is sufficiently moistened to withstand a dry summer and that irrigation may not prove necessary in 1897. Every farmer possessing an irrigation outfit, however, should feel great satisfaction in having means to assure crops in other dry seasons.

### AURORA COUNTY.

In this county there is much interest in artesian-well irrigation, although there are only a few farmers now engaged in irrigation. The following information has been received in regard to results:

Messrs. Mullen Brothers, near White Lake, report the following returns from irrigated crops in 1896. Twenty acres of potatoes on ground irrigated during the winter yielded 100 bushels per acre; 4,000 cabbages averaged 9 pounds each; one-fourth acre of tomatoes were very good, and other kinds of garden vegetables yielded large returns.

Mr. J. D. Barton has a well for irrigation on the SW. ¼ sec. 8, T. 103, R. 63, which was completed in July, 1895. It is 755 feet deep and flows 150 gallons per minute. It cost $1,000. He has a 1½-acre reservoir, which cost $60, and plans to irrigate 80 acres. The reservoir holds 5 feet of water, has a slope of 8 to 1 inside, and its banks do not wash. He is planning to construct another reservoir of 4 acres with which to irrigate an additional 80 acres. The main ditch is one-half mile in length, 3½ feet wide, and 18 inches deep. Its cost was $10. His only irrigation so far has been in a garden, from which for several years he has obtained most satisfactory results.

Mr. O. R. Auld, of Plankinton, raised 20 bushels of potatoes from 9 rows 120 feet long, irrigated from his artesian well.

Mr. Philip Eyer, in T. 103, R. 63, 5 miles southeast of Plankinton, had a well sunk to a depth of 705 feet in 1896. It has a flow of 200 gallons per minute, which will be used for irrigation.

## BEADLE COUNTY.

There are several farms in this county which have been irrigated in previous years, but owing to the rainy season only one or two employed the waters in 1896.

On the farm of Mr. F. B. Brayton, SE. ¼ sec. 30, T. 109, R. 63, there is an 813-foot well with 250-gallon flow and 3-acre reservoir for irrigation. Owing to the abundant rain in the summer of 1896, crops were not irrigated, but on some ground wet the autumn before barley yielded a particularly large crop. Oats yielded from 75 to 100 bushels, but were considerably damaged by rust; cabbages and tomatoes yielded very large returns. A plum orchard set out in the spring of 1895 grew well during the first summer, but the trees were mostly dead in the spring of 1896, it is thought on account of too much flooding.

## BONHOMME COUNTY.

Irrigation interests in this county are gradually enlarging and the waters are now in use at several localities, mainly, however, for gardens and small crops.

Hon. John Brown, residing in sec. 5, T. 93, R. 60, has recently made extensive preparations for irrigation. He has a new 792-foot well, which flows 1,800 gallons per minute. The reservoir occupies 4 acres, and is built against the side of a hill. Part of the wall on the lower side of the reservoir is 10 feet high, with inside slope of 6 to 1 feet. The main ditch is 2 miles long, 6 feet wide, and 2 feet deep, with a width of 3 feet at the bottom, which is about 1 foot below the surface. The cost of this ditch was 25 cents per rod. The total cost of reservoir and ditches is stated to have been $600.

During the season of 1896 there were irrigated 10 acres of barley, which harvested 75 bushels per acre, and about 150 acres of corn, which yielded 75 bushels per acre. Ten acres of alfalfa, just started, were irrigated three times, and on two mowings yielded 2 tons per acre each time. It is planned to irrigate 500 acres on this farm.

At the Hutterische Colony, near Bonhomme, some irrigation has been practiced in previous years with excellent results, but there was sufficient rain for all the crops in the summer of 1896.

## BRULE COUNTY.

There have been several important additions in 1896 to the many extensive irrigation plants in this county, and other wells are in progress or projected.

The twenty-five wells now available for irrigation have a capacity of about 18,000 gallons per minute, or nearly 26,000,000 gallons per day, or sufficient to flood nearly 80 acres 1 foot deep every twenty-four hours. Individually their flows vary in greater part from 800 to 1,300

gallons, but there are notable exceptions, both greater and less. The smaller flows are in the vicinity of Kimball and northeastward for some miles, where, so far as now explored, they are less than 100 gallons, only 40 gallons in the new Ochsner well, and less in other township wells farther east and north. Possibly larger flows may be found in deeper borings.

Information in regard to irrigated crops has been received from a number of farmers.

At the irrigation farm of Hon. J. M. Greene, in sec. 15, T. 102, R. 70, the reservoir is 6 acres in area and has banks 50 feet wide at base, 8 feet high, 8 feet wide on top, and covered with willows which have grown in such a mat as to afford perfect protection from wash. There are 8 miles of main ditch 6 feet wide and 18 inches deep. Cost of well, $3,000; of reservoir, $1,500, and of ditches, $200 per mile. Arrangements have been made to irrigate 640 acres, and then there would be considerable water to spare. During the past season 400 acres were irrigated, but operations were not begun until June. The crops were wheat, oats, barley, and corn. It was found that the irrigated crops yielded about 30 per cent more than those of neighbors who did not irrigate, and on precisely similar land. This is notwithstanding a fairly rainy season. The average wheat crop in the neighborhood was about 12 bushels per acre.

Mr. H. L. Willrodt, located in sec. 21, T. 102, R. 70, has irrigated to some extent. He has a large flow of water from his 1,190-foot well. The reservoir is 3½ acres in extent, with walls 5 feet high inside, sloping 7 to 1, and 8 feet wide on top. This reservoir cost about $300. It has two gates. The main ditch from one gate is 80 rods long; the ditch from the other is 160 rods long. The ditches are 12 feet wide and 1 foot deep. They cost about $200 per mile. During the season of 1896 Mr. Willrodt irrigated about 120 acres with gratifying results. Eighty acres of wheat yielded 28 bushels per acre; 30 acres of oats yielded 50 bushels; his corn produced 40 bushels and his prairie hay 2 tons per acre.

Mr. W. A. Carpenter, of Chicago, has a large irrigation farm in sec. 35, T. 104, R. 70, near Pukwana, in charge of Mr. J. S. Sanborn. A 10-inch well has recently been sunk to a depth of 907 feet, which flows 1,386¼ gallons per minute. Cost, $5,200. A 7-acre reservoir has been built with about 2 miles of main ditch and 4½ miles of laterals. It is proposed to irrigate 1,170 acres.

The city of Chamberlain is planning to pipe water from the new well to the top of the bluffs to fill a reservoir for use in irrigating the bottoms below. Engineers have been at work on the plans.

Mr. Martin Smith has recently completed arrangements for irrigating a farm in sec. 25, T. 103, R. 69. He has a well which furnishes a large volume of water, and plans are perfected for reservoirs and ditches for extensive irrigation.

The well of Mr. Fred Shereda, in sec. 18, T. 101, R. 68, is for irrigation. It was sunk in 1896, has a depth of 900 feet, and flows 200 gallons per minute.

Mr. L. H. Willrodt, near Chamberlain, uses water from the township artesian well, taken by ditch and pumped up to his garden by windmill power. He raised vegetables for household use only, but reports that everything raised showed a wonderful growth, being fully double in size and yield over nonirrigated gardens in the vicinity.

## DAVISON COUNTY.

Of the numerous small flowing wells in this county the waters of many have been employed for irrigation for several years with most satisfactory results. In most cases the irrigated areas are small, but a number of farmers have facilities for flooding from 40 to 100 acres. Some of the results of irrigation reported for 1896 are as follows:

Mr. Everett Smith, sec. 26, T. 104, R. 61, irrigated 15 acres in corn, pumpkins, oats, and truck, and had large crops of all.

Mr. John K. Johnson, sec. 3, T. 103, R. 62, Mount Vernon, irrigated 100 acres direct from his 646-foot well, 700-gallon flow. A reservoir of 10 acres is now under construction. His small grain is reported to have been good and his garden crops very fine. He plans to irrigate 400 to 500 acres. Some of his crops yielded as follows: Wheat, 34 bushels per acre; corn, 48 bushels; oats, 73 bushels; potatoes, 210 bushels. Crops not irrigated in same section went: Wheat, 7 bushels per acre; corn, best, 8 bushels; oats, 22 bushels.

Mr. Ira Frazier, sec. 27, T. 104, R. 61, irrigated 40 acres. His oats and corn were reported to be particularly good, and garden products were also very satisfactory.

Mr. George Schlund, sec. 27, T. 104, R. 62, irrigated potatoes and flax with good results.

Mr. Charles F. Raymond, sec. 2, T. 103, R. 62, Mount Vernon, irrigated 10 acres of corn and garden. Crops were all good.

Mr. Casper Kerr, near Mitchell, reports that portions of his corn which were irrigated yielded 38 bushels per acre, and those which were not irrigated yielded only 15 bushels.

Mr. H. Heidinger, sec. 31, T. 102, R. 62, irrigates a garden from his 642-foot well. Its flow is 20 gallons per minute.

Mr. E. D. Watkins, sec. 20, T. 104, R. 61, irrigates garden and trees. He has a 420-foot well with 22-gallon flow.

Mr. A. B. Seaton, in sec. 8, T. 103, R. 60, has irrigated from 5 to 10 acres of various crops, including garden and truck. No details were furnished, but the results were very satisfactory.

Mr. Nick. Dondelinger, sec. 17, T. 104, R. 60, has a small well from which he irrigated 4 or 5 acres in garden and truck. He reports that the products all doubled by irrigation.

Mrs. A. J. Smith, sec. 18, T. 104, R. 60, is arranging to irrigate 20 acres during the season of 1897.

Mr. Martin Gleason, sec. 5, T. 104, R. 60, irrigated 40 acres with most encouraging results.

Mr. J. Austin Clark, sec. 35, T. 104, R. 61, irrigated 5 to 6 acres of potatoes, corn, and garden, which proved a most satisfactory experiment.

Mr. F. D. Tyler, sec. 34, T. 104, R. 61, irrigates 40 acres and is greatly pleased with the result.

Mr. Alex. Tragier, sec. 33, T. 104, R. 61, made a trial of irrigation with 40 acres with such encouraging success that he will irrigate 80 acres next season.

Mr. Henry Schlund, sec. 26, T. 104, R. 62, near Mount Vernon, reports that during the winter of 1895–96 he flooded about 40 acres of his farm. Excellent results were reported, but no details are given. In his garden he raised over 300 bushels of sugar beets and mangolds from a half acre, and about 75 bushels of tomatoes from a quarter of an acre. Other vegetables yielded large returns.

Messrs. Hatch Brothers, sec. 15, T. 103, R. 62, have a 406-foot well and reservoir. They irrigate 20 acres and a garden, and have irrigated for five years.

Mr. W. M. Smith, sec. 9, T. 102, R. 62, has a 460-foot well with 90-gallon flow. He irrigates 30 acres of wheat and corn and reports that results were good.

Mr. W. M. Smith, sec. 14, T. 103, R. 62, has a 450-foot well with 60-gallon flow. He irrigates wheat and potatoes. Potatoes went 150 bushels per acre; wheat not measured.

The following farmers irrigate, but have furnished no particulars as to crops or outfit:

Mr. Art Frederick, sec. 10, T. 103, R. 62. Ten acres.

Mr. H. A. Stahl, sec. 19, T. 103, R. 61.

Mr. Ed. Lewis, sec. 34, T. 104, R. 62. Ten acres.

Mr. Peter Hogsteadt, sec. 12, T. 103, R. 62.

Mr. Charles Arland, sec. 15, T. 103, R. 62. Five acres potatoes and corn.

Mr. Simon Halverson, sec. 10, T. 103, R. 62. Ten acres.

Mr. M. Grady, sec. 25, T. 101, R. 61.

Mr. J. M. Schmidt, sec. 8, T. 103, R. 61.

Mr. Nathan Noble, sec. 25, T. 104, R. 62.

Mr. F. W. Rowell, sec. 11, T. 103, R. 62. Ten acres.

Mr. C. C. Young, T. 104, R. 61.

Mr. Jake Johnson, sec. 9, T. 103, R. 62.

## DOUGLAS COUNTY.

In this county there has been but little extensive irrigation in 1896, but many farmers and townspeople have irrigated gardens and small areas by way of experiment. They have obtained most gratifying results.

Mr. G. T. Chandler, 7 miles south of Armour, flooded 30 acres of land in the winter of 1895. The corn yielded over 40 bushels per acre and hay yielded 3 tons per acre. Corn on adjoining lands yielded only 20 bushels per acre.

Mr. James A. Wilson, sec. 35, T. 99, R. 63, near Armour, reports that during 1896 he had the following results with irrigation: Eight acres of potatoes on ground flooded the preceding November yielded 100 bushels per acre with cheap cultivation and light seeding; 50 acres of wheat on ground similarly flooded produced 25 bushels per acre; 17 acres of oats on ground flooded in the winter of 1894–95 produced 40 bushels of good quality. He finds that the benefits during the second year after flooding are fully as great as during the first crop. Beets, cabbage, turnips, tomatoes, and all vegetables produced fine growth wherever the water was used.

On the farm of Mr. C. E. Huston, near Armour, portions of 4 acres were irrigated. There were 2 acres planted in potatoes, which harvested 400 bushels, about double the yield from unirrigated land. The other 2 acres were in sweet corn, of which the precise yield was not ascertained, but Mr. Huston is satisfied that the irrigated portion gave more than double the crop the unirrigated portion did, and of much better quality. From a small area planted in pie plant, asparagus, onions, peas, and other small garden stuff, the results were most satisfactory.

The irrigating plant consists of a 12-foot windmill with an 8-inch pump by which the water is lifted 18 feet into a reservoir 100 feet in diameter, which can be filled to a depth of about 5 feet in the center. The water is pumped from the ditch that carries the water from the artesian well at the mill.

## HANSON COUNTY.

Very little irrigation is practiced in this county, but as the results in adjoining regions are becoming known, some interest in the subject has been aroused. Several small trials of the water have been made in the northern townships of the county with most satisfactory results. The only definite information obtainable was from Mr. George Knapp, 5½ miles north and 2 miles west of Farmer. He has a reservoir or wide ditch about 60 rods long, 30 feet wide, and 5 feet deep, to be used for irrigation. In the autumn of 1895 he flooded 20 acres, and the flax on it in 1896 yielded a large return. A small irrigated area of potatoes, squashes, strawberries, and raspberries yielded large crops.

## HUTCHINSON COUNTY.

Many gardens and small areas are irrigated by artesian waters in this county, and the use of the waters in this way is rapidly extending. The following is a list of some of those who irrigate:

Mr. Joseph Oberembt, sec. 10, T. 100, R. 61.
Mr. M. Oberembt, sec. 10, T. 100, R. 61.
Mr. Matt Korter, sec. 22, T. 100, R. 61.
Mr. Joseph Schoenfelder, sec. 21, T. 100, R. 61.
Mr. Paul Schoenfelder, sec. 26, T. 100, R. 61.
Mr. J. P. Puetz, sec. 14, T. 100, R. 61.
Mr. John Schumacher, sec. 20, T. 100, R. 61.
Mr. Theo. Emmery, sec. 33, T. 100, R. 61.
Mr. John Hohn, sec. 27, T. 100, R. 61.
Mr. H. Esser, sec. 13, T. 100, R. 60.
Mr. L. Bower, sec. 24, T. 100, R. 60.
Mr. J. W. Straup, sec. 1, T. 99, R. 61.
Mr. Frank Fritza, sec. 9, T. 99, R. 61. Ten acres.
Mr. Henry Bäke, sec. 14, T. 99, R. 61.
Mr. Carl Radke, sec. 24, T. 99, R. 61. Potatoes.
Mr. C. Raugust, sec. 22, T. 99, R. 61.
Mr. John L. Schmidt, sec. 20, T. 99, R. 61.
Mr. John Tiede, sec. 27, T. 99, R. 61.
Mr. George Heisinger and T. Heisinger, sec. 12, T. 99, R. 61.
Mr. Fred Unger, sec. 7, T. 99, R. 60.
Mr. T. H. Benson, sec. 23, T. 99, R. 60.
Mr. M. Heisinger, sec. 7, T. 99, R. 60.
Mr. H. Benson, sec. 34, T. 99, R. 60.
Mr. Charles Fergen, Parkston.
Mr. John Isaac, sec. 34, T. 99, R. 59.
Mr. F. Mehlhaff, sec. 16, T. 98, R. 59.
Mr. Jake Stoebner, sec. 30, T. 98, R. 60.
Mr. Henry Stoebner, sec. 29, T. 98, R. 60.
Mr. N. V. Morris, sec. 20, T. 98, R. 60. Thirty-five acres.
Mr. Dan Koth, sec. 11, T. 98, R. 60.
Mr. J. Wudel, sec. 3, T. 98, R. 60.
Mr. G. Koenig, sec. 5, T. 98, R. 60.
Mr. William Tiede, sec. 1, T. 98, R. 61.
Mr. J. Tiede, sec. 1, T. 98, R. 61.
Mr. John Heinz, sec. 3, T. 98, R. 61.
Mr. G. Kludt, sec. 4, T. 97, R. 60.
Mr. W. T. Schmidt, sec. 30, T. 97, R. 59.
Miss Anna Hoeffer, sec. 31, T. 99, R. 56.

### JERAULD COUNTY.

Mr. Frank H. Campbell, sec. 6, T. 106, R. 63, has an extensive and successful irrigating outfit. His well is 760 feet deep, 2 inches in diameter, and flows 280 gallons per minute. The reservoir is 400 feet in diameter, with wall 6 feet high. There is half a mile of main ditches.

He states that his results with irrigation in 1896 were as follows: Thirty acres of corn yielded 40 bushels per acre; 7 acres of potatoes yielded 600 bushels of good potatoes, which sold on the farm, to neighbors, for 20 cents per bushel. Owing to lack of experience in using the water some of the plants were drowned and others were not sufficiently irrigated, but those which were properly treated yielded large returns. Thirty-five acres of corn yielded 40 bushels per acre, while adjacent fields yielded only 20 bushels per acre. He is planning to irrigate his entire quarter section, and believes the well will furnish sufficient water, aided possibly by rainfall. His well cost $600 and the reservoir $800.

Mr. F. B. Brayton, near Alpena, is arranging to irrigate from his well. The farm is the SW. ¼ sec. 30, T. 109, R. 62. Mr. W. H. Miller is the manager. The well is 835 feet deep and is said to afford 350 gallons a minute. The reservoir covers 3 acres, and it has walls 6½ feet high. Operations have been very limited so far and no definite results could be reported.

Mr. S. H. Albert, near Wessington Springs, wet his land with artesian water in the fall of 1895, and in part also during the winter. He reports that wheat yielded a little over 30 bushels per acre No. 1 wheat, while on adjoining farms not irrigated the yield was only from 12 to 18 bushels per acre, and No. 2 in greater part. Very satisfactory results were also obtained with potatoes, corn, and beets.

### SANBORN COUNTY.

A few of the farmers irrigated in 1896, mainly gardens or small truck patches. Care has to be taken not to apply the cool well waters of the shallower wells directly to the growing plants. Such oversight has often resulted in damaging the irrigated area.

Mr. H. W. Crawford, of Letcher, reports that he has used the water from the town well with marked benefit on his garden and truck patch. Many experiments were tried and various results obtained, but they were all eminently satisfactory, except in one or two cases where too much water was used while the crop was growing. The yield of potatoes was particularly large.

Mr. W. E. Ryan has continued to irrigate on his farm near the town. Owing to the rainy season, however, operations were less extensive than in previous years. He irrigated portions of his corn and oats with very marked results.

## SPINK COUNTY.

Irrigation by artesian-well waters has been practiced extensively in this county with marked success. The waters lie quite deep, but they are in large volume under the greater part of the county. Irrigation operations were less extensive in 1896 than in the two previous years, owing to the more rainy season and the clogging of one of the most important wells near Redfield.

Mr. A. J. Glidden continued irrigation on his farm near Hitchcock. Owing to the abundance of rain in the early part of the season wheat and oats in this vicinity suffered considerably from rust. In the dry weather which followed he irrigated about 30 acres of wheat, which yielded 15 bushels per acre, while wheat not irrigated yielded only about 10 bushels. Other yields were as follows: 4 acres of barley, 45 bushels per acre; 20 acres of corn, 40 bushels per acre; 2½ acres of cabbage, 12 tons; 6 acres of potatoes, 800 bushels; one-fourth acre of onions, 300 bushels; one fourth acre of tomatoes, 150 bushels; 10 acres of prairie grass, 1½ tons of hay per acre. Several other vegetables were raised in the garden with the assistance of irrigation with most satisfactory returns. Cottonwood and willow cuttings planted in the spring and carefully irrigated showed a growth of from 3 to 5 feet, while those which were not irrigated failed to live.

On the Hunter farm, near Mellette, the irrigated crops were seriously damaged by hail.

Mr. Loren A. Buswell, near Conde, reports that during the past four years he has raised most satisfactory crops of garden truck by means of artesian irrigation. During the last season his crops were seriously damaged by the ravages of cutworms, and the product was thus greatly reduced. The area under irrigation is about 10 acres. It is stated that flooding proved unsatisfactory for strawberries, the young plants of which appear to become choked by the sediments which the water carries.

From the Hassell and Myers farm, near Redfield, now owned by Mr. John J. Myers, it is reported that no crops were irrigated in 1896, owing to clogging up of the well. It is stated, however, that the influences of previous wettings of the land were strongly marked in the crops raised. Thirty-five acres of wheat averaged about 30 bushels per acre, while unirrigated land generally in the same neighborhood yielded only about 6 to 8 bushels to the acre.

Mr. F. W. Hagmen, near Redfield, who depends on the Hassell and Myers well, could not irrigate in the season of 1896 because of the failure of that well. A couple of acres flooded the previous autumn yielded an immense crop of wheat, which is estimated to be at least three times as much as that on adjoining farms.

### YANKTON COUNTY.

Mr. George H. Whiting, of the nurseries near Yankton, reports as follows: For the greater part of the season there was an abundance of rain, so that but very little irrigation was necessary. He did, however, water a portion of his nursery stock and garden a couple of times, and the results were most promising, but July 31 a very severe hailstorm passed through the region and destroyed the greater part of the growing plants.

### TEMPERATURE OF THE DEEPER ARTESIAN WATERS.

The waters from the deeper artesian wells in the Dakota basin are of a decidedly thermal character. This is notably the case at Pierre, where the great pool of warm water at the sanitarium is supplied from an artesian well. Here the temperature is 92°. The highest temperature recorded is from the well at Harold, 94.9°. In many of the wells in James River Valley the temperature of the water is about 70°; at Crow Creek and Chamberlain it is 72°; at Fort Randall 80°, and in many wells from Yankton to Kimball and Woonsocket the temperatures are from near 60° to 70°.

All waters from deep-seated sources are warmer than those from shallow wells, for the temperature of the earth increases gradually with increasing depth. In the first 40 feet the temperature is found to be that of the mean annual temperature of the region, but thence downward the rate of increase in many portions of the earth is about 1° for each 50 feet. Artesian waters flowing in fairly large volume bring to the surface the underground temperature of the strata from which they are derived, so that with an increase of temperature of 1° for each 50 feet a well 1,000 feet deep would yield water having a temperature of 20° above the mean annual temperature of the surface. In the greater part of the artesian basin of the Dakotas the amount is found to be greatly more than this, which indicates a much higher rate of increase than the normal. On examining the distribution of the wells it is found that the rate of increase of underground temperature indicated is distributed in a very regular manner, with a rapid rise to the south and west, notably in the Fort Randall district.

So far as our present observations go the culmination is reached at Fort Randall, where, although the temperature of the water is only 80°, or possibly slightly more, the depth from which it is derived is only 576 feet, indicating an increase of temperature of 1° for each 17½ feet. This is a very phenomenal feature, and is quite exceptional among records of high underground temperatures outside of volcanic regions. At Chamberlain a rate of 1° for 21½ feet is indicated, and at Pierre 1° for 24½ feet. To the north and east these amounts decrease, but over a wide area the amount of increase is 1° for every 25 to 35 feet.

From various sources the writer has been able to obtain records of

observations on the temperatures of waters of many of the wells, so scattered over the artesian basin as to afford the means of forming a very definite idea as to the areal distribution of the underground temperatures. These data are brought together in the accompanying table, and they are represented graphically in the map, Pl. XLIV.

*Table of data bearing on artesian-well temperatures in the Dakotas.*

| Locality. | Depth of bed yielding the water. | Temperature of flow. *a* | Flow per minute. | Mean annual temperature. | Rate of temperature increase to 1° F. |
|---|---|---|---|---|---|
| | *Feet.* | ° *F.* | *Gallons.* | ° *F.* | *Feet.* |
| Aberdeen, city well No 1 | 1,077–1,100 | 66.9 S | 400 | 42 | 44 |
| Andover | 1,070–1,075 | 71.6 S | 300 | 42 | 36 |
| Armour | 696–757 | 68.3 S | 1,500 | 44 | 30 |
| Britton | 976–1,000 | 64 N | 600 | 42 | 45 |
| Chamberlain: | | | | | |
| Mill | 585–600 | 71.6 | 4,000 | 45 | 21½ |
| 25 miles southeast | 851–937 | 70 | 1,098 | 45 | 36 |
| Cheyenne Agency | 1,337 | 79 | 500 | 45 | 39 |
| Crow Creek | 760–780 | 72 | Many. | 45 | 28 |
| Columbia | 927–964 | 63 N | 940 | 42 | 45 |
| Doland | 880–895 | 69.05 S | 370 | 42 | 33 |
| Ellendale | 1,042–1,087 | 69 N | 700 | 40 | 37 |
| Fort Randall | 576 | 80 N | 600 | 47 | 17½ |
| Frederick | 1,045–1,139 | 69 N | 135 | 41 | 39 |
| Faulkton | 1,032? | 74.5 S | 100 | 42 | 30¾ |
| Greenwood | 641–651 | 70 | 3,000 | 47 | 28 |
| Groton, 4 miles north | 840–942 | 63 N | 150 | 42 | 43 |
| Harold | 1,435–1,451 | 94.9 S | 84 | 43 | 28 |
| Hitchcock | 950–953 | 70.1 S | 1,260 | 42 | 34 |
| Huron | 960 | 70 | 2,250 | 42 | 34 |
| | 836 | 65 | 360 | 42 | 36 |
| Ipswich | 1,000? | 71.6 S | Many. | 42 | 34 |
| Iroquois | 850–855 | 71.4 S | 1,000 | 42 | 29 |
| Jamestown | 1,458–1,476 | 76 N | 460 | 37 | 37½ |
| Kimball | 988–1,068 | 66.9 S | 185 | 43 | 42½ |
| Lake Andes | 725–773 | 70 | 1,500 | 45 | 30 |
| Letcher | 570–577 | 58 N | 80 | 42 | 36 |
| Mellette: | | | | | |
| Mill well | 884–920 | 65 N | 1,320 | 42 | 39 |
| Brunn well | 925–958 | 65 N | 60 | 42 | 41 |
| Baker well | 871–920 | 65 N | 894 | 42 | 39 |
| Day well | 915–993 | 65 N | 1,300 | 42 | 41½ |
| Bird well | 902–930 | 65½ N | 670 | 42 | 39 |

*a* Temperatures marked S are given by Prof. J. H. Shepard, South Dakota Experiment Station Bulletin No. 41. Those marked N are by Colonel Nettleton.

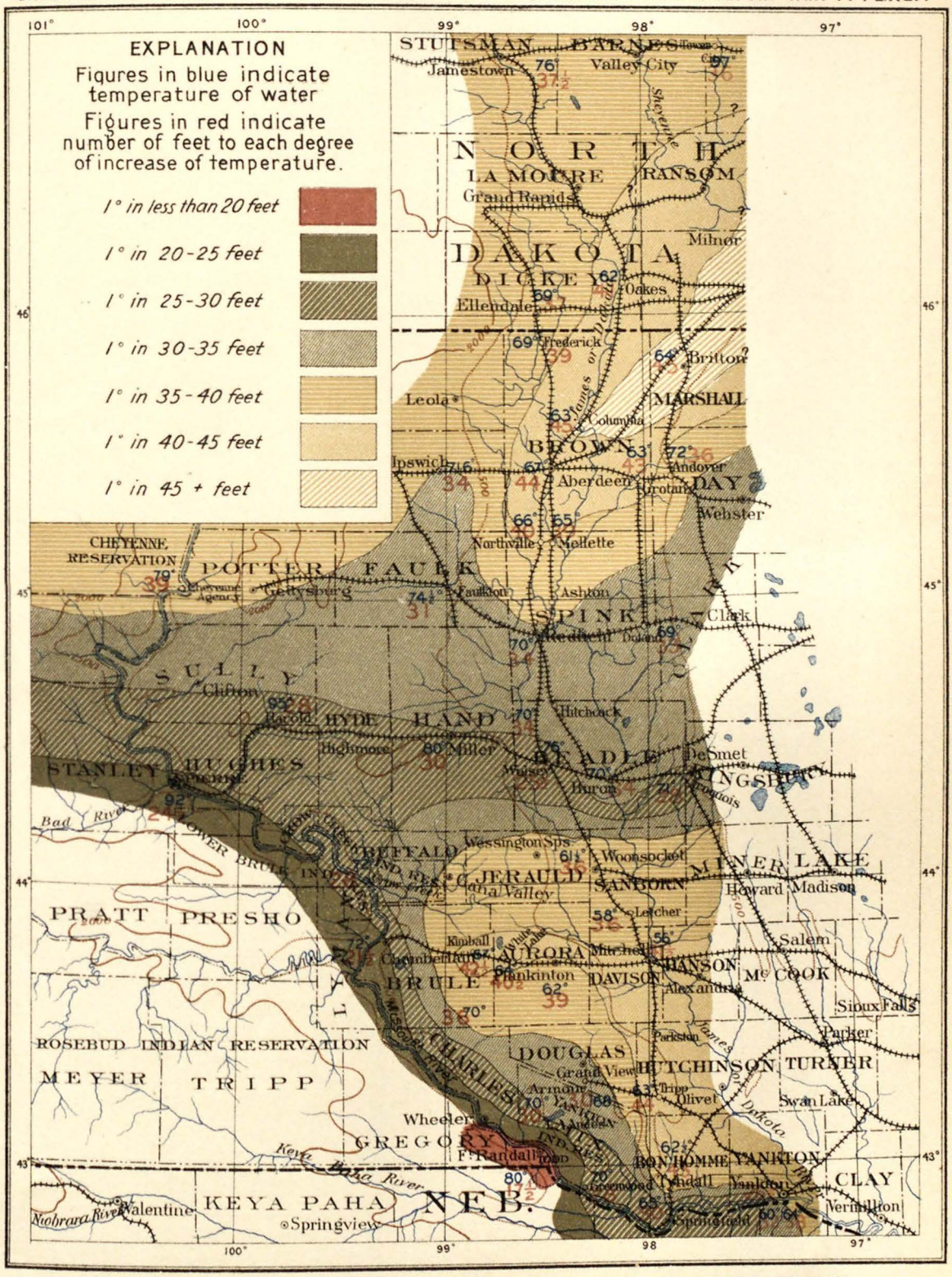
*Table of data bearing on artesian-well temperatures in the Dakotas*—Continued.

| Locality. | Depth of bed yielding the water. | Temperature of flow. | Flow per minute. | Mean annual temperature. | Rate of temperature increase to 1° F. |
|---|---|---|---|---|---|
| | *Feet.* | ° *F.* | *Gallons.* | ° *F.* | *Feet.* |
| Miller | 1,115–1,139 | 79.8 S | 363 | 42 | 30 |
| Mitchell | 530–548 | 56 N | ..... | 43 | 41½ |
| Northville | 958–980 | 66.1 S | 1,900 | 42 | 40 |
| Oakes | 937 | 62 N | 817 | 39 | 41 |
| Pierre | 1,150–1,170 | 91.8 S | 900 | 45 | 24½ |
| Plankinton | 740–745 | 62 N | 225 | 43 | 39 |
| Redfield | 944–964 | 70.1 S | 1,260 | 42 | 34 |
| Springfield | 530–592 | 65 N | 3,292 | 46 | 29 |
| Tripp | ?–815 | 63 | 700 | 45 | 44 |
| Tyndall | 700–735 | 62.6 S | 1,000 | 46 | 43 |
| White Lake | 842–850 | 64 N | 150 | 43 | 40½ |
| Wolsey | 858–878 | 76 N | 330 | 42 | 25½ |
| Woonsocket | 684–725 | 61.5 S | 1,150 | 42 | 36 |
| Yankton | 489–595 | 62 N | 1,450 | 46 | 34 |
| | 432–455 | 60 N | 330 | 46 | 32 |
| | 610–615 | 62 N | 880 | 46 | 38 |
| | 600–672 | 64 N | 165 | 46 | 35 |
| Yankton, cement works 4 miles west | 450–500 | 64 N | 1,300 | 46 | 26½ |

The observations of temperatures given by Professor Shepard are very accurate, and they have been employed in place of figures given by Colonel Nettleton; but in most cases the differences were unimportant. The Doland water, reported at 64° by Nettleton, the Redfield water, at 64°, and the Woonsocket water, at 65°, are the principal exceptions. The figures for the Huron wells were given by the well owners. The Cheyenne Agency, Crow Creek, and Greenwood wells were reported by the United States Indian agents at those points; the well 25 miles southeast of Chamberlain was reported by the driller, Mr. Kaufman, and the Tripp well was reported by Mr. Hassett, of the town board, as "about 63°."

The mean annual temperatures which have been used for the comparisons are based on observations which have been made by the United States Signal Service, as follows:

| | Degrees. |
|---|---|
| Jamestown, North Dakota | 37 |
| Huron, South Dakota | 42 |
| Kimball, South Dakota | 43 |
| Fort Meade, South Dakota | 45 |
| Fort Randall, South Dakota | 47 |
| Fort Sisseton, South Dakota | 48 |
| Fort Sully, South Dakota | 45 |
| Webster, South Dakota | 43 |
| Yankton, South Dakota | 46 |




MAP SHOWING RATES OF INCREASE OF UNDERGROUND TEMPERATURE IN DEEP WELLS IN EASTERN SOUTH DAKOTA AND NORTH DAKOTA BY N. H. DARTON

For the other points, I have assumed what appeared to be the most probable mean temperature in comparison with the localities at which the observations were made. It is realized that there is, of course, some chance for error in this procedure, but the small difference does not greatly affect the final product of the calculation. In most cases it has been possible to take for the depth the middle of the water-bearing bed as far as pierced by the well. The rate of temperature increase has been calculated from the surface down to the middle of the portion of the water-bearing bed penetrated by the well, without deducting the usual 40 feet at the surface, as has been done sometimes in making such calculations. In considering the data, I have only taken wells over 400 feet in depth and yielding large flows. The well at Highmore was excluded on account of its small flow, for in such cases the water loses much of its heat before reaching the surface. The temperature of the Highmore water, however, is 72°, according to Nettleton. The flow is 9 gallons, and the source is about 1,550 feet below the surface.

The difference of rate in the increase of temperature in the wells at Chamberlain is thought to be due to the relative positions of these wells. The city well, with the smaller rate, is some distance east of the mill well, which may account for the difference, as it is in line with the diminution eastward to 1° in 41 feet at Kimball. At Aberdeen one of the earlier city wells was reported by Nettleton to yield water with a temperature of 66° from a depth of 905 to 918 feet, which is at the rate of 1° for each 38 feet, somewhat less than in the deeper well recorded in the table. I prefer, however, to take the figures of Professor Shepard for this deeper well, for here the conditions appear to be more definitely determined.

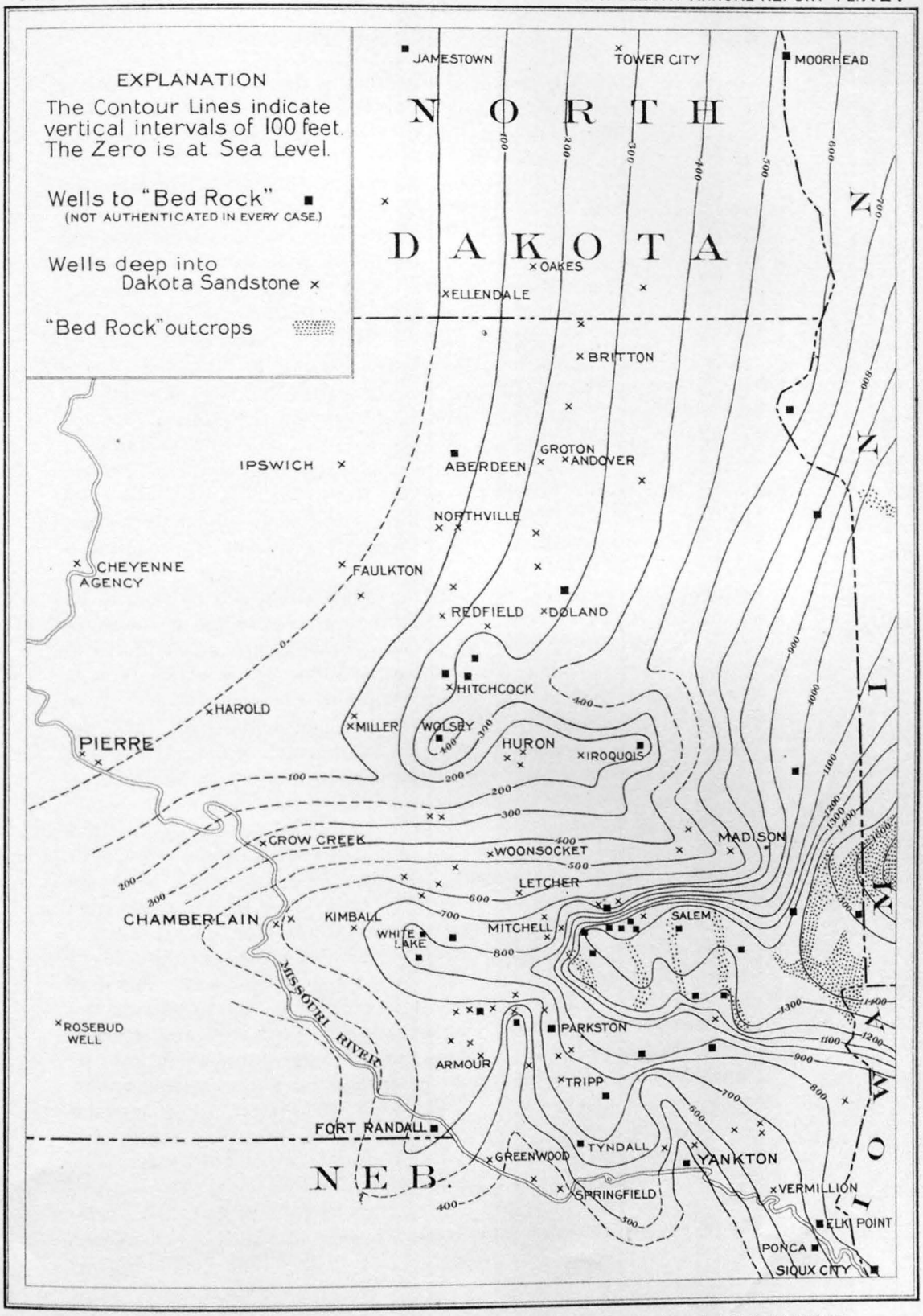
In the wells at Yankton the difference of actual temperatures of the waters is not great, but as the depths of the wells vary considerably, the ratio of temperature increase varies from 32 to 38 feet for each degree. It is probable that in a case of this sort the water may all come from one stratum, and if the minimum depth of this be taken the rate of 1° for each 32 feet is obtained. In the cement works, 4 miles west of Yankton, an increased rate is indicated.

It will, of course, be obvious that where underground drainage is circulating rapidly a flow of artesian water in horizontal beds would retain the same temperature over quite a wide area, under high land and low land alike; consequently, if a well were sunk on high land the rate of increase in feet to a degree would be a very much larger figure than in the adjoining low lands, where the water would be reached at much less depth. I have weighed this suggestion in the region in question, and, except possibly about Tyndall, Yankton, and Springfield, believe that its influence is practically nothing. We must bear in mind in this connection that underground waters move at an extremely low rate of speed, probably in the sands of the Dakota formation at not over a mile or two per year, and under these conditions the water represents

very nearly the underground temperature at the bottom of the casing of the well. Of course, in the case of a well with large flow, the time of transit from the bottom of the well to the top is a very few seconds, for there is no impediment.

The areal relations of the water temperatures and rates of temperature increases are shown in Pl. XLIV. Fortunately the data are so distributed as to cover the district without long intervals between the wells, and the results of the calculations are surprisingly accordant. The most notable features are: The strip of high temperature along the Missouri River Valley, beginning near Pierre and extending to Yankton, with its culmination at Fort Randall; the long area of moderately thermal district extending eastward along the latitude of Pierre through Miller, Wolsey, Huron, and Iroquois; the area of relatively cool underground conditions extending westward as a tongue through Mitchell, Plankinton, White Lake, and Kimball, and southward toward Tyndall, and the similar oblong area extending through Britton toward Aberdeen. In considering the data it was at once observed that these features of areal distribution were closely similar to the configuration of the bed-rock surface. Accordingly, I have reproduced in Pl. XLV a contour map of this surface for comparison. The cooler underground conditions from Mitchell to Kimball will be seen to be almost coincident in area with the underground ridge of quartzite shown in Pl. XLV. The area of higher temperatures just north is approximately coincident with the bottom of the valley, which extends from Madison through Huron and south of Wolsey. Beyond these very striking features the resemblances are not noteworthy, but those above pointed out are sufficiently striking to strongly suggest that the cooler area from Mitchell to Salem is in some way due to the presence of the ridge of crystalline rock beneath the surface.

This brings us to the question of the cause of the thermal conditions in the Dakota artesian basin, but no satisfactory solution has as yet been suggested. So far as we know, there are no metamorphic processes or orogenic movements in progress in this region which would give unusual underground heat. One suggestion was that the oxidation of pyrites might produce heat, and as the formations are all highly pyritiferous this suggestion at first seemed to contain some degree of plausibility. It seems, however, entirely incompetent to explain the peculiar distribution of the heat as shown on Pl. XLIV, and it could not be expected to heat uniformly the very large flows which are furnished by most of the wells. Of course, all the water passing underground in the intake region in the high lands westward from which the waters are derived carry oxygen, which would oxidize iron pyrites and produce heat. It is known, however, that usually oxidation of this sort does not take place below very moderate depths. Then, again, the waters are not sufficiently ferruginous to account for much oxidation of pyrites, although they contain considerable amounts of various




CONTOUR MAP OF "BED-ROCK" SURFACE IN A PORTION OF THE DAKOTA ARTESIAN BASIN. BY N. H. DARTON

SCALE 0 5 10 20 40 80 MILES

sulphates. It may be, however, that together with the oxidation of the pyrites there would be a reaction with alkaline earths, which would precipitate the iron as oxide and give rise to waters containing sulphates of these replacing bases.

Another suggestion offered to explain the relations of the thermal conditions to the flow of the artesian basin is that the crystalline bedrock has been deeply chilled by the presence of the glacier and still retains sufficient of the chill to in a measure neutralize a general thermal condition distributed evenly from below and preserved with greater intensity in the great mass of shales and sandstones.

## CHEMICAL ANALYSES.

As there is much interest in the composition of the artesian waters, an endeavor has been made to obtain all available information on the subject. There has recently appeared a further contribution from the chemical department of the agricultural college at Brookings, entitled "Shallow artesian wells of South Dakota," by Prof. J. H. Shepard. In this valuable paper analyses are given of the waters of the shallow wells in a basin in Grant County, the Hurley basin, the Turkey Ridge Creek basin, and the Sanborn basin.

The waters from the three first-mentioned basins are clearly shown to have the character of surface waters, which gives strong confirmation to the hypothesis that they are derived from local beds of sand and gravel in the drift formations. In the Sanborn basin analyses were made of several wells with the following results, calculated to salts. The depths of the wells are also given:

*Analyses of artesian waters from the Sanborn basin, South Dakota.*

[Principal salts—parts per 1,000.]

| Locality. | Sodium chloride (common salt). | Sodium sulphate (Glauber's salts). | Magnesium sulphate (epsom salts). | Calcium sulphate (gypsum). | Calcium carbonate (chalk). | Depth. |
|---|---|---|---|---|---|---|
| | | | | | | *Feet.* |
| Artesian, Sanborn County | 0.1123 | 0.3941 | 0.2687 | 0.6739 | 0.1880 | 120 |
| Beaver, Miner County | 0.2449 | 0.4271 | 0.4947 | 0.7684 | 0.1496 | 430 |
| Redstone, Hanson County | 0.1910 | 0.4493 | 0.4659 | 0.7451 | 0.1446 | 480 |

These analyses show close resemblance in character of the waters to that of the deep wells of the main artesian basin, and confirm the opinion that they are all derived from one source, the waters of the shallower wells coming near to the surface with the rise of the artesian strata and being prevented from escaping by the clay beds in the overlying drift formation.

Arrangements are in progress for analyses of the stream waters which are supposed to supply the artesian basin, and it is hoped that by this means a more definite idea may be obtained of the nature of the saline ingredients which are derived from the strata through which the waters pass. The samples will be collected along the foothills of the Black Hills and Rocky Mountains, along the zone in which the waters sink into the Dakota sandstone and underlying sedimentary formations. An analysis has been secured of waters of the Missouri River from the vicinity of Great Falls, where a considerable volume of river water is believed to pass underground in the Dakota formation. There are also given two analyses of waters from the Giant Spring, which is an outlet for waters that pass into the formation at higher levels.

*Mineral analysis*[1] *of water from the Missouri River at a point about 500 feet above the Giant Spring, 5 miles below Great Falls, Montana.*

| | Grains per gallon. |
|---|---|
| Silica | 1.308 |
| Carbonate of lime | 3.520 |
| Carbonate of magnesia | 3.028 |
| Sodium and potassium chlorides | 1.980 |
| Sodium and potassium sulphates | 5.936 |
| Total | 15.772 |

[1] Made December 2, 1895, by Edgar and Mariner, Dearborn Drug and Chemical Works, Chicago, Illinois.

*Analysis*[1] *of water from the Giant Spring, near Great Falls, Montana.*

| | Grains per gallon. |
|---|---|
| Sulphate of lime | 14.04 |
| Carbonate of lime | 4.38 |
| Carbonate of magnesia | 4.98 |
| Sodium chloride | 0.56 |
| Salts of potassium and lithium | Trace. |
| Borates | Slight tr. |
| Total | 23.96 |
| Hardness, 28 degrees. | |
| Reaction neutral. | |
| Gases, none except carbonic. | |

[1] Made May 15, 1891, by James A. Dodge, professor of chemistry, University of Minnesota, Minneapolis.

BED-ROCK SURFACE AT DEADWOOD, SOUTH DAKOTA, SHOWING POTSDAM SANDSTONE LYING ON PRE-CAMBRIAN SCHISTS.

*Mineral analysis*[1] *of water from the Giant Spring, situated on the south bank of the Missouri River about 5 miles below Great Falls, Montana.*

| | Grains per gallon. |
|---|---|
| Silica | 0.712 |
| Oxide of iron and aluminium | 0.058 |
| Carbonate of lime | 5.201 |
| Carbonate of magnesia | 5.367 |
| Sulphate of lime | 8.256 |
| Sodium and potassium chlorides | 0.990 |
| Sodium and potassium carbonates | 0.556 |
| Total | 21.140 |

[1] Made December 2, 1895, by Edgar and Mariner, Dearborn Drug and Chemical Works, Chicago, Illinois.

Information has been received from the War Department that an analysis of the water from the well at Fort Randall, made in 1886 by W. W. Mew, showed over 87 grains per gallon of saline ingredients. Of this at least 20 grains were carbonate of lime.

An analysis of the water from the well at Highmore,[1] made several years ago, is as follows:

*Analysis of water from the well at Highmore, South Dakota.*

| | Grains per gallon. |
|---|---|
| Alkaline chlorides | 28.04 |
| Alkaline sulphates | 69.09 |
| Calcium carbonate | 1.92 |
| Calcium sulphate | 0.46 |
| Magnesium carbonate | 1.69 |
| Iron, alumina, and silica | 2.33 |
| Total | 103.53 |

## VOLUME OF FLOW.

In the artesian basin of the Dakotas the deep wells present considerable diversity in the amounts of their flows. Some of the apparent variations are due to differences in the diameters of the wells, the number and sizes of perforations where they contain perforated tubing at their bottoms, and various local features at the bottom of the well which are often known to cause partial clogging. It is to be expected that in any formation of such variable character as the Dakota sandstone we should find frequent and rapid variations in degree of per-

[1] Resources of Dakota, page 185.

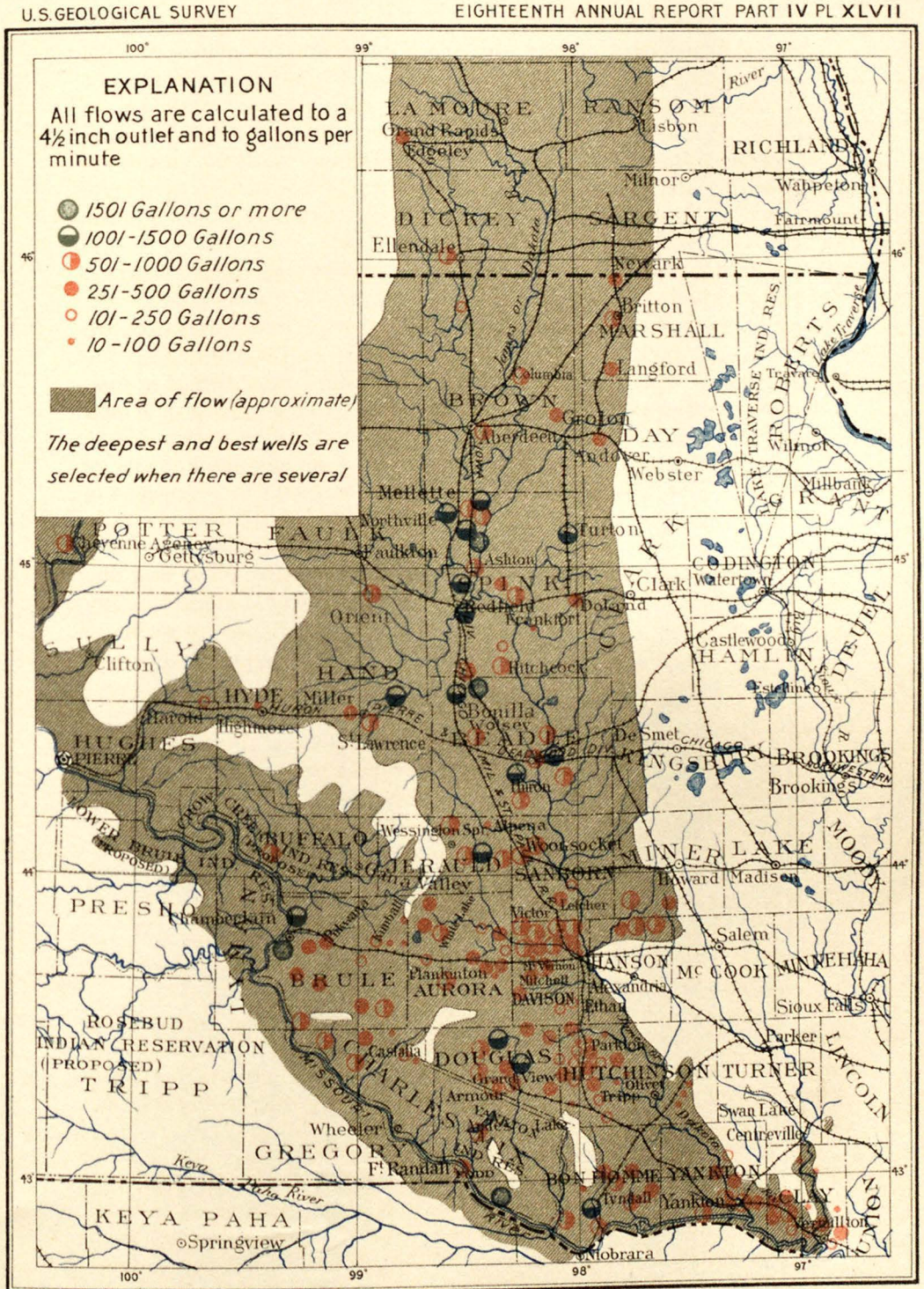
meability to the underground waters which would strongly modify the volume of flow. On carefully studying the flows of the principal wells evidence of this sort of thing is soon discovered, but so far it has not been found practicable to represent on a map regional variation in porosity. In the first place, the data are not sufficiently reliable, and, in the second place, it was found on a preliminary trial that variations are probably abrupt and local, so that it would require a very large-scale map, and many areas would have to be left blank between the wells.

Data in regard to the flow of wells are particularly untrustworthy. Frequently the information which is sent is based on mere guesswork, generally with much exaggeration, and usually if measurements are made they are not accurate in themselves, nor do they represent the flow of water from the entire bore of the well working with entire freedom. When there are impeding valves or constricted outlets of which the ratios of constriction are not accurately known it is impossible to estimate the volume of unimpeded flow. Often we have no knowledge of the size of the inner casing, which of course tends to increase the apparent resources of the well. Data are also frequently lacking as to the number and size of perforations when the water enters the casing by this means. If the perforations are small and infrequent and the casing is closed below, a smaller volume of water would enter than by the wide open bottom of the casing. Moreover, wells are often more or less clogged at the bottom by shale and other material which has fallen into a cavity formed by sand carried out by the waters, and these conditions greatly impede the egress of the water from the water-bearing bed, so that the product of a well of this character is not a fair indication of the resources of the water-bearing horizon. Then, again, some wells do not go sufficiently deep into the water-bearing bed to obtain a maximum flow, but either are contented with one of the upper flows, or, owing to some mechanical difficulty, can not be sunk deeper.

To illustrate the variability in volume of flow, I have selected a number of wells in Spink County, where the conditions are very favorable for comparison. Many of the wells are 4½ inches in diameter and are sunk deep into the Dakota sandstone, nearly a thousand feet below the level prairie surface.

Nineteen wells, either 4½ inches in diameter or calculated to that bore, yield 2,000, 1,660, 1,320, 1,313, 1,260, 1,250, 1,080, 1,000, 800, 600, 550, 350, and 75 gallons per minute. Some of these figures are no doubt somewhat roughly approximate, but with all due allowance they at least exhibit a very wide range of flows.

The pressure in these wells shows considerable variation, which indicates that the waters are not obtained from precisely the same horizon or from a continuous sheet of permeable water-bearing sandstone. Now, flow is volume, and the principal factor of volume in a restricted tube is pressure. Under a pressure of 150 pounds, about three times as much water will pass through a tube of given size as at a pressure of 50 pounds. For example, in the reports of these Spink County wells I




MAP OF PORTION OF DAKOTA ARTESIAN BASIN SHOWING RELATIVE VOLUMES OF FLOWS FROM WELLS NOW FLOWING

by N. H. Darton

Scale

25 0 25 50 75 100 MILES

find that the 4½-inch wells which yield less than 700 gallons per minute have low pressure, with a few exceptions. The following list will illustrate this:

| Well. | Gallons. | Pounds. |
|---|---|---|
| Motley | 75 | 87 |
| Ashton No. 1 | 100 | 60 |
| Budlong | 150 | 125 |
| Doland No. 1 | 370 | 122 |
| Glidden | 550 | 50 |
| Bird | 670 | 153 |
| Ashton No. 2 | 633 | 153 |

These variations can be explained only by variations in the underground conditions—mainly, no doubt, variations in permeability. In the case of the Ashton wells, the deeper one has the greater pressure and volume of flow.

As there is much demand for information as to how much water may be expected from a well of given size in various parts of the artesian basin, a map has been prepared (Pl. XLVII) in which are shown the relative volumes of flows of wells now flowing. Wells of sizes other than 4½-inch bore at the bottom or inner tubing have been calculated to that capacity for the purpose of comparison. Where there are several wells near by, the deepest and best was selected, for it represents the conditions which can probably be duplicated in the immediate vicinity by wells sunk to proper depth and with adequate precaution.

The data shown do not in all instances indicate the utmost resources of the water-bearing strata, for in many cases the wells have not been sufficiently deep to test all the beds. Only in a few of the wells has bed rock been reached, and it is not until we have gone through all of the Dakota sandstone that we can feel assured of having obtained the maximum flow. It is not in every case, however, that the largest flow is nearest the bottom, but in more than two cases out of three the larger flows are from the deeper wells in the same region. This is notably the case in much of Davison, eastern Aurora, Hutchinson, and Yankton counties. At the city well in Yankton, which was recently deepened, the exceptional condition was indicated, for no increase in flow was found in the deeper portion of the Dakota formation.

It will be seen from Pl. XLVII that some of the wells having great flows owe their volume mainly to their large diameters. Many small wells indicate that if they were of the same diameter their flows would be equal to or much greater than those from larger wells with notable volume.

The large volumes of water in Brule County are due in no small measure to the size of the wells, with the exception of the immediate vicinity of Chamberlain, where the flows are phenomenally large.

# RESERVOIRS FOR IRRIGATION.

BY

JAMES D. SCHUYLER.

# CONTENTS.


| | Page. |
|---|---|
| Introduction | 625 |
| Rock-fill dams | 627 |
| Escondido District dam, California | 627 |
| Lower Otay rock-fill steel-core dam, California | 637 |
| Morena rock-fill dam, California | 640 |
| Upper Otay reservoir, California | 642 |
| Barrett dam site, California | 642 |
| Chatsworth Park rock-fill dam, California | 643 |
| Pecos Valley rock-fill dams, New Mexico | 645 |
| Proposed Lytle Creek rock-fill dam, California | 648 |
| Hydraulic dam construction | 649 |
| La Mesa dam, California | 649 |
| Pine Valley dam, California | 653 |
| Lake Helena dam site, California | 654 |
| Dam at Tyler, Texas | 654 |
| San Leandro and Temescal dams, California | 656 |
| Hydraulic fills on the Canadian Pacific Railway | 657 |
| Hydraulic fills on the Northern Pacific Railway | 659 |
| Hydraulic construction elsewhere | 660 |
| Masonry dams | 661 |
| Hemet dam, California | 662 |
| Sweetwater dam, California | 669 |
| Amount of water used | 671 |
| Run-off | 672 |
| Enlargement of dam | 674 |
| Profile and form of dam | 677 |
| Conduits | 679 |
| Evaporation | 680 |
| Sedimentation | 681 |
| Bear Valley dam, California | 682 |
| Lagrange dam, California | 686 |
| Folsom dam, California | 687 |
| San Mateo dam, California | 688 |
| Run-off of the Spring Valley watersheds | 690 |
| Little Bear Valley dam and reservoir, California | 690 |
| Pacoima dam, California | 693 |
| Agua Fria dam, Arizona | 695 |
| Concrete dams of the Portland (Oregon) waterworks | 698 |
| Earthen dams | 698 |
| Cuyamaca dam, California | 698 |
| Merced reservoir, California | 700 |
| Buena Vista Lake reservoir, California | 701 |
| Projected reservoirs | 703 |
| Kern River reservoir sites, California | 703 |
| Southern California reservoir sites | 707 |
| Victor dam, California | 708 |
| Antelope Valley Water Company, California | 711 |

Projected reservoirs—Continued. Page.
Alpine reservoir, California ..... 711
Santa Ana Canyon steel dam, California ..... 715
Tonto Basin reservoir project, Arizona ..... 715
Proposed reservoirs on Rio Verde, Arizona ..... 717
McDowell reservoir project, Arizona ..... 718
Buttes reservoir site on Gila River, Arizona ..... 719
Queen Creek reservoir site, Arizona ..... 720
New Walnut Grove reservoir dam, Hassayampa River, Arizona ..... 721
Reservoir sites on Little Colorado River, Arizona ..... 722
Proposed Rock Creek reservoir on Humboldt River, Nevada ..... 723
Lost Canyon reservoir site and natural dam, Colorado ..... 724
Tarryall reservoir site, Colorado ..... 726
Antero reservoir site, South Park, Colorado ..... 726
South Fork reservoir site, Colorado ..... 726
Acknowledgments ..... 726
Appendix: Tables of reservoir capacities and areas ..... 727

# ILLUSTRATIONS.


| | | Page. |
|---|---|---|
| PLATE XLVIII. | Feeder canal on the side of Rodriguez Mountain | 628 |
| XLIX. | Plans and profiles of Escondido dam | 630 |
| L. | Back of Escondido Irrigation District dam | 632 |
| LI. | Contour map of reservoir of Escondido Irrigation District | 634 |
| LII. | Map of Lower Otay reservoir | 636 |
| LIII. | Plans of Lower Otay reservoir | 637 |
| LIV. | Steel web plate and anchor trench at west end of Lower Otay dam | 638 |
| LV. | Explosion of great blast at Lower Otay rock-fill dam | 639 |
| LVI. | Morena dam site, looking east | 640 |
| LVII. | Barrett dam | 642 |
| LVIII. | Details of outlet gate and well culvert of La Mesa dam | 650 |
| LIX. | La Mesa reservoir; beginning of the construction of hydraulic-fill dam | 652 |
| LX. | Construction of hydraulic dam, La Mesa reservoir, illustrating the method of suspending pipes | 654 |
| LXI. | View of finished dam and wasteway of La Mesa reservoir | 656 |
| LXII. | Hemet dam, Riverside County, California | 662 |
| LXIII. | Hemet dam as finished, showing the spillway ridge south of the dam | 664 |
| LXIV. | Elevation and sections of Sweetwater dam | 668 |
| LXV. | Details of Sweetwater dam | 669 |
| LXVI | Original Sweetwater dam as completed to the 60-foot contour | 670 |
| LXVII. | Sweetwater dam as finished, April, 1888 | 672 |
| LXVIII. | Sweetwater dam during great flood of January 17, 1895 | 674 |
| LXIX. | Repairing and increasing the height of parapet of Sweetwater dam | 676 |
| LXX. | Sweetwater dam, showing new apron of spillway and protecting spur walls on pipe line | 678 |
| LXXI. | Spillway of Sweetwater dam, seen from below | 680 |
| LXXII. | Bear Valley dam, looking south toward spillway | 682 |
| LXXIII. | Spillway of Bear Valley dam, with flashboard gates | 684 |
| LXXIV. | Plan, cross section, and elevation of weir and headworks of Folsom Canal | 686 |
| LXXV. | American River dam at Folsom | 687 |
| LXXVI. | Plant for mixing and handling concrete at San Mateo dam | 688 |
| LXXVII. | Construction of intake of San Mateo dam | 689 |
| LXXVIII. | Molds for concrete blocks, San Mateo dam | 690 |
| LXXIX. | Roughening surface of concrete blocks to receive fresh cement at San Mateo dam | 691 |

Page.

PLATE LXXX. San Mateo dam being inspected by American Society of Civil Engineers, in July, 1896 ..... 692
LXXXI. Plans and sections of San Mateo dam and map of Crystal Springs reservoir ..... 693
LXXXII. Newell curve ..... 694
LXXXIII. Map of Little Bear Valley reservoir ..... 695
LXXXIV. Excavation of trench for Pacoima subterranean dam ..... 696
LXXXV. View of flood passing over Pacoima subterranean dam ..... 697
LXXXVI. Foundations of west channel of Agua Fria diverting dam ..... 698
LXXXVII. Inner face of concrete dam at Portland, Oregon ..... 699
LXXXVIII. Exterior view of reservoir dams at Portland, Oregon ..... 700
LXXXIX. Map of sources of water supply in the vicinity of the city of San Diego, California ..... 706
XC. View of Victor dam site, looking upstream ..... 708
XCI. Map of Victor reservoir ..... 710
XCII. View of a corner of the basin of Alpine reservoir before work was begun ..... 711
XCIII. Reservoir of South Antelope Valley Irrigation Company ..... 712
XCIV. Crain Lake, a reservoir site of the Antelope Valley Water Company ..... 713
XCV. Map of Tonto Basin reservoir ..... 714
XCVI. Dam site on Salt River below mouth of Tonto Creek ..... 716
XCVII. Plan of Tonto dam ..... 717
XCVIII. Map of Gila and Salt River valleys, showing existing and proposed irrigation works ..... 718
XCIX. Map of Salt River Valley, showing canal constructed and proposed ..... 720
C. Map of site of Horseshoe reservoir on Verde River ..... 722
CI. Map of Rock Creek reservoir, canal lines, and lands to be irrigated ..... 724
CII. Contour map of Rock Creek reservoir and dam site ..... 726
FIG. 86. Map of Escondido Irrigation District and system of works ..... 628
87. Feeder conduit of Escondido Irrigation District ..... 629
88. Escondido irrigation dam, looking north, showing spillway ..... 630
89. Details of gate of Escondido dam ..... 631
90. Pick-up weir at head of distributing system in Escondido Irrigation District ..... 634
91. Construction of facing of Escondido dam ..... 636
92. Sketch of reconstruction of Chatsworth Park rock-fill dam ..... 644
93. Sketch map of dam at head of Pecos Canal ..... 646
94. Cross sections of Pecos Valley reservoir dams ..... 647
95. Cross section of La Mesa dam ..... 650
96. Plans and cross sections of San Leandro and Temescal dams ..... 656
97. Map showing location of Lake Hemet, the main conduit, and irrigated lands ..... 662
98. Contour map of the Lake Hemet reservoir ..... 663
99. Hemet dam, Riverside County, California ..... 664
100. Hemet dam construction plant ..... 666
101. Plan of Sweetwater dam ..... 669
102. Profile and sectional view and plan of waste-way tunnel, Sweetwater dam ..... 670
103. Details of tower of Sweetwater dam ..... 675
104. Comparison of profiles of Zola, Sweetwater, and Bear Valley dams ..... 678
105. Map of Bear Valley reservoir ..... 682

Page.
FIG. 106. Cross section of Bear Valley dam ..... 683
107. Plan and elevation of Bear Valley dam ..... 684
108. Upper face of Lagrange dam ..... 686
109. Lower face of Lagrange dam ..... 687
110. Hydraulic jacks for raising shutter on Folsom dam ..... 688
111. Comparison of contents of Little Bear Valley, Houston Flat, and Grass Valley reservoirs ..... 692
112. Plan and profile of Pacoima dam ..... 693
113. Measuring box used by Maclay Rancho Water Company ..... 694
114. Cross sections of Agua Fria diverting dam and storage reservoir dam, Arizona ..... 696
115. Map of Manache meadows reservoir ..... 703
116. Map of Manache meadows dam site ..... 704
117. Cross sections of dam sites in San Diego County, California ..... 707
118. Map of watershed and the lands to be irrigated from Victor reservoir ..... 708
119. Cross section of Victor dam site ..... 709
120. Map of Little Rock Creek Irrigation District ..... 712
121. Details of tunnel outlet of the Alpine reservoir ..... 714
122. Sections of dam and canyon of Tonto reservoir ..... 716
123. Map of lower portion of McDowell reservoir ..... 719
124. View of back of Walnut Grove rock-fill dam ..... 721
125. Sketch of longitudinal section of Lost Canyon natural dam ..... 724
126. Sketch of cross section at upper end of Lost Canyon natural dam ... 725

# RESERVOIRS FOR IRRIGATION.

By James D. Schuyler.

## INTRODUCTION.

Throughout a large portion of the regions where irrigation is necessary to the success of agriculture the streams are lowest during the irrigating season, and the flood waters must be stored in artificial lakes or reservoirs, to be drawn upon as needed, in order to develop the full measure of their usefulness. Even were the streams uniform in their flow throughout the year, the necessity would still exist for conservation of the water during months when irrigation is not practiced.

There are few localities where all the water flowing in the streams can be utilized, because there is such a wide fluctuation in the total run-off of any stream from one season to another, a variation between maximum and minimum which on large rivers may be in the ratio of 12 to 1, and even greater on smaller streams, one notable stream in California having shown extremes of 70 to 1 during ten years of observation. The reservoirs which might be provided to catch all the flow of ordinary years would occasionally be overwhelmed by freshets so extraordinary as to fill them many times over. For this reason it is not practicable to hold the total discharge of a stream, and it is necessary to provide large spillways for reservoirs, whether large or small, for the greatest flood is as likely to come when the reservoir is full as at any other time.

The importance of reservoir construction and water storage has been generally recognized within comparatively recent times, and it is only during the years since about 1885 that capital has been extensively enlisted in such works, except for city water supply storage. With a few prominent examples of successful achievement in that line as precedents, however, the subject of water storage has awakened widespread attention, and each year it appears to be attracting deeper public interest. The mountain regions of all the arid West are coming to be regarded as valuable, not only for their timber, stone, and precious metals, but also for the water which they will give forth, due to their greater altitude and heavier precipitation and steeper slopes—the higher and more rugged and rocky the mountains the greater their productiveness in the element most needed by the thirsty plains below.

The mountains supply not only the water but usually the best sites for reservoirs to impound it, while the forests and undergrowth that clothe the mountain sides have more than a commercial value when fulfilling their best function in the way nature provides, as means for retarding and conserving the water supply and preventing its too rapid flow into the streams and out to the valleys and the sea.

Attention is now being paid to the extent and character of the watersheds that are expected to furnish water supply for projected systems of storage reservoirs, and rain gages and other means of recording precipitation on mountain drainage areas are being established in connection with stream gagings and records of stream flow. This work, carried on not only by National and State authorities, but also by corporations and individuals, is coming to be recognized as of prime importance. Thus, with the gradual systematization of the entire irrigation question, a tendency has been developed toward a more thorough study of the producing capacity of watersheds of different areas, exposures, slopes, and elevations, the precipitation upon them, and the degree with which their surface is clothed with natural vegetation. This method of taking an account of stock in water resources prior to construction of works is in gratifying contrast with the haphazard ways of the earlier stages of development.

Since the publication of the Twelfth Annual Report of the United States Geological Survey, 1891–92, wherein a general review of the subject was made by Mr. Herbert M. Wilson, C. E., substantial progress has been made in the development of storage throughout the West, and there are few irrigation projects recently proposed which have not one or more storage reservoirs as vital parts of their plans. It is the purpose of this paper to make note of such works as have come within the knowledge or observation of the writer in the course of his professional practice, describing in a general way their characteristics as reservoirs, the results which have been accomplished by them, and the methods employed in the construction of the dams which form them. At the same time data have been gathered concerning a large number of projected reservoirs, which will be presented in convenient shape for reference, and can not fail to be of interest as a demonstration of the rapidity with which that particular department of irrigation science is developing.

It may be taken for granted at the outset that storage reservoirs are a necessary and profitable adjunct of irrigation development. There is little question that they are an expression of the highest type of that development, and that in the future much more land will be irrigated from stored water than can ever be from the direct normal flow of the streams. As equalizers and regulators of floods they serve a most useful purpose, and indeed it may be said that an irrigation supply depending upon a reservoir is in general much more satisfactory, even though it may be more costly, than one derived from a fluctuating river

that often runs lowest when most needed to mature crops. The one objection which may be raised, and always will be raised as long as dams continue to break, is the possible failure of a structure upon which everything depends, resulting not only in the immediate loss of crops and orchards, but in the sweeping away of the entire investment, as well as serious damage to everything lying in the line of the released waters, and possible loss of life. The security of a dam from collapse or failure is, however, quite as susceptible of absolute attainment as the stability of a building or a bridge, and while every structure of that nature devolves a grave responsibility upon its designer and the engineer in charge, perfect stability requires only intelligence and painstaking care commensurate with its importance in every stage of its construction. The necessity for rigid governmental supervision of the erection of dams, and for the appointment of a board of control in every State to approve all plans proposed for such works, with power to order them altered and built upon safe lines or not at all, is emphasized with every such failure that takes place.

## ROCK-FILL DAMS.

### ESCONDIDO DISTRICT DAM, CALIFORNIA.

Many projected enterprises for storage reservoirs throughout the West have been delayed and construction postponed on account of the general financial stringency, the low prices prevailing for all farm and orchard produce, the lack of active demand for farming lands, and the hesitancy of capitalists to invest in such enterprises during the prevalence of "hard times." In California particularly progress has been hampered by the long delay in securing final adjudications arising under the Wright law—a well-known measure intended to promote irrigation district organization—and the consequent discredit of the bonds of the districts formed under this law by reason of the uncertainty as to their validity or value.

California is further handicapped in all water development, whether for city and town waterworks or for public irrigation enterprise involving the investment of capital for the supply of communities with the element needed in irrigation, by a provision which was ingrafted into her new constitution in 1877 by the "sand lot" element controlling it, permitting county boards of supervisors once each year to fix such water rates as they may see fit for the sale of water under any system within their jurisdiction.

The law not only permits this, but it is mandatory, requiring the rates to be fixed anew during the month of February each year. The books of the companies are thrown open to public examination at such times, and the supervisors hold a public hearing, wherein all the items of expenditure made by the company are publicly reviewed and criticised, and then the rates are fixed at any amount which the supervisors may see

fit to impose. All water companies are therefore at the absolute mercy of men elected to political office, and have either to confront the necessity of purchasing a majority of the boards of supervisors every year or accept the possibility of being compelled to furnish water at rates which are too low to give any return upon the capital invested. An amendment to the constitution eliminating this objectionable and obstructive feature of the fundamental law is felt to be a necessity for the equitable protection of capital, the investment of which the State needs to encourage by all fair and honorable means.

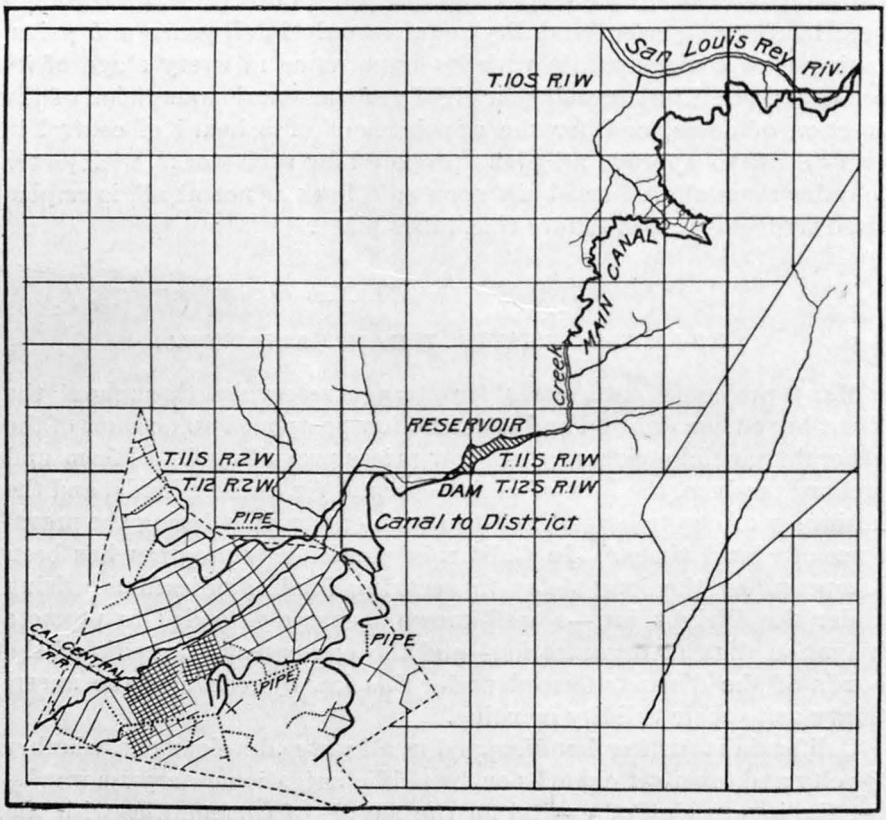
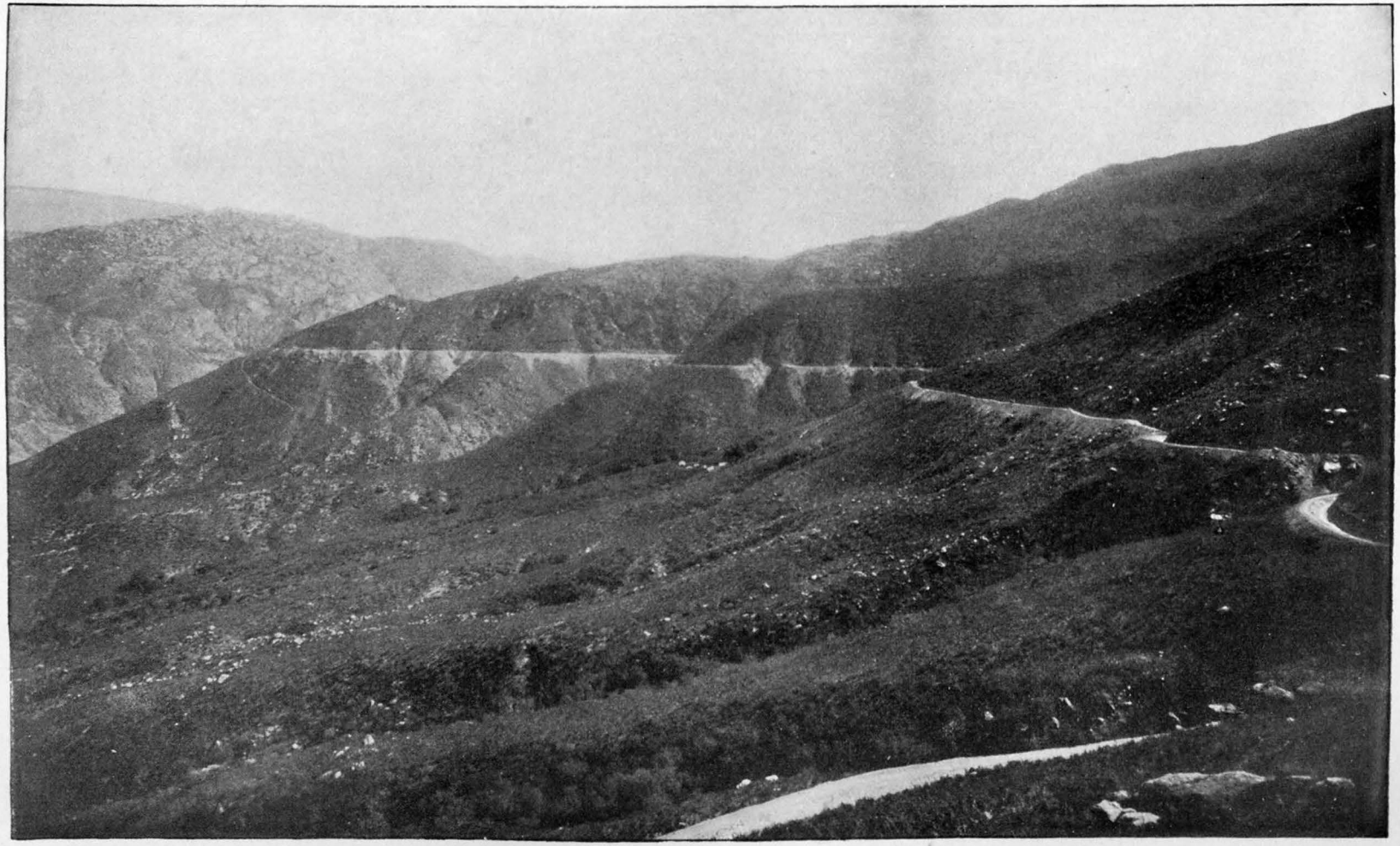



FIG. 86.—Map of Escondido Irrigation District and system of works.

Notwithstanding this uncertainty, one of the Wright law districts, of 13,000 acres' area, organized at Escondido, San Diego County, has succeeded in constructing a notable and interesting storage-reservoir dam and distributing system, which, although not entirely completed, is sufficiently connected to have been in service for two years past—1895 and 1896—accomplishing the irrigation of about 2,000 acres, chiefly planted with orchards of citrus fruits. The district (fig. 86) is in a valley surrounded by mountains, and the dam is on the Von Segern branch of San Elijo Creek, which passes through the town of Escondido.



FEEDER CANAL ON THE SIDE OF RODRIGUEZ MOUNTAIN, ESCONDIDO IRRIGATION DISTRICT.

It is about 2 miles east of the nearest line of the district and at an elevation of 1,300 feet above sea level, or about 650 feet above the town.

The immediate watershed tributary to the reservoir measures about 8 square miles, which in that region affords insufficient run-off to fill the reservoir. Hence the main supply is brought to it from the San Luis Rey River, the nearest stream to the north, by a conduit which taps the river at an altitude of 1,600 feet, in a wild canyon which is almost inaccessible by reason of its roughness. The conduit has a capacity of 28

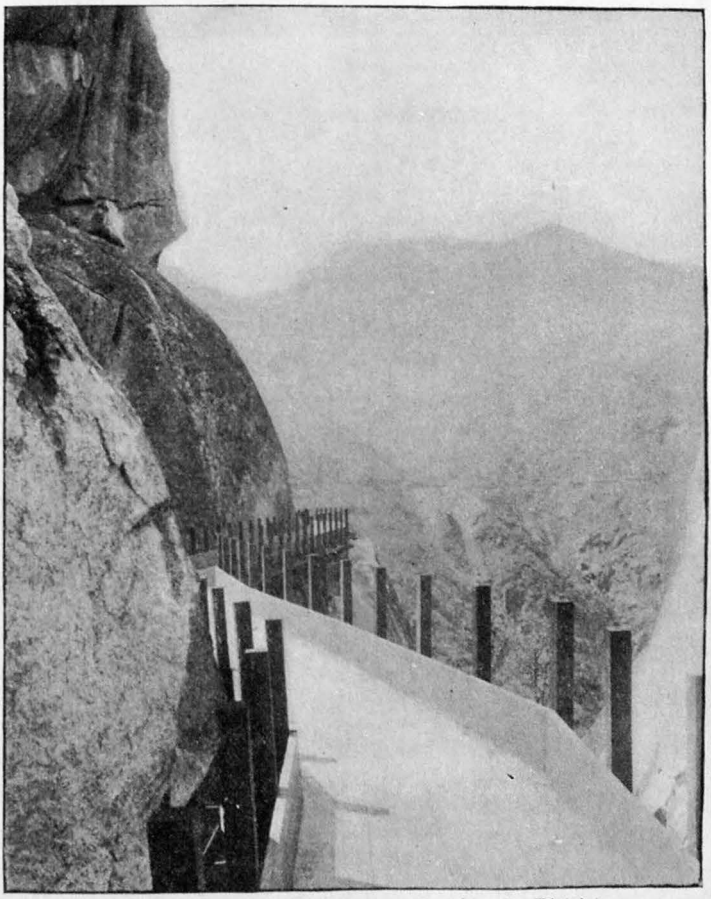


FIG. 87.—Feeder conduit of Escondido Irrigation District.

second-feet and is 15.6 miles long, consisting of 67,287 feet of ditch (see Pl. XLVIII), 14,142 feet of flume, and 806 feet of tunnel. The intake is made by a tunnel 356 feet long, heading in the river 3 feet below low-water level, while at the other end the rim of the reservoir basin is pierced by a tunnel 450 feet long to convey the water to a natural channel leading to the dam, 3½ miles below. The intake tunnel is through solid granite, which is excavated below grade at its lower end to form a settling basin, in which sand accumulates at the rate of 1,000 cubic

feet daily, and from which it is sluiced back into the river by the opening of a side outlet gate.

The upper 8,000 feet of the conduit consists of a flume supported on posts on the slopes of a rugged canyon. The lumber for this flume was hauled by a roundabout road to a bluff on the opposite side of and 600 feet above the river bed, whence it was transported by a wire cable

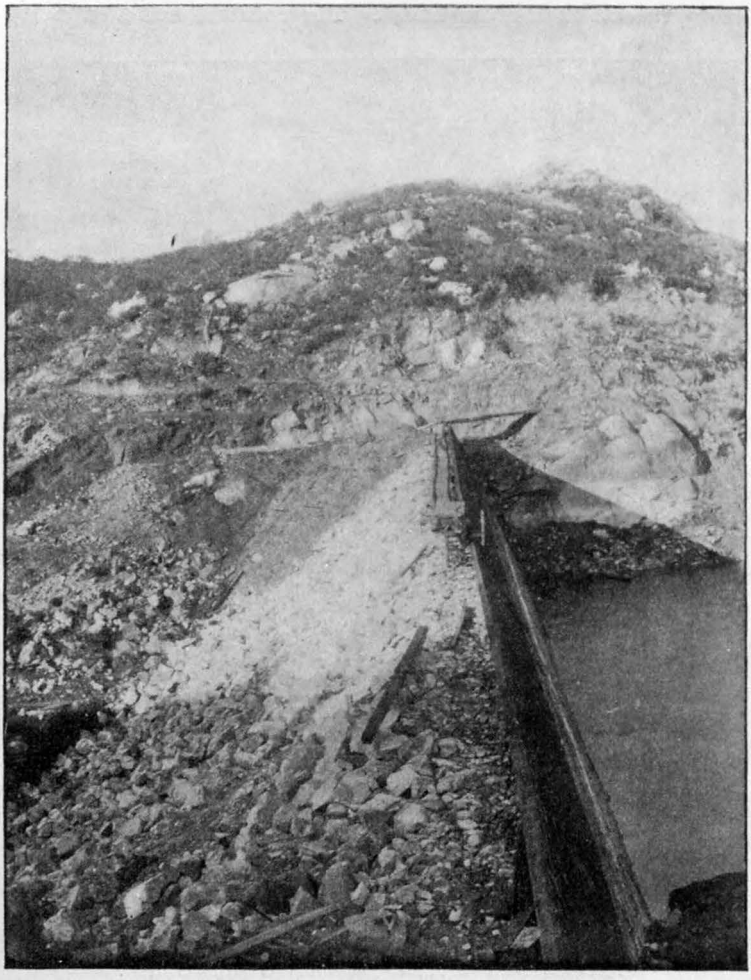
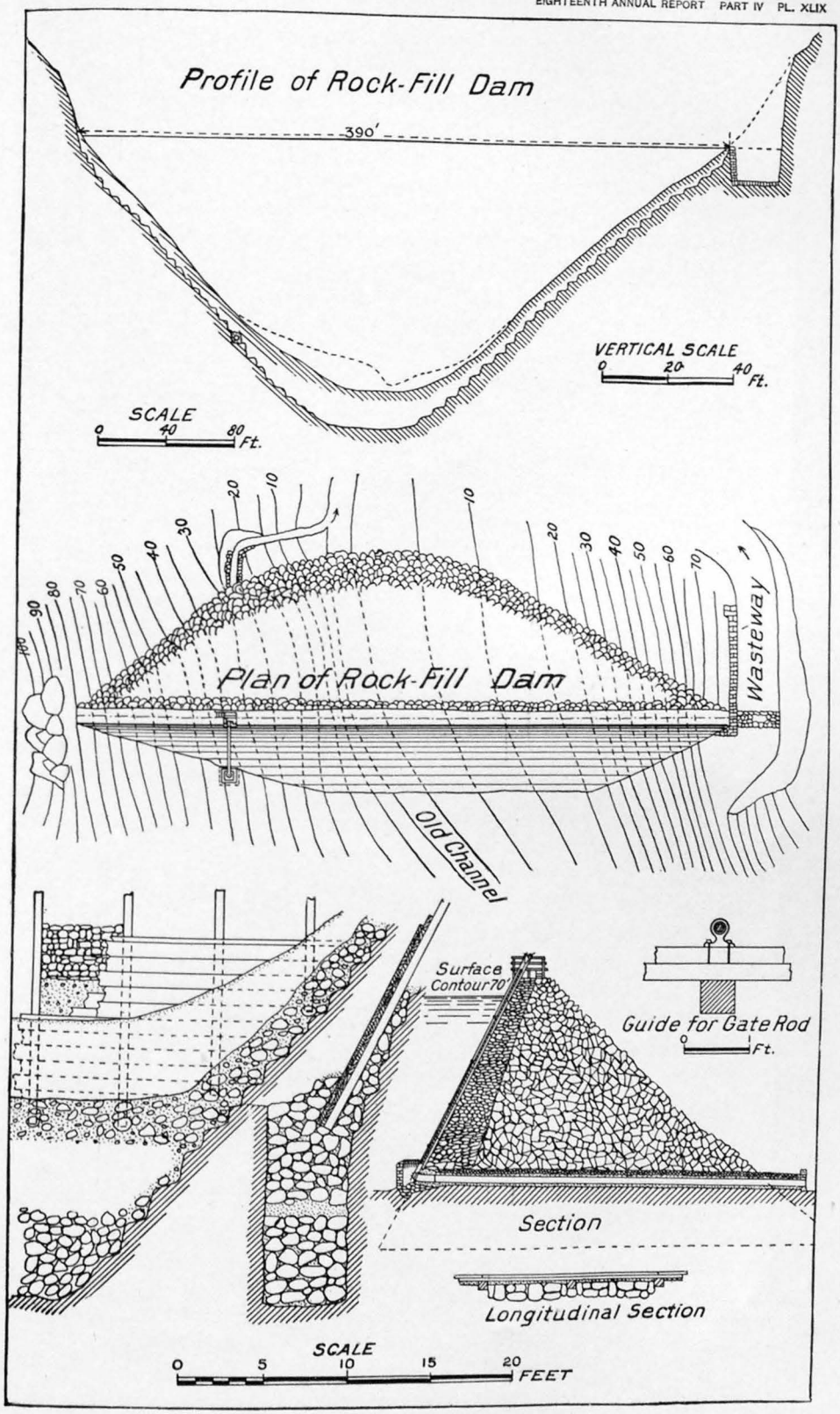


FIG. 88.—Escondido irrigation dam, looking north, showing spillway

with a span of 1,500 feet by means of a trolley manipulated by hand windlass and rope. At other points the lumber was hoisted to the line by horsepower by means of a car and portable wooden track, several hundred feet in height. The flumes are mainly 4 feet wide by 3 feet deep, and the ditch is excavated with a bottom width of 5 feet and side slopes of 1 to 1, the minimum excavation on the lower side being about 3 feet. The formation throughout that region is granitic, partially




PLANS AND PROFILES OF ESCONDIDO DAM.

decomposed, the disintegration forming a few feet of soil, from which protrude large bowlders of very hard granite embedded in the softer rock in situ.

The total cost of the conduit was $116,328.60, or $1.29 per foot for

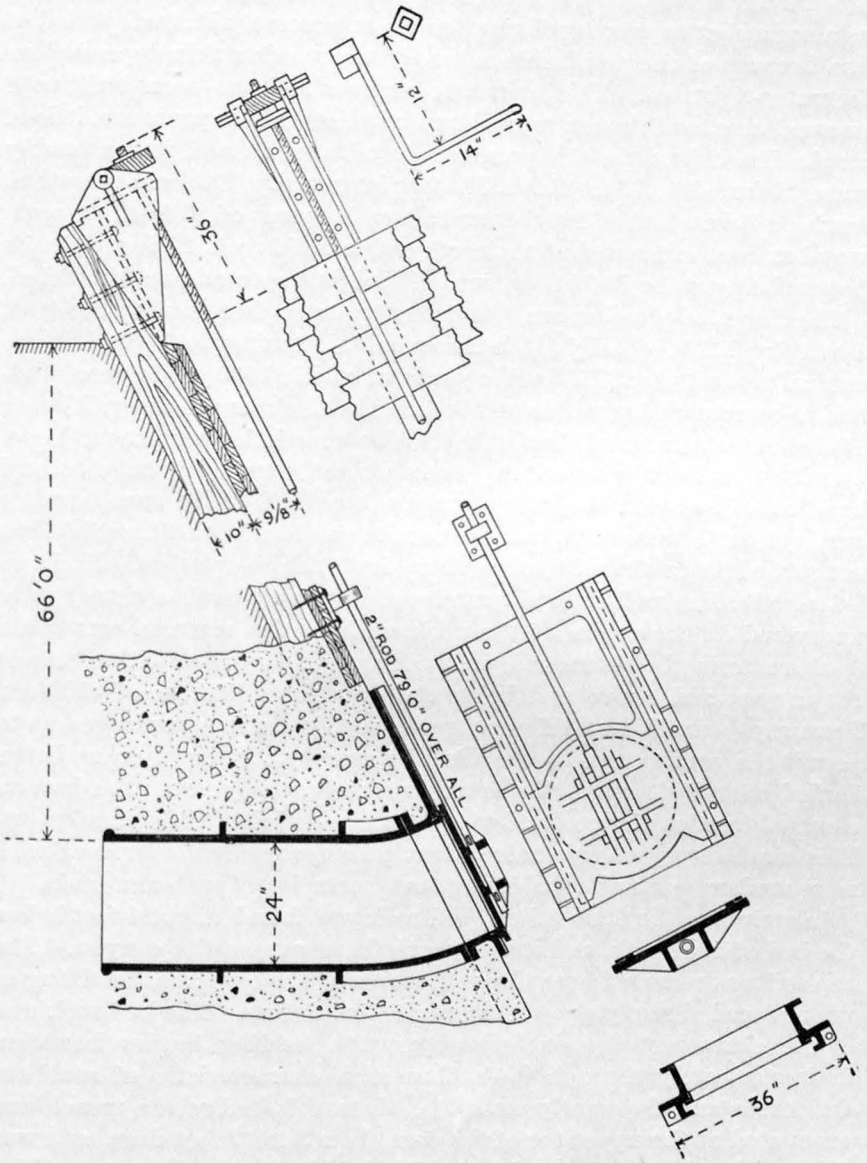



FIG. 89.—Details of gate of Escondido dam.

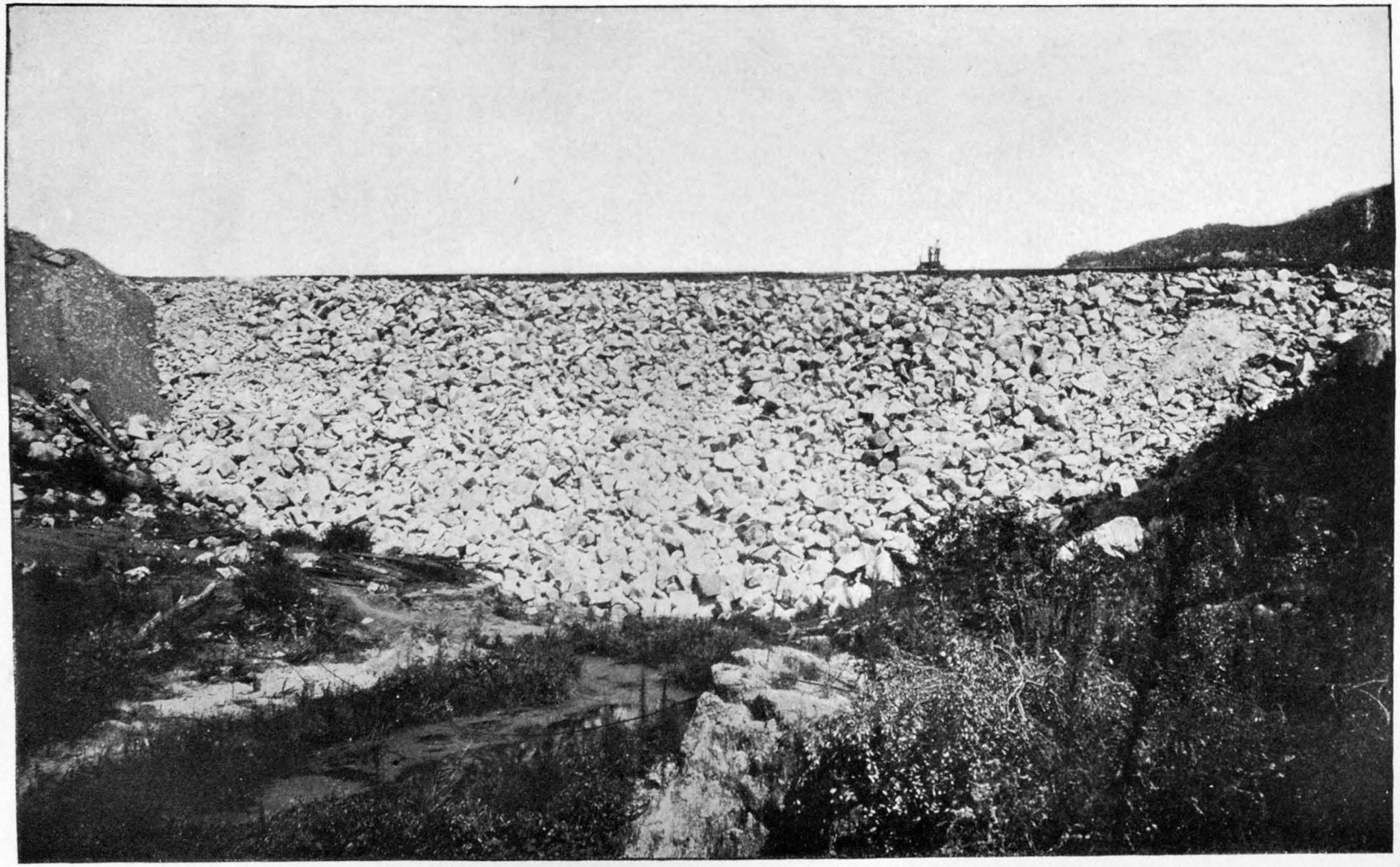
construction and engineering, besides 12 cents per foot for right of way, commissions, etc. The conduit is capable of filling the reservoir in sixty days when running to its full capacity, while the immediate water-

shed of the stream flowing to the reservoir sometimes yields sufficient to fill it without any other auxiliary.

The dam is of the ordinary type of loose rock-fill dam, with plank facing—a type which has given satisfactory service for many years in the mining regions of northern California, although generally regarded as a somewhat temporary device for a comparatively limited period of use, because of the perishable nature of the wooden skin depended on for water-tightness. This structure appears to have been built with unusual care, and though ragged and unfinished in appearance, it is of ample dimensions for the pressures it withstands and is reasonably water-tight. It is 76 feet high, 380 feet long on top, 100 feet on bottom, having a base width of 140 feet and a top thickness of 10 feet. A spillway has been excavated at the north end in solid rock, 25 feet wide, its bottom being at the 70-foot contour. This is left open and unobstructed.

The slopes of the dam are ½ to 1 on the water face, and on the back 1 to 1 for half the height, the lower half flattening to 1¼ to 1. The cubical contents are 37,159 cubic yards, of which 6,000 yards were hand-laid in courses of dry rubble on the face, the thickness of the wall being 15 feet at bottom and 5 feet at top. The remainder consists of loose, angular granite blocks, up to 4 tons weight, dumped from cars and handled to some extent with derricks (see Pl. L). No small quarry spalls or earth were used, and the result is a clean rock-fill, which has not settled more than 3 inches since its final completion. No large ledges affording well-defined quarries of any considerable extent were uncovered in the course of the work, and all the material was taken from scattering bowlders and protruding rock masses on either side of the canyon and above and below the dam for a distance of 800 feet. Tramways were laid at different levels on either side, so arranged as to permit the cars to run to the dam by gravity, the empty cars being hauled back by horses. These tracks were carried across the dam on elevated trestles, the posts of which remain buried in the embankment. This method proved expensive, slow, and inconvenient compared with more modern systems of cableway transportation of such materials.

In stripping the foundations, bed rock was found about 4 feet below the bed of the creek, and it was nearly level across the canyon. The top soil was removed over the entire base of the dam and the filling of rock placed directly upon the granite foundation. The bed rock was of the character of disintegrated granite, holding harder bowlders indiscriminately through it—a formation characteristic of southern California and frequently met with. Into this bed rock a trench was excavated at the upper toe of the dam, from 3 to 12 feet deep, and was filled with rubble masonry 5 feet thick, laid in Portland cement, which serves to connect the plank facing with the canyon walls. Redwood 6 by 6 inch timbers, in vertical lines, 5 feet 4 inches apart between centers, were embedded in the hand-laid face wall to a depth of 4 inches, and to these timbers the plank were spiked. As each row of



BACK OF ESCONDIDO IRRIGATION DISTRICT DAM

plank was put in position concrete was rammed into the 2-inch space between the plank and the face of the wall, giving a full bearing for the plank throughout. On the lower third of the dam these plank are 3 inches thick, on the middle third 2 inches, and on the upper third 1½ inches, double throughout. Joints were broken as far as possible, both at the end and side, by the second layer, the joints being calked and smeared with hot asphaltum.

Springs of water were developed in the excavation of the foundation to the extent of 3 to 4 miner's inches constant flow. These were led out by pipes to the outer toe. The maximum leakage through the dam when filled to the 57-foot level was found to be 8 miner's inches, exclusive of the springs. This leakage remains quite constant, and it is doubtful whether it is percolation under the dam through the disintegrated granite or leakage through the joints of the facing. Whatever may be its origin, it is entirely harmless as far as can be seen, and is not a source of anxiety, although the amount of it—100,000 gallons per day—is an annoying loss at times when no water is needed for use. While this amount of leakage would be dangerous to an earth dam, and in a masonry dam would be an indication of the existence of an upward pressure on the joints that might be fatal to its security if the section were too light, yet in a work of this nature the drainage is perfect below the inner skin of plank, and the gravity of the mass is not reduced by upward pressures transmitted through the body of the dam.

The facing plank has been carried up 3 feet higher than the top of the stone fill, as a wave protection, so that the ultimate crest is 9 feet above the floor of the spillway, as shown in Pl. XLIX.

The outlet was originally designed to be controlled by means of a tower, the foundations of which were laid at the upper toe of the dam on the south side, but the plan was changed and a grating placed over the base of the tower a few feet above the gate covering the outlet. The gate is set at the incline of the inner slope, and is controlled by a rod leading up the incline to a worm gear placed at a convenient height above the top of the dam. (Fig. 89.) The outlet pipe is 24 inches in diameter, and is vitrified sewer pipe of ordinary weight, laid in a trench and embedded in concrete, which covers it 12 inches in depth.

The total cost of the dam under the contract was $86,946.21, or $27.82 per acre-foot of reservoir capacity up to the floor of the spillway. The land for the site cost in addition $23,112.88, including clearing, making the total $110,059.09, or $38.41 per acre-foot. The prices paid will be recognized as unusually high for such work. They are as follows, the cost being given per cubic yard: Earth excavation, 30 cents; rock excavation, $1.10; rock-fill, $1.50; dry stone masonry, $3.75; rubble masonry in cement, $8; concrete, $14; lumber, $50 per M.

The detail of this work is given with special fullness, as it is the first rock-fill dam yet constructed in California for irrigation storage, and is of a type which is likely to be repeated many times in the near

future in localities where its use will be more advantageous than it was here, where stone was comparatively scarce immediately at the dam.

Owing to the irregularity of the topography of the district, the system of distribution must necessarily consist largely of pressure pipe, alternating with ditches and flumes. The main conduit, beginning at a masonry pick-up weir (shown in fig. 90) half a mile below the dam, has a capacity of 20 second-feet, and the laterals of from 1 to 10 second-feet. When completed, in 1895, the distributing system consisted of 14.5 miles of riveted steel pipes 3 to 20 inches in diameter, 2 miles of flumes, 1.5 miles of vitrified clay and cement pipes, and 13.5 miles

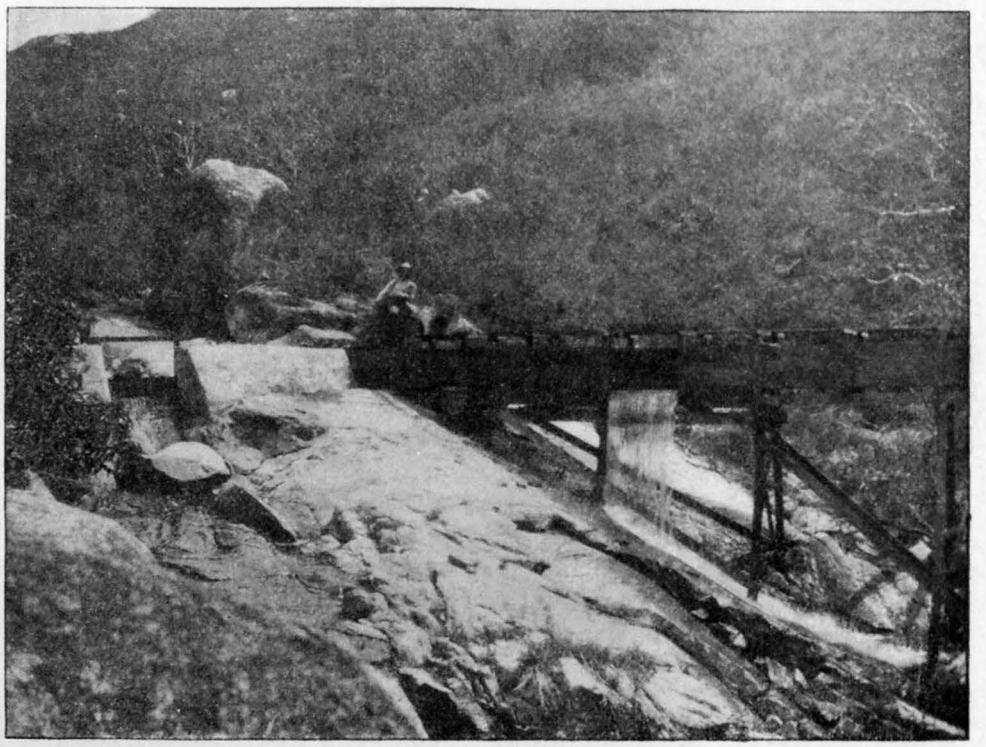
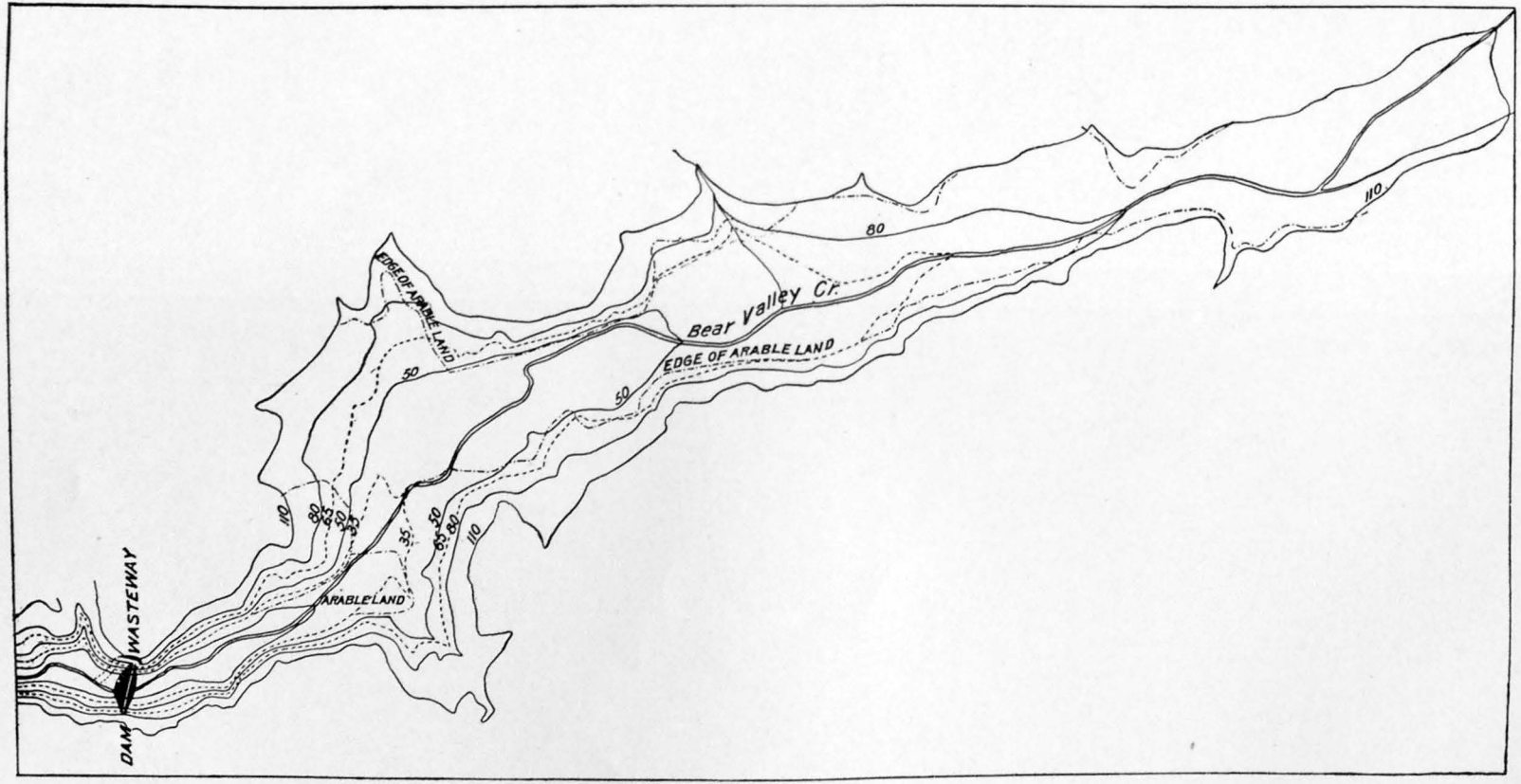


FIG. 90.—Pick-up weir at head of distributing system in Escondido Irrigation District.

of open ditches—a total of 31.5 miles, aside from 15 miles of 2-inch and 4-inch pipes in the town of Escondido, which is a part of the irrigation district and is provided with water by the district in the same ratio as a similar area of farming lands. The system cost $85,727.80, which includes $9,000 in bonds paid for the town waterworks to the private company owning them when the district was organized. In this purchase the district obtained, besides a lined and covered reservoir of 800,000 gallons capacity, a Worthington pump of 500,000 gallons capacity per day, three 20-foot brick-lined wells 20 feet deep, and twenty 2-inch driven wells. This auxiliary supply, though small in amount, is




CONTOUR MAP OF RESERVOIR OF ESCONDIDO IRRIGATION DISTRICT.

very convenient to draw upon for domestic service in the late summer and fall when the water in the reservoir becomes foul with decaying algæ.

The first issue of bonds by the district, out of the total amount of $350,000 authorized, was $344,500, which realized $313,750, all of which was expended on first construction, and the proceeds of the remaining $5,500, together with $2,500 additional, were expended in the early part of 1897 in lining the main distributing ditches with cement plaster to save the excessive loss by percolation. The irrigators using water in 1896 were 150 in number, cultivating 2,000 acres, the average holding being 13 acres. In addition to these the town consumers number 140, i. e., the taps on the system are that number.

The annual cost of operation is about $4,000, which, added to the interest on the bonds, $21,000, brings the total annual cost per acre-foot of storage capacity to about $8, although taking into account the losses by evaporation in the reservoir and seepage from the open ditches and flumes in transit, the cost of water actually available for use on the lands is about $12.50 per acre-foot. The average requirement for adequate irrigation is estimated at about 1 acre-foot of water per acre. The total annual expenses divided by the total area of the district gives an average of about $1.80 per acre. The assessed valuation of the district is about $677,500, and the irrigation tax rate is $3.69 per $100. As the best land is assessed at $40 per acre, it is shown on that basis that the average cost to the owner is but $1.48 per acre, which is a low rate if it would insure him a sufficient supply for the irrigation of his land, but as the provision thus far made for the district is less than one-fourth of the water needed for the entire area within the limits of the district, and as the water available is apportioned to the irrigator pro rata to the amount of tax he pays, his annual rate must necessarily be higher than the amount stated if he receives the water he actually requires.

The apportionment is made in regular runs, once each month, beginning at the head of the system, and in order to accomplish the satisfactory irrigation of their tracts the orchardists are obliged to buy what they lack from such of the neighboring taxpayers as do not yet use the water to which they are legally entitled. This assigned water is sold at about 10 cents per inch (twenty-four hours' run), which is about one-third cost. A toll of 1 cent per twenty-four-hour inch, or 25 cents as a minimum, is charged as a gate tax for zanjeros' fees for turning water on and off, which brings in a revenue of about $80 per month during the irrigating season, and $60 per month during the rest of the year.

A large number of orchards had been started and were being irrigated by pumping with windmills and gasoline engines before the completion of the works of the district. The cost of pumping by the various methods employed ranged from 3 to 8 cents per 1,000 gallons ($10 to $26 per acre-foot), and this high cost, together with a moderate

and inadequate supply, caused many of the outsiders who had not been incorporated in the area of the district to seek admission on equal terms with those inside. Several hundred acres were thus taken in after the works had been completed to their present stage upon payment of all back charges pro rata. From the fact that the cost of water in the district is actually nearly 4 cents per 1,000 gallons, and

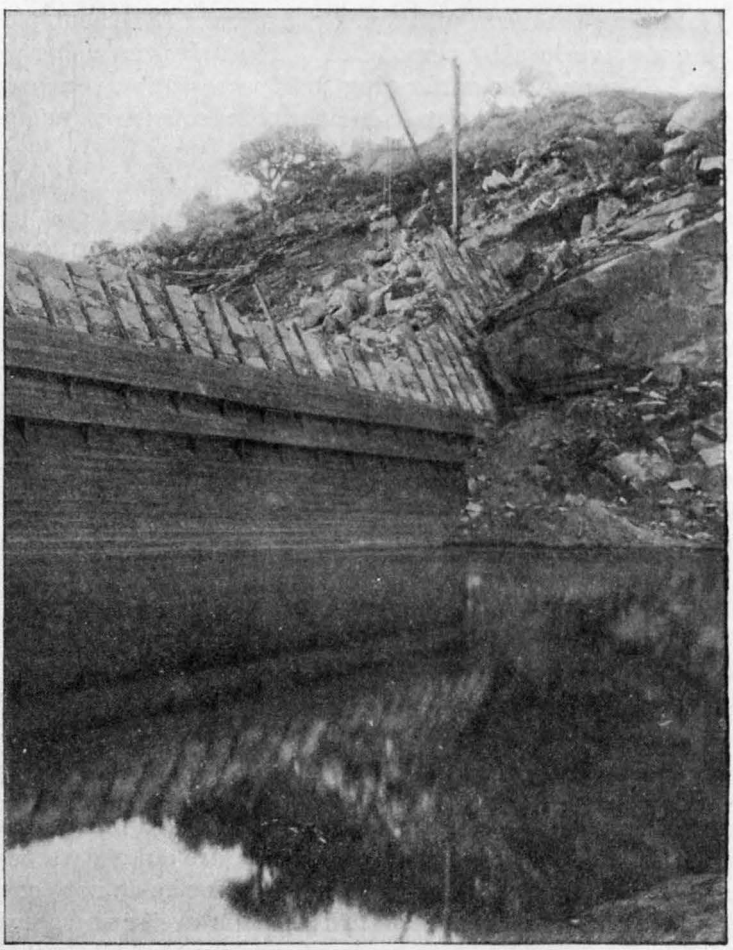
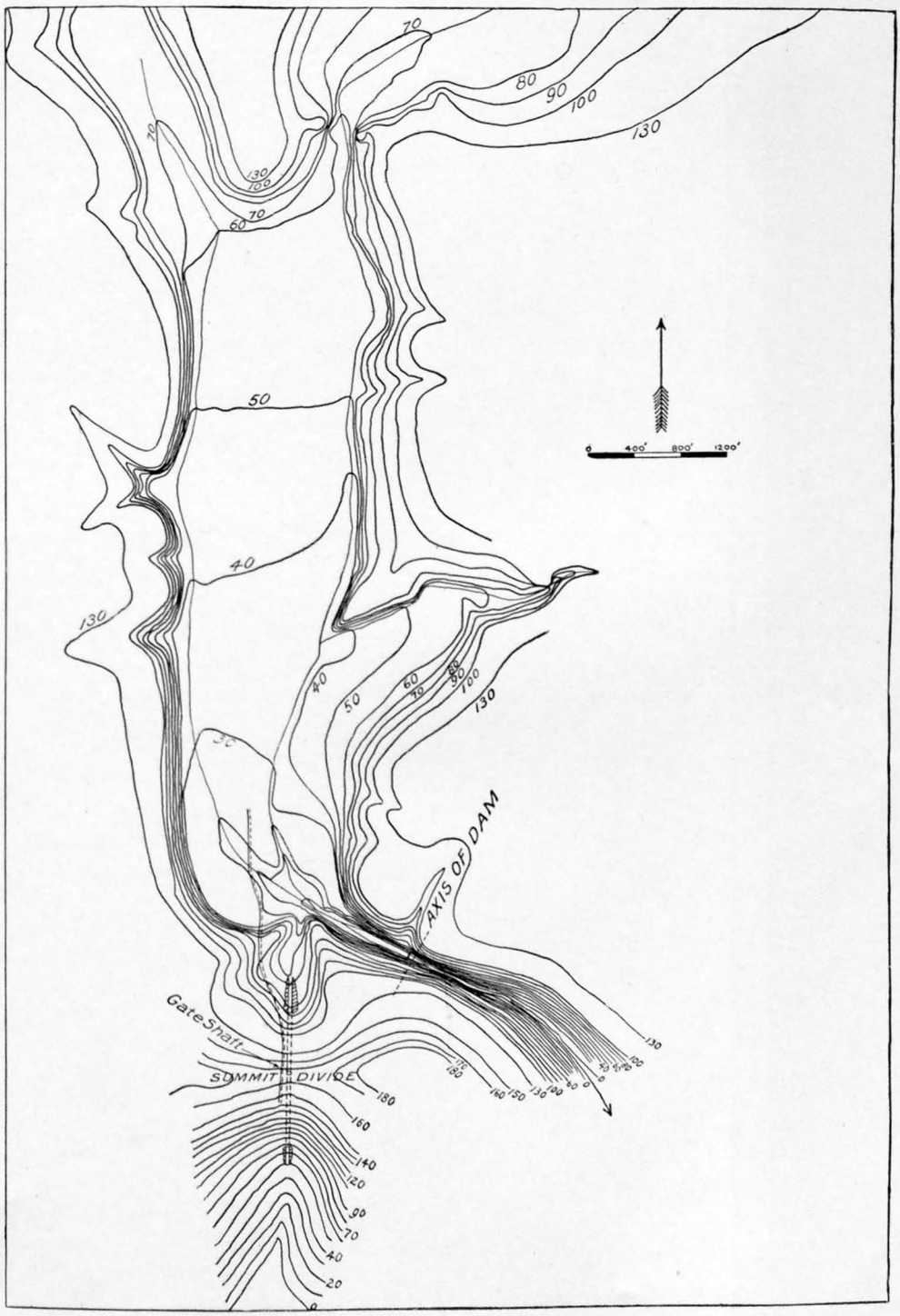


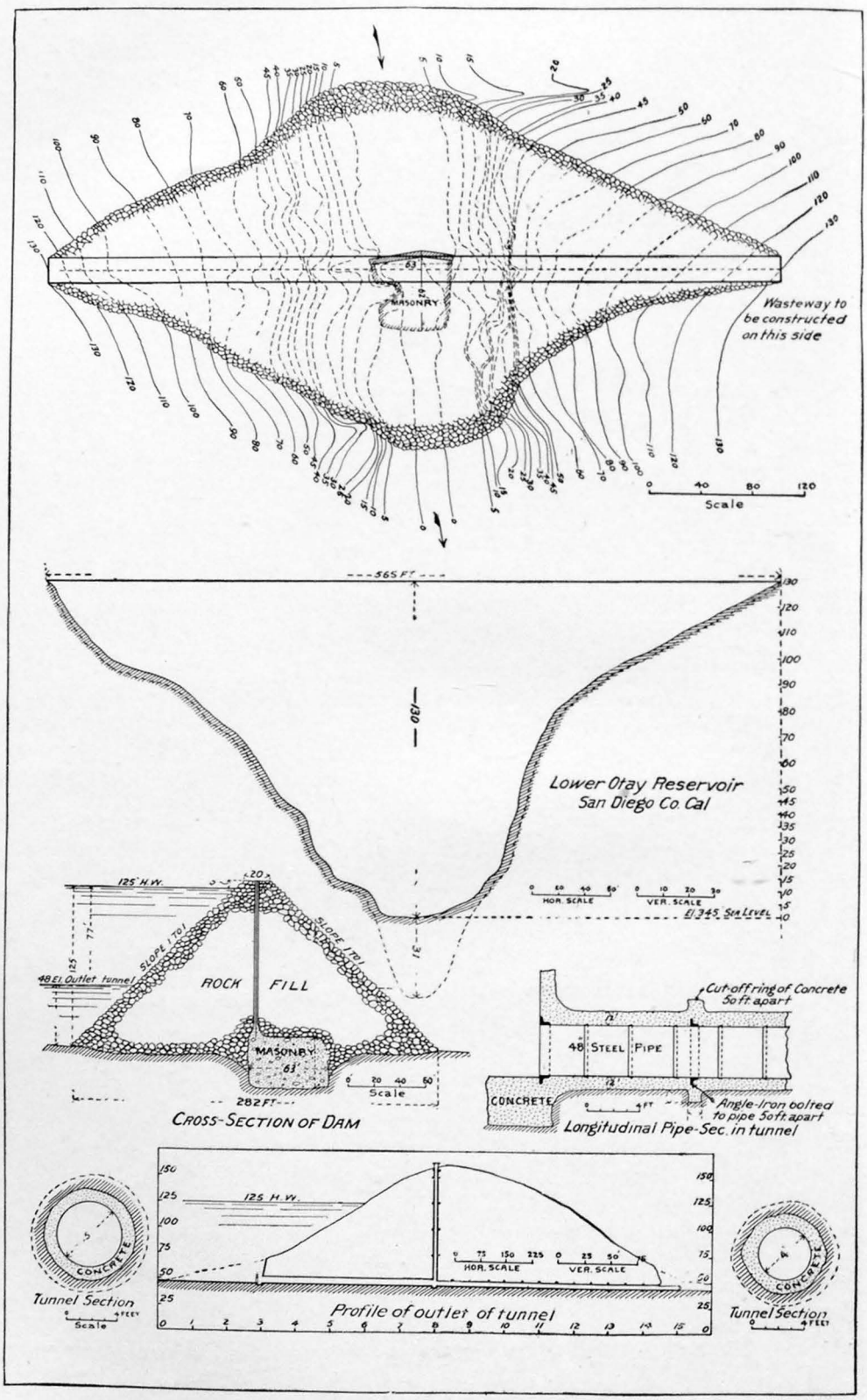
FIG. 91.—Construction of facing of Escondido dam.

that this charge was deemed preferable to previous methods of supply, the cost of pumping may be surmised.

The residents of the district realize that their works are in an incomplete stage, and that to secure an adequate supply it is necessary to carry the storage dam 40 feet higher, giving it a capacity of 11,335 acre-feet. This is contemplated in the near future, and besides it is proposed to secure a small additional storage on the river above the head of the main feeder canal to serve as a regulator of the flood flow,




MAP OF LOWER OTAY RESERVOIR.




PLANS OF LOWER OTAY RESERVOIR.

the normal low-water flow being the property of the Cuca Indians and other tribes living below the head works, and depending upon it for the irrigation of their crops. A very capacious reservoir site exists at Warner's ranch, 15 miles above the head of the canal, where the drainage of 210 square miles of watershed may be impounded. The cost of an earth dam, 36 feet high, to hold 30 feet depth of water and impound 6,400 acre-feet, forming a reservoir of 740 acres, has been estimated at $45,000, including land occupied at $40 per acre. The cost of increasing the rock-fill dam to its ultimate height of 110 feet is estimated at $110,000. When these improvements are made it is believed that the entire district will have an ample supply for future needs at an average annual cost of $2.50 to $3 per acre and a total outlay of about $40 per acre. The works were planned and their construction was supervised by E. F. Tabor, C. E., of Escondido.

## LOWER OTAY ROCK-FILL STEEL-CORE DAM, CALIFORNIA.

One of the most interesting and remarkable dams now under construction is located 20 miles southeast of San Diego, California, about 10 miles back from the coast, on Otay Creek (see Pls. LII and LIII). The stream here cuts through the great porphyry dike which traverses San Diego County from north to south nearly parallel with the coast line. The dike is several miles in width, and is crossed and cut into by all the streams of the county that reach to the ocean, affording sites for the Sweetwater and the La Mesa dams, already built, and others farther north that are projected. The dam is being built to store water for irrigation and domestic supply on Coronado Beach and the region south and east of the head of the Bay of San Diego. Its ultimate height above the stream bed is to be 130 feet, and it will be completed early in 1897. It is a simple embankment of loose stone, dumped in, without any portion of it being laid by hand as a wall, and depending for water-tightness on a central core of steel plates riveted together after the fashion of a huge tank, forming a web-plate across the canyon from wall to wall, filling the entire cross section. It was originally intended to build a masonry dam at this place, and a foundation was laid for that purpose, 62 feet thick at the base. This masonry reaches down to a depth of 31.4 feet below zero contour, into an irregular "pothole" excavated in the softer portion of the bed rock under the stream bed, and it was carried up to 8.6 feet above zero before the plan was changed, its length being about 100 feet at this level. The upstream side of this masonry was built as an obtuse angle of about 164°, and on this foundation and 6 feet back from the face the line of steel plates was begun, following the same central angle as the masonry foundation. The plates were 5 feet wide and 17.5 feet long, and the three bottom courses were 0.33 inch thick. From 28 to 50 feet height they are one-fourth inch thick, and above 50 feet they are 8 feet wide and 20 feet

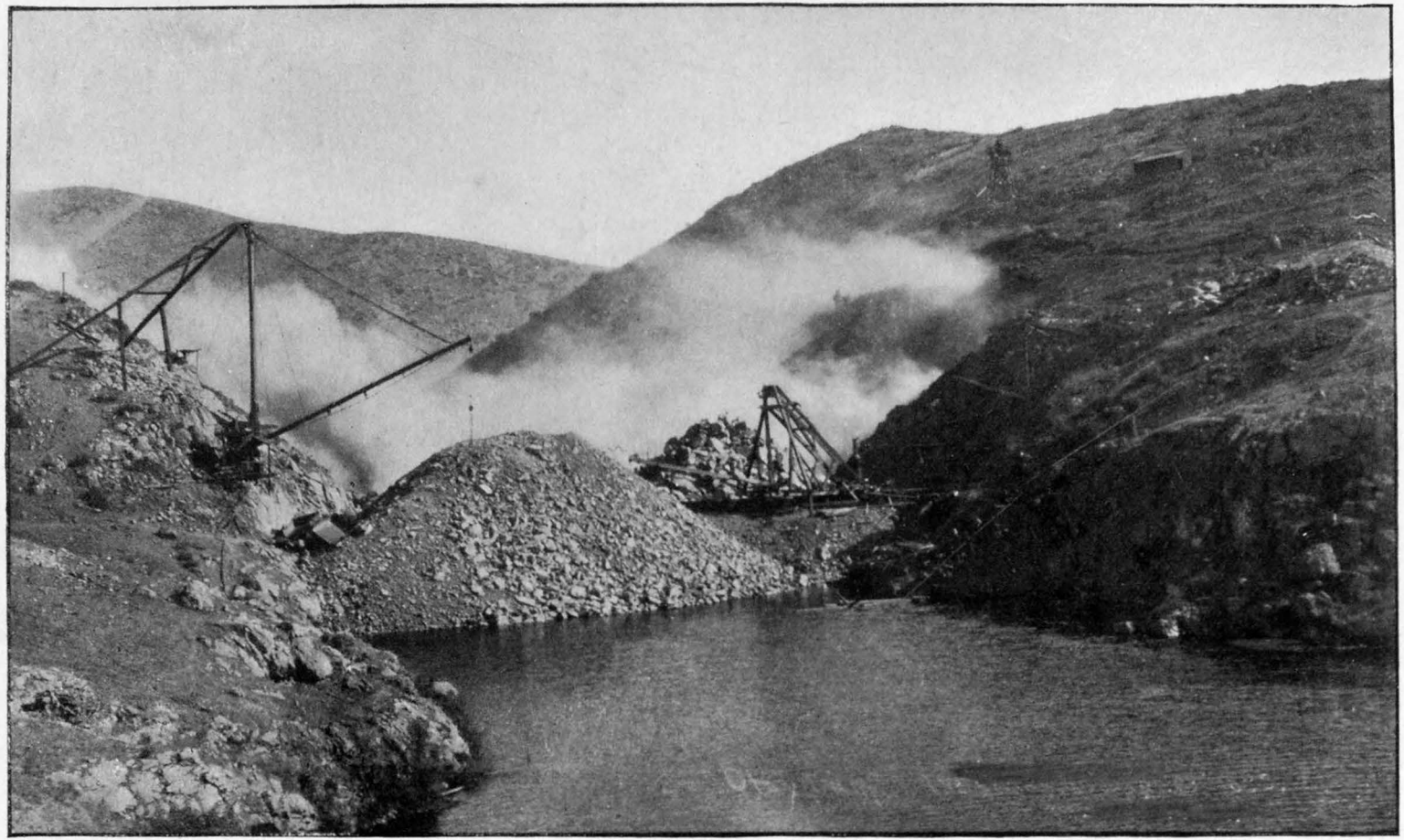
long. The plates were riveted in position, chipped and calked, and afterwards smeared with hot asphaltum and covered both sides with burlap saturated in the same material.

Starting at the foundation, a rubble-masonry wall was built up each side of the plates, 6 feet thick at bottom, battering up on both sides in a height of 8 feet to 1 foot, which thickness was continued to the top. This masonry was somewhat in the nature of concrete, as it was rammed in between a mold of planks and boards placed on each side of the plate, with large rock, often the full thickness of the wall, embedded in the mortar. Its function was evidently to stiffen and steady the web-plate and protect it from injury from the loose rock piled against it. At the ends the plates were carried into a trench excavated into the solid rock, and fastened to anchor bolts set into the rock, the masonry being expanded to a greater width for a few feet at the sides. The depth and width of the trench were quite irregular, depending upon the direction and position of seams in the rock. Pl. LIV shows the trench on the right bank, about at the 40-foot contour.

The expansion of the plates after they were riveted together gave them a very irregular alignment, and before they had reached the 50-foot level the angle in plan had almost disappeared, and the sheet was in a practically straight, but wavy, line from side to side. In order to straighten up in this way the sheet must be inclined from the vertical at some points, and this inclination may be as great as 7 feet in the total height. The possible effect of the settlement of the great mass of stone in the rupturing of the plate when the reservoir is filled and one-half of the wall is enveloped in water must be regarded with some measure of concern. The uncertainty as to the strains set up in the central core and the impossibility of calculating them in advance must be urged against this innovation in dam construction, although the experiment will be watched with genuine interest by the engineering profession.

The stone was quarried immediately below the dam on the right bank, and was transported by means of a Lidgerwood cableway, the cable having a diameter of $2\frac{1}{4}$ inches and a span of 948 feet between towers, crossing the canyon at an angle of about 60° with the axis of the dam. The head tower was 100 feet high, the tail tower downstream was 40 feet in height, and a direct line between them crossed the site of the dam 260 feet above the bed of the stream. The cableway has a maximum capacity for carrying 10 tons' weight, under which load the deflection is 88 feet. It has therefore not been necessary to move the cable during construction, from the time of its erection in the fall of 1894 till the completion of the dam. The distribution of the rock either side of the line of the cable has been made by powerful derricks, and latterly by a small auxiliary cable stretched parallel with the line of the dam and anchored to cars movable on parallel tracks on either side of the valley.

STEEL WEB-PLATE AND ANCHOR TRENCH AT WEST END OF LOWER OTAY DAM.



EXPLOSION OF GREAT BLAST AT LOWER OTAY ROCK-FILL DAM.

In dumping the rock brought from the quarry the largest were placed below the center core, and the smaller stones and earth above. The quarry being near the lower toe of the dam, the first large blast filled in the toe with large rock masses, some of which weighed 50 tons and upward, and a subsequent freshet, pouring over and through these rocks, scoured out the sand beneath them so as to settle them well to bed rock, which was a fortunate occurrence. All of the rock has been loosened in the quarry by very heavy blasts, the first of which was made by driving a tunnel 50 feet into the face of the wall, from the end of which two lateral drifts, 18 and 28 feet long respectively, were driven. In the first, 4,000 pounds of Judson powder under a depth of 70 feet, and in the second, 8,000 pounds under a depth of 85 feet, were exploded simultaneously, which resulted in loosening and throwing out about 30,000 cubic yards, at a cost of 6 to 7 cents per yard (see Pl. LV). A number of such blasts have been required to complete the work. The cost of loosening, breaking into portable sizes, hoisting, and conveying to the dam was about 50 cents per cubic yard, bank measure, although there was the disadvantage of having but one quarry to work from, located at one end of the cableway, and all the rock had to be hoisted to a considerably greater height than would have been required from a quarry entirely above the top of the dam.

The total volume of the dam to the 130-foot line, with top width of 20 feet and side slopes of 1 to 1 on each side, is approximately 140,000 cubic yards. Pl. LIII illustrates the general plan, showing a longitudinal section of the site of the dam and details of the outlet tunnel. The only outlet to the reservoir has been made by means of a tunnel, 1,150 feet long, through a gap in the ridge 1,000 feet west of the dam. The bottom of the tunnel is at the 50-foot level. The material encountered in the tunnel was hardpan and cemented gravel, bone dry. For 500 feet from the inner heading it was lined with concrete to a clear circular diameter of 5 feet, the concrete being from 12 to 18 inches thick, and plastered with cement mortar. At the end of this section a shaft, 104 feet in depth, reaches to the surface, to admit of the operation of a gate across the conduit. Outside of the shaft a 48-inch riveted steel pipe is laid to the outside; this is surrounded with 1 foot or more of Portland cement concrete, filling the space between the pipe and the irregular surface of the tunnel, with collars of concrete every 25 feet and 1 to 2 feet deep all around the pipe. There are no pipes or openings of any sort through the dam.

The wasteway is to be located on the left bank, some hundreds of feet away from the dam and discharging at a safe distance below the foot of the embankment. The dam is the property of the Southern California Mountain Water Company, and has been designed by the president of the company, although the execution of the work has been under the supervision of Mr. W. S. Russell, engineer in charge.

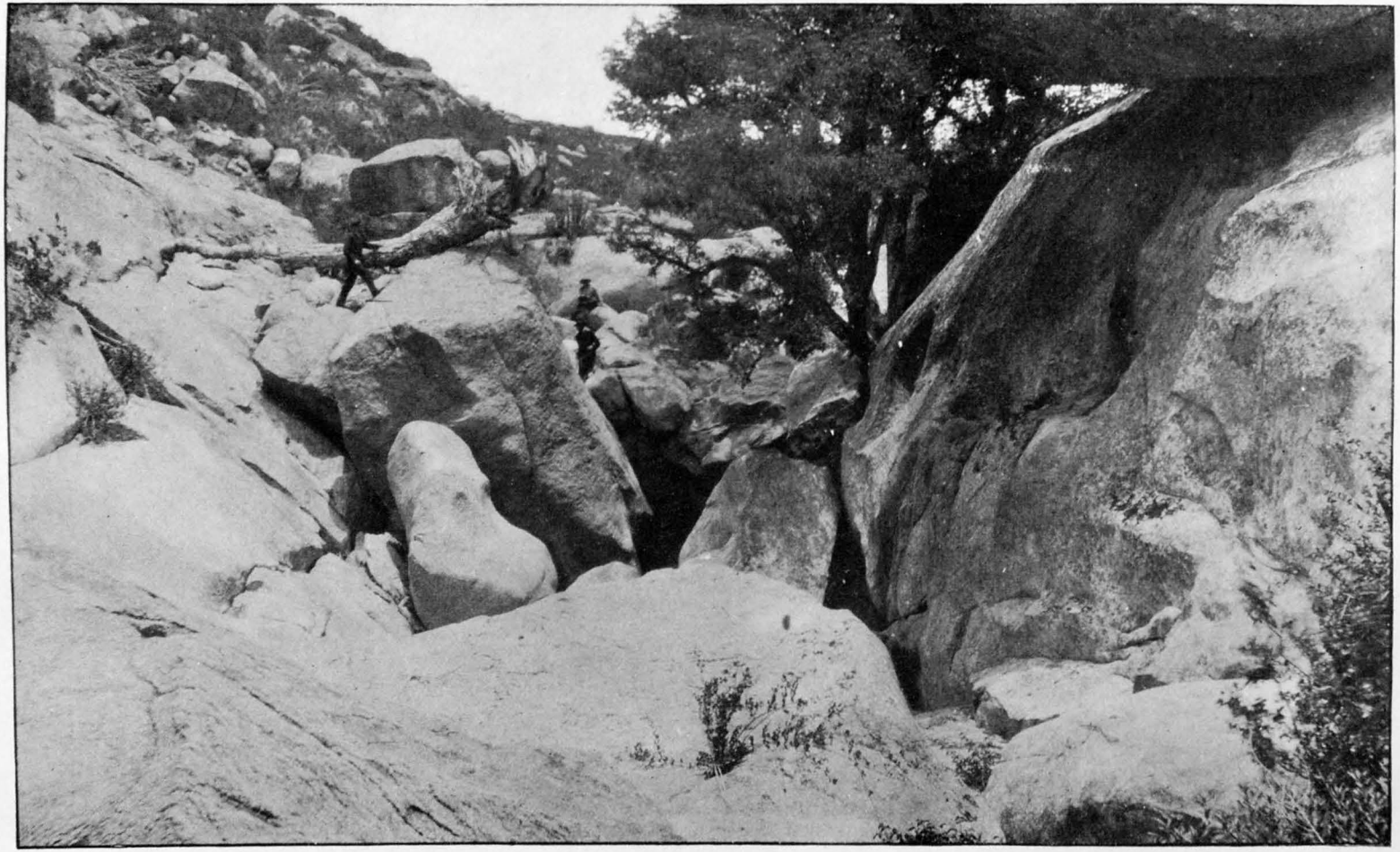
The watershed of Otay Creek above the reservoir is about 100 square

miles in area, but as its average altitude is not over 1,500 feet the precipitation is light and the run-off insufficient to fill the reservoir except in occasional years. In dry seasons there is no flow whatever. To make up for this shortage and to fill the reservoir regularly the company is planning to divert water from Cottonwood Creek, a larger and more reliable stream on the south and lying next to Mexican territory, by a conduit 12 miles in length from the diverting weir at what is known as the "Barrett dam" to Dulzura Pass, where the water will drop over into the Otay drainage. In order to regulate the flow of the stream and store an additional supply for lands higher than can be supplied from the Lower Otay dam, as well as for the city of San Diego, the same company is engaged in closing another reservoir by the erection of another rock-fill, known as the Morena dam.

### MORENA ROCK-FILL DAM, CALIFORNIA.

The location of this structure is on Cottonwood Creek, a tributary of Tia Juana River, 7 miles north of the international boundary and about 50 miles from San Diego (see Pl. LVI). It is at an elevation of 3,100 feet above sea level, and is placed on the brink of a precipitous fall or cataract, where the stream takes a plunge of 1,500 feet in a mile and has eroded a very narrow, deep gorge in the rock, back of the brink, which has been filled to the present surface by large bowlders. The canyon walls are of clean, hard granite, singularly free from fissures and seams, and but 80 feet apart at the stream bed and 470 feet at the height of 160 feet above. Had the planes of the side slopes continued underneath the surface till they met, the depth to bed rock would have been but 30 feet, but when excavation was undertaken for the upper toe wall it was found necessary to go to a depth of 112.5 feet, although the width for the lower half was only from 4 to 10 feet between the sides. This toe wall was made 30 feet thick at base and 16 feet at top. In the top of it a groove was made 1 foot deep to receive the facing of asphalt concrete which is to extend up the inner slope and form the water-tight skin of the dam. This facing is to be laid over a dry wall, 5 feet thick, carried from bottom to top on a slope of 1 to 1. The body of the dam is to be a loose fill of stone, placed similarly to that in the Otay dam by means of cableways and steam power.

The dam is expected to be carried to a height of 160 feet and to hold a maximum depth of 150 feet of water, and will contain 256,000 cubic yards. The cost of this work is considerably less than that at the Otay dam, as the rock is obtained from quarries on each side and above the top of the embankment, and can therefore be more speedily handled, while much of the material may be thrown into place by the use of explosives. The first blast of 100,000 pounds of powder, exploded December 26, 1896, was reported to have moved 150,000 tons of rock. A second blast was fired five days later, in which 80,000 pounds were



MORENA DAM SITE, LOOKING EAST.

exploded, doing good execution, and on March 24 the explosion of 70,000 pounds is said to have loosened 100,000 tons.

The outlet to the dam is placed at the 30-foot contour, and consists of a 6 by 6 foot tunnel, 600 feet long, in solid rock, in which are to be laid two pipes, each 24 inches in diameter, and one of 12 inches, all bedded in concrete. These will connect inside with a steel intake inclined well or pipe, 36 inches in diameter, running up the side of the canyon at the toe of the slope of the dam, and fitted with 36-inch intakes every 30 feet in height, with valves at each controlled by rods passing up the slope to the top.

The dam is being built under a contract with the city of San Diego, by which the company undertakes to deliver 1,000 miner's inches of water, continuous flow (12,960,000 gallons daily), at a point designated as the "Meter House Site," about 11 miles southwest of the nearest limits of the city. The services of an engineer have apparently been considered superfluous in the construction of this work, and aside from an occasional visit from the city engineer of San Diego it has had practically no engineering supervision. Between the outlet level and the 120-foot contour the reservoir has sufficient capacity to supply the agreed amount of 1,000 inches flow for one year, and under the contract so much of the reservoir is conveyed by deed to the city, while all the land above the 120-foot level is reserved by the company, together with the privilege of building the dam to a greater height and storing water for its own use and for sale to other parties on top of the city's reservoir.

An addition of 30 feet to the reservoir height will increase its capacity 200 per cent, giving the company about 30,000 acre-feet of water without making deduction for evaporation, or possibly 25,000 acre-feet net. This is on the assumption that the reservoir will fill every year, which is not an unreasonable assumption, considering the area of the watershed (135 square miles) and its high altitude and heavy precipitation. The reservoir would be filled with a run-off of 20 per cent of 32 inches of precipitation.

The Morena reservoir site was originally surveyed in 1892 by the writer for the Otay Irrigation District, formed under the Wright law, and covering the Otay and San Miguel mesas, the Otay Valley, and a part of the National Rancho, embracing in all 44,000 acres. This district is now in process of disincorporation, and the territory in it will be irrigated from the private system now under construction by the Southern California Mountain Water Company, as described above.

Various complications have arisen regarding the construction of the Morena dam. The question of the validity of the contract entered into by the city council with the company, as well as the validity of the city bonds voted for the waterworks, is in litigation, and the city engineer alleges extraordinary negligence in laying the foundation, or toe wall, which was said to have been completed 112.5 feet in height in the

unprecedented time of eighteen days, while some of the crevices were alleged to be filled only with gunny sacks.

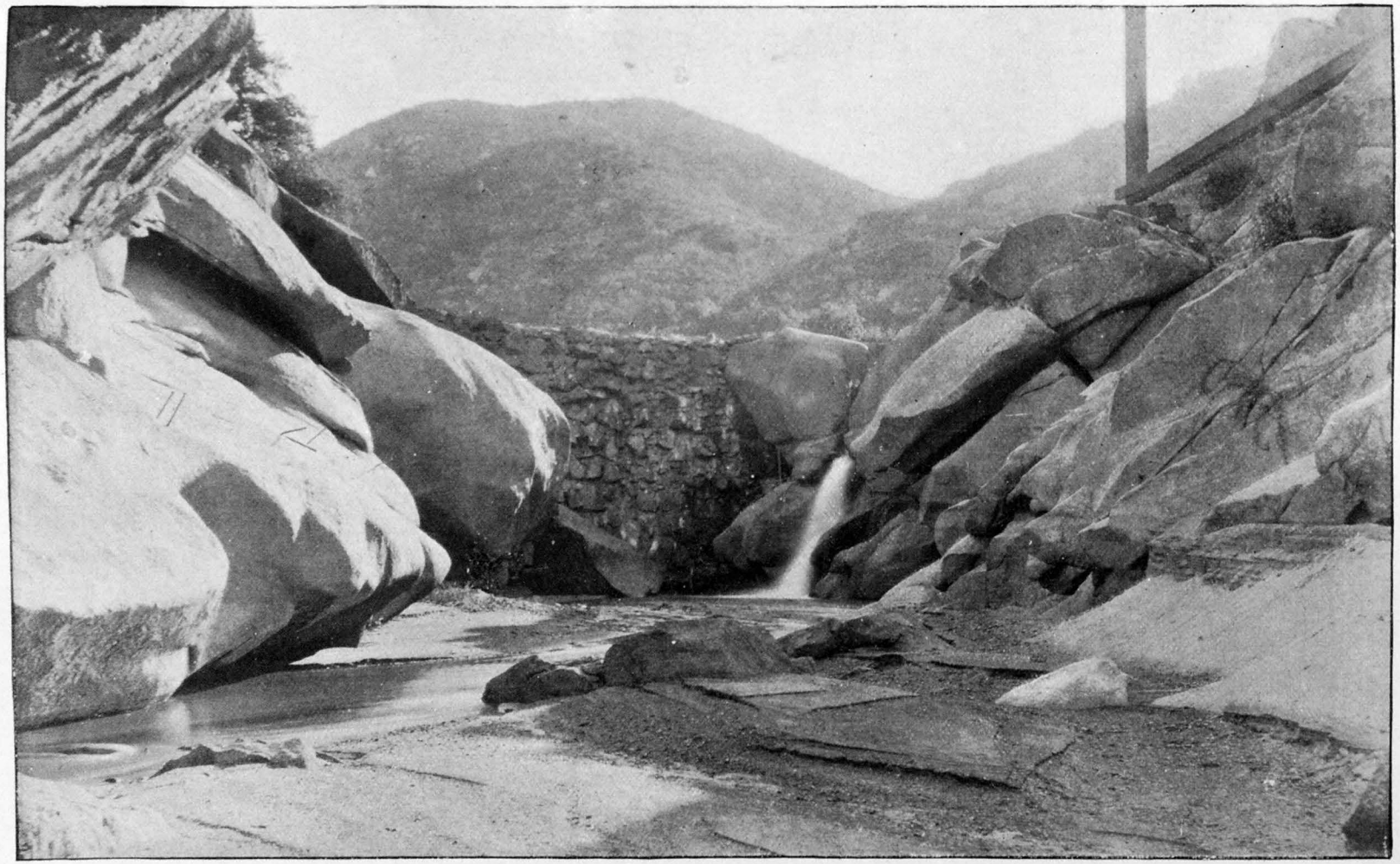
Water released from the Morena dam will flow down the natural channel of Cottonwood Creek for 8 miles to the Barrett dam site, whence it will be carried to the Dulzura Pass by the same conduit heretofore mentioned as the feeder to the Lower Otay dam. This conduit is planned for a capacity of 190 second-feet, is to consist of cement-lined canal and flume, and will be 11.75 miles in length, including the 1,500-foot tunnel through Dulzura Pass. This pass is 12 miles above Otay dam, and here the water is divided, the larger part dropping down into the channel of Otay Creek. A conduit of 60 second-feet capacity will start three-fourths of a mile below the pass and follow a grade line 26 miles long to the aforesaid "Meter House Site," where 20 second-feet is intended for delivery to the city pipe line and the remainder to be used in the irrigation of the higher mesas and to feed the Upper Otay reservoir.

### UPPER OTAY RESERVOIR, CALIFORNIA.

This reservoir, a part of the above-named company's system of storage, is on the west fork of the Otay, and is at such an elevation that the high-water line of the Lower Otay reservoir will touch the foot of the dam of the upper one. The dam site is in a porphyry-rock gorge, narrower than the Lower Otay site, the width between walls being but 20 feet at base, although the basin above is not nearly so capacious, and at 100 feet height the length of dam is much greater. At the 120-foot contour the reservoir will have a surface area of 452 acres and a capacity of 15,300 acre-feet. The foundations have already been laid for a dam at this point, but no work has been done on it for some time.

### BARRETT DAM SITE, CALIFORNIA.

The pick-up weir at the Barrett dam site (Pl. LVII) consists of a masonry wall 72 feet in height from its base, 22 feet below the stream bed, to its top, 50 feet above, and is 14 feet thick at bottom and 5 feet at top. The length across stream is but 7 feet at base and 30 feet at the crest. It rests on solid granite throughout. It was originally intended to build this dam 150 feet high as a storage-reservoir dam, but on making excavations above the 80-foot contour on the left bank a mass of disintegrated, rotten granite was uncovered that was regarded as an unfit foundation for a high masonry dam. This site, together with 560 acres of the reservoir basin, was purchased by the Jamacha Irrigation District for $105,000, an amount which was supposed to buy a title to water rights in the stream to the extent of the reservoir capacity in addition to the land. It is understood that the dam site which has cost the district so dearly is simply to be used as the diverting weir of the Southern California Mountain Water Company in consideration of an arrangement by which the people of the district expect to be served with water by the company.



BARRETT DAM.

## CHATSWORTH PARK ROCK-FILL DAM, CALIFORNIA.

A structure of more than common interest as an example of "how not to do it" was erected on Mormon Canyon, in the westerly part of the San Fernando Valley, California, near the station of Chatsworth Park, in the winter of 1895–96, for impounding water for irrigation and to serve as a diverting dam for a conduit to carry the flood water of the stream to a secondary reservoir of much larger capacity a short distance away to the south. Two failures of earth dams erected at the same site had already occurred prior to the building of the dam in question, both having been overtopped and carried away by reason of insufficient spillway capacity. The last one was swept out shortly before beginning work on the rock-fill, as the result of bad management. The spillway had been filled with sand bags to make the reservoir hold a little more, and when the flood came there was no one there to remove them. When the attendant finally arrived the sluice gate was stuck and could not be opened, and before anything could be done the water rose over the top and quickly washed it away.

The present rock-fill dam is 41.33 feet high above the creek bed, is 10 feet wide on top, and slopes at an angle of 60° on each side, or 1 vertical to .057 horizontal, which gives a base width of 60 feet. The length on bottom is 100 feet and at top 159 feet; cubical contents, 6,025 cubic yards; area of water face, 7,700 square feet, covered with Portland cement concrete from 8 to 16 inches thick. The rock used for the fill is a soft sandstone, quarried on the line of the dam at one end, 500 feet away, and 75 to 100 feet higher than the top of the dam. The quarry face was 30 to 40 feet high. A light trestle was built on a sharp incline from the quarry to and across the dam, and a cable, passing over a drum or pulley at top and with a car at each end, was the means employed for transportation, the loaded car fetching up the empty one. The material was dumped in place promiscuously and without selection. Some of it disintegrated and crumbled into sand when blasted or hammered or dropped from a few feet in height, and as everything loosened in the quarry was put into the fill the proportion of sand and earth is very large and the angle of repose of the mass is much flatter than that of rock alone, and flatter than the slopes proposed by the plans.

The specifications required the slopes to be laid up for 2 feet in thickness as a dry wall of uncoursed rubble, but this was done in such an indifferent manner that within two weeks after the contractor had moved off the work more than three-fourths of the lower face wall fell or slid down, and was followed by so much of the fill behind it as to leave the concrete facing practically unsupported and exposed to view for several feet from the top down. The dam was not of much value for water-tightness, as it leaked considerably with but 10 feet of water behind it. The work was done by contract, at a total cost of about $9,000, part of which was payable in land. After the work was done

the contractor took advantage of the failure of the company to comply with the California law requiring contracts to be recorded to make them valid, and brought suit to recover a greater amount than the contract price. He succeeded in getting a jury to give judgment for about 40 per cent additional, while the owners have been obliged to reconstruct the dam. This is being done as illustrated in fig. 92, the lower slope being hand-laid to a thickness of 4 feet and covered with a masonry wall 6 feet thick. This is believed to be the first case on record of a dam falling down before the water pressure had been applied to it.

The watershed is about 15.5 square miles in area, and from 1,000 to 3,800 feet in elevation, from which maximum floods of 700 to 800 second-

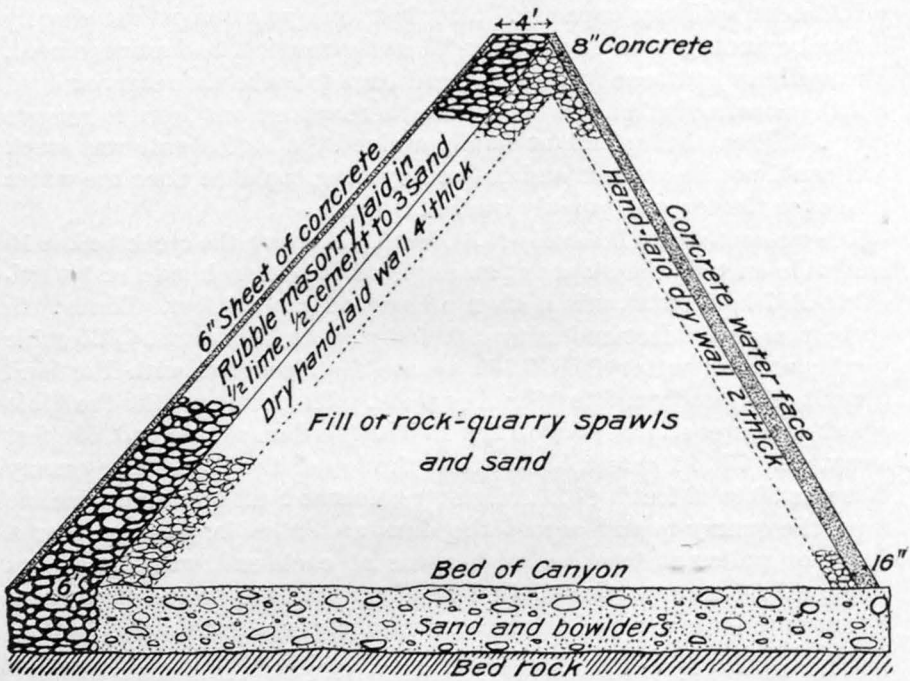



FIG. 92.—Sketch of reconstruction of Chatsworth Park rock-fill dam.

feet may be expected—sufficient to fill the reservoir in three or four hours, as the capacity is not in excess of 200 acre-feet.

The dam bears some resemblance in form of construction to the Castlewood dam in Cherry Creek, Colorado, ably described by Mr. H. M. Wilson in American Irrigation Engineering,[1] except that the facing of the Castlewood dam is much thicker, being 12 feet at bottom and 8 feet at top, while the lower face is in steps of 18 to 30 inches, the masonry wall being from 5 to 7 feet thick. It is somewhat higher, also—63.5 feet—85 feet wide at base and 586 feet long on top, while the water side is reenforced by an earth embankment, added after the facing wall was built, and extending about half way up to the top.

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, p. 303.

## PECOS VALLEY ROCK-FILL DAMS, NEW MEXICO.

In the foregoing pages five distinct types of rock-fill dams have been described, but there is still another which has been most boldly exemplified in the Pecos Valley, New Mexico, in two large storage reservoirs built across the valley of the Rio Pecos, one of which is 6 and the other 15 miles above the town of Eddy. They differ from the others in the use of earth alone as a facing of the rock-fill for the stoppage of leakage, and they appear to have been eminently successful.

The principal dimensions of the lower dam are as follows: Length, 1,380 feet; maximum height, 48 feet; outer slope of rock-fill, 1½ on 1; width of rock base, 106 feet; crown, 10 feet. The earth facing has also a crown width of 10 feet, making the total width 20 feet. The slope of the earth embankment is 3 on 1, which is covered with a pitching of loose stones for wave protection. The dam was built in 1889–90, and was in service until August, 1893, when it was ruptured by a flood wave that was in excess of the spillway capacity—the old story connected with dam failures. The water poured over its crest, and as this style of dam is not calculated to withstand such an overflow, it speedily washed out a breach of over 300 feet in length. This was immediately repaired and built 5 feet higher, at a total cost of $86,000. The spillway capacity was increased to the following:

| | Second-feet. |
|---|---|
| Through head gates of main outlet canal | 3,200 |
| Through waste-weir gates | 14,500 |
| Over top of waste gates | 2,400 |
| Through spillway No. 1, west end of dam | 5,600 |
| Through spillway No. 2, one-half mile west of No. 1 | 7,300 |
| Total | 33,000 |

This amount of discharge is estimated to take place when the water is 7 feet below the top of the dam. The reservoir has a capacity of about 7,000 acre-feet, and serves the double purpose of an auxiliary storage dam and a means of raising and diverting the water of the Pecos to the main canal at a safe level above the stream, beyond the reach of floods. This canal has a capacity of 1,300 second-feet for 3.2 miles, to the junction of the Southern and East Side canals, the width on bottom being 45 feet, depth of water 7 feet, and grade 1.5 feet per mile. The second section, of 9 miles, has the same grade and a capacity of 680 second-feet. On this section the canal is carried across the river in a flume 25 feet wide and 6 feet deep, supported on high trestle bents. The third section is 4.2 miles long, and has a capacity of 460 second-feet. Then follow 2 miles with 385 second-feet capacity, and 21.6 miles in which the maximum capacity is but 215 second-feet, the width on bottom being 14 feet and the depth 4 feet. The total length is 40 miles. The East Side Canal is 19.6 miles long, and has a capacity of 224 second-feet.

In 1893 the upper dam was constructed in similar manner to the other,

except that the rock-fill was made 4 feet wider at top and the earth facing 4 feet less in width, the slopes remaining the same. The inner face of the rock-fill against which the earth rests has a batter of $\frac{1}{2}$ on 1, the wall being laid up 2 feet thick by hand. It required 102,400 cubic yards of rock, 103,600 yards of earth, 3,800 yards of dry retaining wall, and 6,200 yards of riprap. Its cost is given as $170,000 complete. An auxiliary embankment, 5,200 feet long and 18.8 feet high, was thrown up to close a gap, at a cost of $10,000. It was made entirely of earth, faced for 5 feet with stone, to protect it from wave action. The main dam is 1,686 feet in length, 52 feet in height, 20 feet wide on top, and 280 feet wide at base. In the fall of 1895, when visited by the writer, it

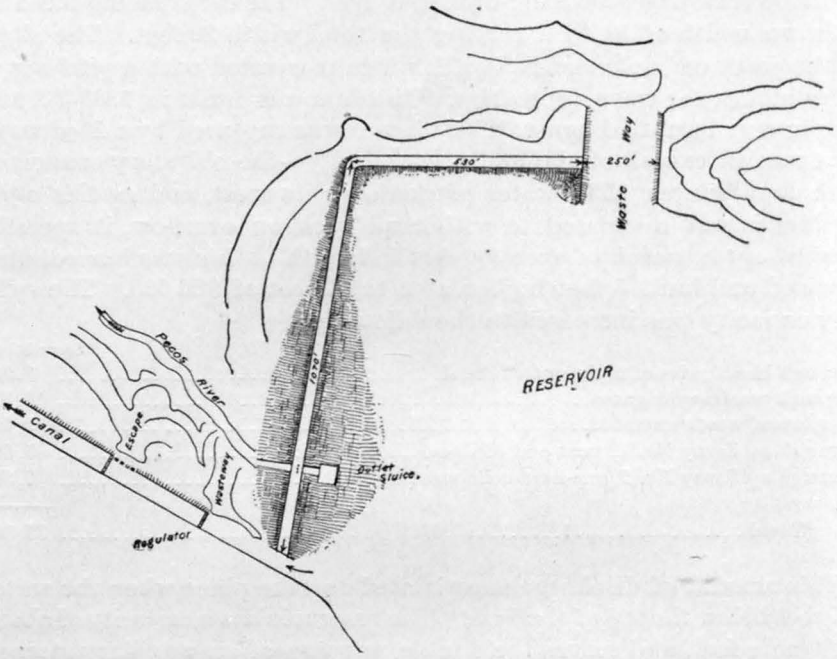



FIG. 93.—Sketch map of dam at head of Pecos Canal.

showed no sign of leakage or settlement or any form of weakness, although the reservoir was more than half full.

An outlet canal 1,100 feet long is cut through solid limestone at the east end of the dam, to a maximum depth of 35 feet below the top of the embankment, in the upper end of which are placed six gates, each 4 feet wide and arranged to open to a height of 8 feet by screws. The gates are of wood, 6 inches in thickness, substantially ironed. They constitute the sole means of controlling the discharge from the reservoir, and the water issuing from them is carried back to the river channel below the dam and thence flows to the lower reservoir. The canal is 30 feet wide, and required the excavation of 68,000 cubic yards (solid measurement) of rock, all of which was used for the rock-fill of the dam. The canal head works cost $20,000. The gates have a maximum

discharging capacity of 4,400 second-feet, and the main spillway is said to have the excessive capacity of 200,000 second-feet. This is through a natural gap over limestone. The reservoir has a capacity of 82,640 acre-feet, covering 8,331 acres. It is locally known as "Lake McMillan."

The cost of the storage has been at the rate of $2.05 per acre-foot stored. The Pecos River is reported to have carried a maximum volume of 42,500 second-feet in 1891, and a minimum of 202 second-feet in the month of August of that year.

This particular type of rock-fill dam appears to have every element of safety so long as sufficient spillway is provided, and to be particularly well adapted to the conditions found in the Pecos Valley, where ledges

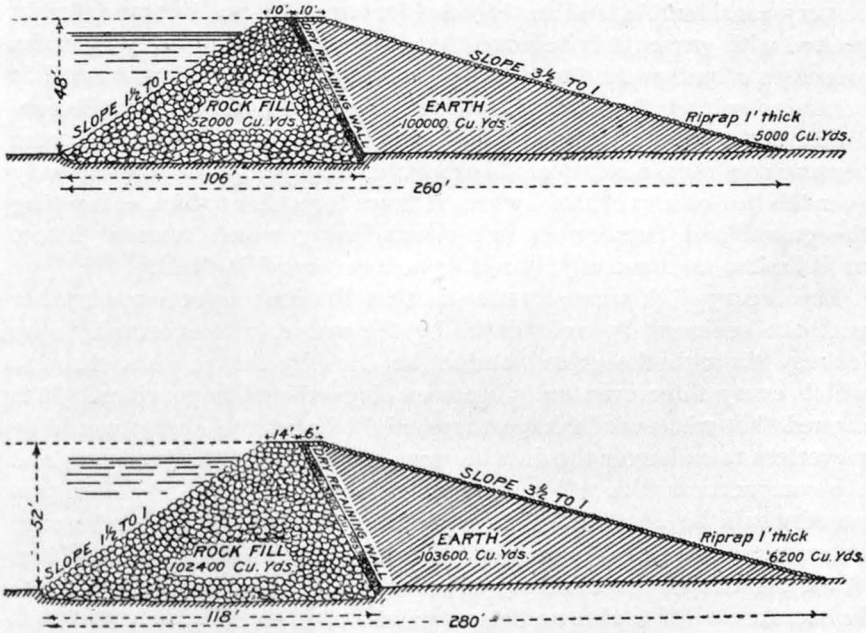



FIG. 94.—Cross sections of Pecos Valley reservoir dams.

of limestone crossing the valley come to the surface at intervals, affording reliable foundations for dams, and where an abundance of suitable earth is available, and where the dams are low and the country is so open as to make the site easily accessible from all sides, conditions which do not prevail in mountain canyons, or in places where construction is cramped for room and earthy matter is scarce and hard to obtain. As heretofore mentioned, the upper and higher dam does not leak, and it is said that the lower one is also impervious, although a pond of water stands at its lower toe and flags are growing there in oozing water, but this is said to come from springs which issue from the limestone along the river bank so abundantly as to afford an additional supply between

the dam and the town of Eddy of about 80 second-feet. This is used for power at the Eddy "power dam" and for irrigation farther down the river.

## PROPOSED LYTLE CREEK ROCK-FILL DAM, CALIFORNIA.

While on the subject of rock-fill dams it will be of interest to mention a dam proposed by F. C. Finkle, C. E., engineer of the Grapeland Irrigation District, for storage of flood water in the canyon of Lytle Creek at the "Lower Narrows," which is novel in one respect—the building of the rock-fill directly upon the bowlder bed without excavation to bed rock, which is of an unknown depth, but probably more than 50 feet below the surface. The expense of this excavation would be very considerable, and as the bowlders are of large size and firmly packed with gravel, it is believed that it would be safe to rely upon the processes of nature for the silting of the bed of the reservoir until it became absolutely impervious. Some reliance is placed upon the condition of the low-water flow issuing from the North Fork, which comes bearing so strong a solution of carbonate of lime as to deposit heavily over the bed of any channel where it flows for a short time, cementing the gravel and forming an impervious lining which remains intact until broken mechanically by rolling stones carried in flood.

The theory of this construction is that the lime accretion, together with the sediment brought down by the water, will effectually stop leakage through the gravel under the dam, by the process through which every filter eventually becomes clogged and impervious. It is argued that whatever leakage there might be at the outset would be powerless to endanger the dam because of the size of the bowlders and the compactness with which they are placed together. The dam proposed would be about 125 feet high, 286 feet long at base, and would impound about 11,400 acre-feet. To arrest the flood flow of bowlders down the canyon, an auxiliary dam above the reservoir would have to be constructed of timber and stone cribs.

The rock-fill dams that have been cited as the prototypes of that class of construction in the West are chiefly to be found in the hydraulic mining districts of northern California, and are mostly on the watersheds of the Yuba, American, and Feather rivers. In general they have been made as large timber cribs, filled with stone, and faced with two or three layers of pine plank.

The following is a table giving data of the capacity of the principal mining reservoirs of the district referred to, the area of the reservoirs, and the height of dams constructed. They are mostly located at the site of natural lakes, whose surface has been raised by the erection of dams at their outlets.

*Capacity of the principal mining reservoirs of the hydraulic mining districts of northern California.*

| Name. | Company. | Capacity of reservoir. | Area. | Height of dam. | Length of dam. |
|---|---|---|---|---|---|
| | | *Cubic feet.* | *Acres.* | *Feet.* | *Feet.* |
| Bowman | North Bloomfield Mining Co. | 900,000,000 | 500.0 | 100.0 | 425 |
| Shot Gun Lake | do | 3,423,000 | 26.2 | 10.0 | |
| Inland Lake | do | 23,028,000 | 48.8 | 12.8 | |
| Middle Lake | do | 2,395,800 | | | |
| Round Lake | do | 2,907,700 | 10.3 | 3.0 | |
| Weaver Lake | Eureka Lake Mining Co. | 150,000,000 | 83.5 | 21.8 | |
| Eureka Lake | do | 661,000,000 | 337.3 | 68.2 | |
| Fancherie Lake | do | 58,800,000 | 90.0 | 21.0 | |
| Jackson Lake | do | 15,000,000 | 20.0 | 5.0 | 250 |
| Smaller lakes | do | 50,000,000 | | | |
| English dam | Milton Mining Co. | 650,000,000 | 395.0 | 131.0 | 331 |
| Fordyce dam | South Yuba Mining Co. | 1,075,525,000 | 1,200.0 | 75.0 | 650 |
| Meadow Lake | do | 107,950,000 | 262.0 | 28.0 | 500 |
| Sterling Lake | do | 53,975,000 | | 30.0 | 300 |
| Omega | | 300,000,000 | | | |
| California | | 1,070,000,000 | | | |

## HYDRAULIC DAM CONSTRUCTION.

### LA MESA DAM, CALIFORNIA.

A novel and exceedingly interesting type of dam (see Pls. LVIII–LXI) is that constructed in the spring of 1895 by the San Diego Flume Company for the purpose of storing the flood water of San Diego River in winter at the lower end of the flume, as well as to provide means of catching the tail water or waste from the lower end of that conduit. The dam was designed and constructed by J. M. Howells, C. E., president of the San Diego Flume Company, and is located on the mesa 8 miles northeast of San Diego, at an elevation of 433.5 feet above sea level at base. It is an earth and rock-fill dam, 66 feet high, 251.5 feet thick at base, and 20 feet wide at top, the materials for which were transported and deposited in place by flowing water, by the process known to miners as "ground sluicing," the surplus water from the flume being used for this purpose and at the same time stored in the reservoir as it was being formed back of the dam.

The dam site is in a narrow gorge cut through porphyry, whose walls are but 40 feet apart at the stream bed and stand nearly vertical on one side for 40 feet in height. The site was regarded as a particularly

suitable one for a masonry or rock-fill dam, as the foundations were of the best character and the materials at hand entirely suitable, and with these advantages in view the first plans made were for a rock-fill with plank facing, the structure to have the following dimensions: Top width, 12 feet; height, 55 feet; length on top, 470 feet; base width, 110 feet; upper slope, $\frac{1}{2}$ to 1; lower slope, 1 to 1; the volume to be about 15,000 cubic yards. Bids were received on these plans, the lowest of which was 99 cents per cubic yard for the rock-fill and $2.08 for dry rubble wall, prices which are but 55 to 66 per cent of the contract prices paid for the Escondido dam. The total cost of this dam under these bids would have been $20,260, exclusive of facing and the outlet pipes and gates. The hydraulic dam was, however, given the preference by the company on a guaranty of a material reduction of cost given by the engineer, Mr. Howells, and it was finally completed for about $17,000, including plant, excavation of foundations and spillway, outlet gates, culvert and standpipes, paving of slope, etc.

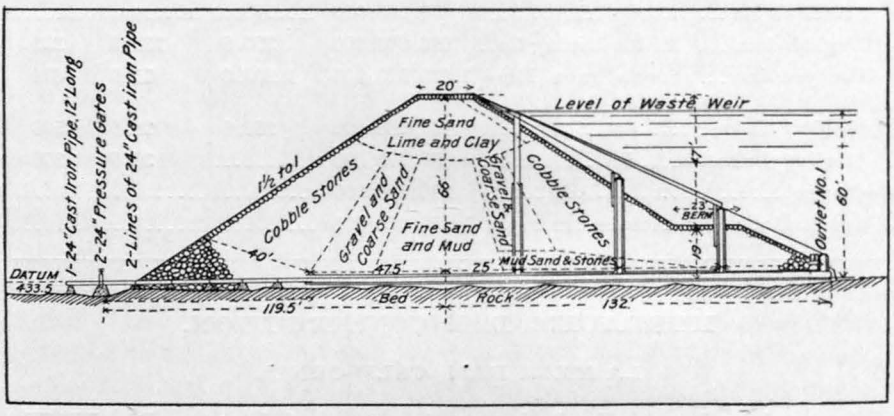
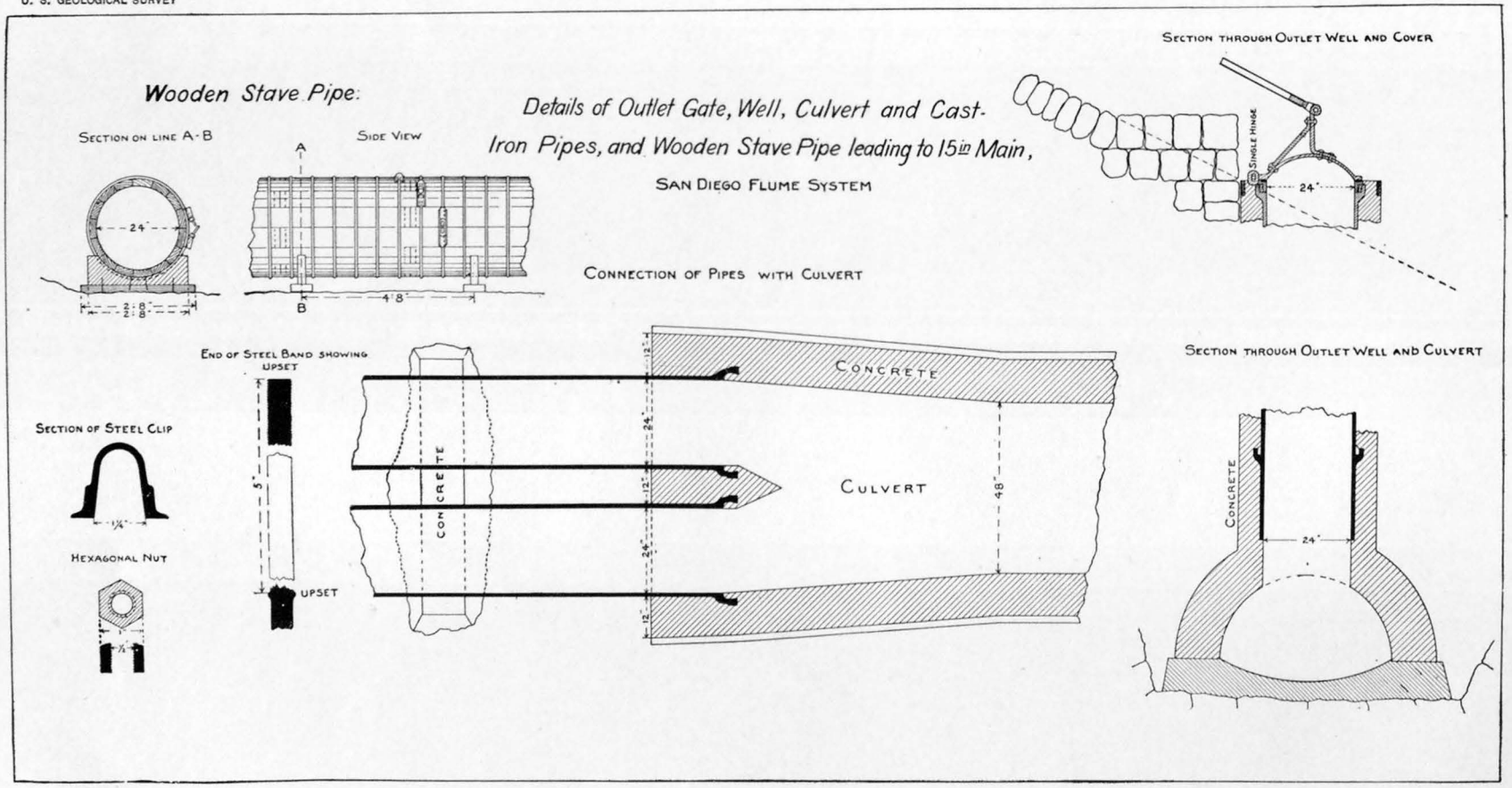



FIG. 95.—Cross section of La Mesa dam.

The volume of material handled was 38,000 cubic yards, which had to be brought an extreme distance of 2,200 feet, and stripped from an area of 11.5 acres to a mean depth of 2 feet. Had the material been as abundant throughout construction as it was up to the time one-fourth of it was in place, it is thought the entire dam could have been finished for 25 or 30 per cent of its ultimate cost, but unfortunately it was found that below a depth of 2 feet from the surface the gravel and cobbles of the mesa were cemented together so hard as to resist further washing, and this drove the engineer to the necessity of using horses and scrapers to bring the material to the sluiceways, at greatly increased cost. The results, considering all the unfavorable conditions, are an indication of what can be accomplished by this process where surrounding circumstances are more auspicious. The surface soil and sand contained in the cobbles constituted less than one-third of the mass, and consequently the dam can more properly be termed a rock-




DETAILS OF OUTLET GATE AND WELL CULVERT OF LA MESA DAM.

fill dam with an earth core. The gravel is of all grades, from egg size to large cobbles 8 to 10 inches in diameter. On the outer slopes the largest of these are laid up in a dry wall of uniform pitch and surface.

In beginning the work a trench was excavated in the bed rock from 2 to 5 feet deep, 20 feet wide at center, and tapering to 5 feet at the ends, the material being thrown out each side and afterwards incorporated in the embankment. A culvert was laid on the bed of the gulch up and down stream to reach entirely through the dam at its widest point. This consisted of a double line of 24-inch cast-iron pipes extending 72 feet in from the lower toe and connecting with a concrete conduit, 48 inches wide and 30 inches high, which reaches to the inside of the reservoir. The walls of this conduit are 12 inches in thickness. Four standpipes connect with this culvert at intervals of 35 feet from the inside end. They consist of 24-inch vitrified pipes, surrounded with concrete, and are now used as outlet pipes to the reservoir at four different levels, but during construction they performed the important function of conveying the water into the reservoir after it had dropped its load of gravel and sediment onto the surrounding embankment. They were built up a joint (2 feet) at a time, as the work progressed, and were finished off at the top with a brass ring and flap valve, the latter being controlled by rods reaching up the slope through the water to the surface. (See Pl. LIX.)

The water used was from 300 to 400 miner's inches—6 to 8 second-feet—which was all that could be spared from the flume after supplying the domestic consumption in San Diego and along the line and the little irrigation which is kept up, even in winter, when the rains do not come just right. From the end of the flume (which terminates on the mesa 10 miles from San Diego) the water was siphoned across a deep ravine by a wooden stave pipe 3,000 feet long and 36 inches diameter, emptying into a ditch 1.5 miles long, extending to the top of the ridge overlooking the dam site on the south. From this main ditch at various points laterals were carried down the slope of the hill toward the dam on grade of 6 per cent, dividing the ground into irregular zones of 50 to 100 feet in width by several hundred feet in length, reaching back to the top of the ridge. In sluicing, these divisions were stripped off clean to bed rock, beginning next to the dam and working back to the head ditch, the water being carried along the upper side of the strip to the lower side across the end of the division where the ground sluicing was progressing.

The fall from the upper line, or clear-water ditch, to the lower side of the zone was as great as the slope of the ground would admit of—the greater the fall the more rapid the sluicing. The work done was highly satisfactory as long as this slope was not flatter than about 1 in 4, but as the hill rounded off toward the top the velocity of the water in the ditch became lessened, until it was insufficient to erode the material from its bed, and it had to be assisted by use of picks or plows

where the ground was not too soft for teams to get over it. This additional labor, of course, increased the cost.

As the stream secured its load of earth or gravel, with or without such assistance, it was conveyed along the line of the lower ditch by 24-inch wooden stave pipes until deposited on the embankment. About 2,000 feet of this pipe was used in the work, the first cost of which was 90 cents per foot, not including the cost of lining with strips of steel inside to resist wear and tear. It was made in sections of 10 to 14 feet, loosely placed together and connected by strips of canvas wound around the ends of abutting joints and held in place by an ingenious tourniquet of tarred rope placed back of the last round band on the end of each section, the twist on one being made by a long nail and on the other by an 8-inch section of one-fourth-inch gas pipe the nail slipping into the end of the gas pipe and so preventing both ropes from loosening or untwisting. The ends of the suspended portion of the pipes, crossing the canyon to the farther side of the dam, were held in line by means of loose straps of iron on each side, bolted to the pipes, which kept them in place, and the water inside the pipe would shoot across the gap without material loss. It was necessary to suspend them for a part of their way across the dam to maintain a grade, and for this purpose a cable 1½ inches in diameter and 900 feet long was used. Pl. LX illustrates the method of suspension and shows the dam when constructed to about the 30-foot contour. The pipes were found to wear very rapidly, and were lined first with strips of wood and then with strap iron or tire steel. Cast-iron pipe is found to be preferable for this sort of service.

The work on the dam was begun February 14, 1895, and during the first thirty working days 21,000 cubic yards were put in, an average of 700 yards per day, although under favorable conditions more than double this amount was placed in twenty-four hours. The force of men employed varied from 27 to 45, working in three eight-hour shifts. Two men were kept on the dump directing the stream of material and building up the outer edges of the slopes to the proper lines, while the others were chiefly needed for ground sluicing. With looser or deeper soil, or under conditions permitting the use of a jet of water under pressure, the cost of loosening, which in this case was the chief item of expense, would be reduced to a nominal amount. The necessity of taking all the material from one side of the dam only was a disadvantage in this case, which might not apply to other localities where this method of construction is applicable. It is apparent that an embankment built in this manner is compacted as thoroughly as it could be by any process of rolling, and is not subject to further settlement. It is also manifest that the finer materials are by this process precipitated in the interior of the fill, and that the particles are in a general way graded in size from the outside toward the center.

All of the standpipes are inside of the center line, as shown by the

LA MESA RESERVOIR: BEGINNING OF THE CONSTRUCTION OF HYDRAULIC-FILL DAM.

section of the dam (fig. 95), and therefore more of the coarse and permeable bowlders and gravel are placed on the outside, where they afford ready drainage to the percolation that might find its way through the dam; thus the failure of the structure through the ordinary process of supersaturation and the sloughing of the outer slopes is rendered highly improbable, if not impossible. A dam built in this way is tested as it grows by the pond of water standing on top of it and the rising lake behind it, and if any weakness exists it is sure to be discovered and remedied by the operation of natural laws. This dam is not entirely free from leakage, and will be faced with a layer of cement or asphalt concrete, although as the water comes through perfectly clear it causes no anxiety. The leakage measures 100 gallons per minute, with the water at gage 54 feet, having increased from 23 gallons per minute when the water stood at the 46-foot level. The upper 12 to 15 feet of the dam was finished off by hauling in material with wagons.

The reservoir basin is sufficiently capacious to impound 18,890 acre-feet at the 140-foot contour, and the company is now contemplating plans for raising the dam to that height, the structure to contain 682,000 cubic yards. A dam 130 feet high would require 433,000 cubic yards. It is proposed to excavate the material from the interior of the reservoir, conveying it to the dam by the hydraulic method, and there hoisting it to the top by specially designed elevating machinery.

The conduit connecting the reservoir with the 15-inch steel main from the end of the flume to San Diego is a 24-inch wooden stave pipe 6,500 feet long. This is banded with half-inch round steel rods spaced to withstand a maximum pressure due to a head of 180 feet at the lowest point in the line. The end joints are made with tongues of one-fourth-inch oak set into the ends of the staves 1½ inches. The pipe is laid on wooden saddles on top of the ground, to preserve the metal of the bands from corrosion, which, in the mesa soils of this section, quickly destroys ordinary pipes. The location and elevation of the connection of this pipe with the 15-inch steel main has practically determined the 43-foot contour in the reservoir as the lowest level to which the water will ordinarily be drawn.

## PINE VALLEY DAM, CALIFORNIA.

The San Diego Flume Company has recently purchased a reservoir site in Pine Valley, in the Laguna Mountains, on the northern fork of the Tia Juana River, at an elevation of 3,700 feet, where it is proposed to build another hydraulic dam, 130 feet high, with slopes of 2 to 1 inside, 1½ to 1 outside, top width 30 feet, to store 30,000 acre-feet of water. This reservoir will be connected with the main line of flume by a conduit to carry the water across the intervening drainage basin of the Sweetwater, and will afford a much-needed addition to the general supply, as the tributary drainage area is some 45 square miles, or four

times the area draining into the Cuyamaca reservoir. The water to be used for sluicing will have to be pumped to a height of 400 feet in order to reach the deposits of material available for sluicing, but the engineer estimates that even this high lift is feasible and profitable, and he expects to increase the duty of water used from about 5 per cent of solids conveyed (the maximum accomplished at La Mesa dam) to about 20 per cent of solids, or 13 cubic yards per miner's inch of twenty-four hours.

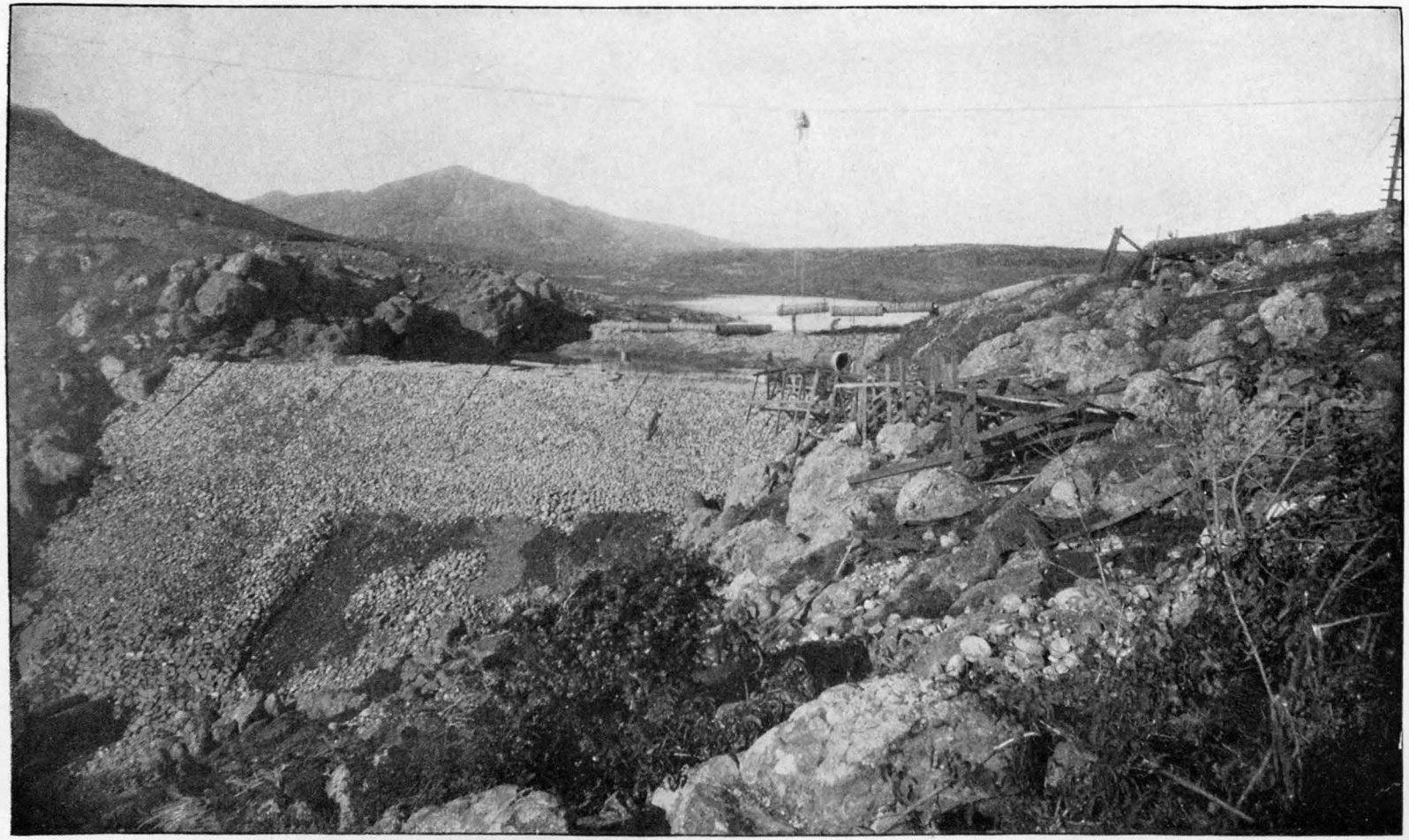
If this duty can be maintained, and the cost of pumping be assumed at a maximum of 5 cents per 1,000 gallons, the cost per yard for water will be about 5 cents, with but little additional cost for loosening, on account of the looser condition of the materials as they lay, having been disintegrated from the rock in position and not deposited and packed and cemented together by water.

### LAKE HELENA DAM SITE, CALIFORNIA.

The same company has projected a storage-reservoir dam across the San Diego River 1 mile above the pick-up weir at the head of the flume, which is designated the "Lake Helena" site. A dam 155 feet high will impound 15,800 acre-feet and contain 789,000 cubic yards, with 2 to 1 slopes and 25 feet top width. It would be 1,100 feet long on top, 190 feet at base, and have a bottom thickness of 650 feet. This site is considered favorable for hydraulic construction because of the abundance of material on both sides and the possibility of using water under high pressure from the Cuyamaca dam to loosen the material by powerful jets from hydraulic mining "giants." This reservoir would have a catchment of about 80 square miles.

### DAM AT TYLER, TEXAS.

The experience which led up to the construction of the La Mesa dam and the planning of the other structures described was obtained by Mr. Howells by the building of a dam in Tyler, Texas, by the same method, in 1894, which developed so many interesting features that a brief account of it will here be given, as it has never been described in print before. The dam is 575 feet long, 32 feet high, and contains 24,000 cubic yards, the inner slopes being 3 to 1 and the outer 2 to 1, with a 4-foot berm on the inside 10 feet below the top. This impounds 1,770 acre-feet, covering 177 acres. The maximum depth is 26 feet. All of the materials used in the dam were sluiced in from a neighboring hill at a cost of $4\frac{3}{4}$ cents per cubic yard, including the plant and all the appurtenances of the reservoir. The water was pumped through a 6-inch pipe from the old city pumping station situated on the opposite side of the valley from the hill which supplied the materials. This hill is 150 feet high, and the pipe terminated about half way up from its base, where a common fire hydrant was placed, to which was attached an ordinary $2\frac{1}{2}$-inch hose, with a nozzle of $1\frac{1}{2}$ inches diameter.



CONSTRUCTION OF HYDRAULIC DAM, LA MESA RESERVOIR, ILLUSTRATING THE METHOD OF SUSPENDING PIPES.

From this nozzle a stream was directed against the face of the hill under a pressure limited to 100 pounds per square inch. The washing was carried rapidly into the hill on a 3 per cent grade, which soon gave a working face of 10 feet or more, increasing gradually to 36 feet in vertical height. By maintaining the jet at the foot of the cliff it was undermined as rapidly as it could be broken up and carried away by the water.

The material found in the hill consisted of a soft, friable sandstone, infiltrated with ocher of varying shades—yellow, brown, and red—alternating with clay and sand, the whole overlain by a sandy loam soil from 2 to 6 feet deep. Experiment and observation led to the conclusion that 65 per cent of the entire mass washed into the dam was sand and 35 per cent clay.

In beginning the work a trench 4 feet wide was excavated through the surface soil down into clay subsoil, a depth of several feet, and this was first filled with selected puddle clay sluiced in by the stream. Then the form of the dam was outlined by throwing up low sand ridges at the slope lines, which were maintained, as the dam rose in height, by men with hoes. A pond of water was thus maintained over the top of the dam, the water being drawn off from time to time, either into the reservoir or outside, as preferred. The material was transported from the bank in a 13-inch sheet-iron pipe, with loose joints, stovepipe fashion, extending from near the face of the bluff, where the jet was operating, across the center line of the dam. These were so arranged as to be easily uncoupled at any point, so as to direct the deposit where required to build up the embankment uniformly. It was found that the quantity of solids brought down by the water varied from 18 per cent in solid clay to 30 per cent in sand.

Sharp sand does not flow as readily as rounded sand or gravel, and is improved in delivery by an admixture of clay and stones. The entire amount of water pumped, computed by the percentages of solids given, must have been less than 20,000,000 gallons. The limitation of the nozzle pressure to 100 pounds per square inch is thought to have restricted the duty of the water used to considerably less than might have been accomplished with higher pressure. The entire cost of the dam with all its accessories is given at $1,140, which must be regarded as a marvel of cheapness, and gives an average cost per acre-foot of storage capacity of reservoir formed by it of 65 cents. The dam is reported to have no apparent defects, and gives satisfactory service. Mr. L. W. Wells was engineer and foreman in charge of the work, from whose memoranda, furnished by Mr. Howells, consulting engineer, the foregoing description has been compiled.

## SAN LEANDRO AND TEMESCAL DAMS, CALIFORNIA.

The hydraulic process of building up reservoir embankments has been employed in a small way in the mines of California from the earliest

days of hydraulic mining, and was largely used in the construction of the storage-reservoir dams of Temescal and San Leandro, which yield a part of the water supply of Oakland, a city of 60,000 inhabitants. These dams were constructed by their principal owner, Mr. A. Chabot, who had been a practical hydraulic miner. The Temescal dam was built in 1868. It is 105 feet high, 18 feet wide on top, with side slopes of 2½ to 1, both above and below, which have been greatly increased and flattened by the material sluiced in from year to year subsequently. The water being limited in supply to a few days after storms, the work was continued for a number of seasons as an economical method of increasing the volume of the dam, which forms a reservoir of 18.5 acres, with a capacity of 188,000,000 gallons.

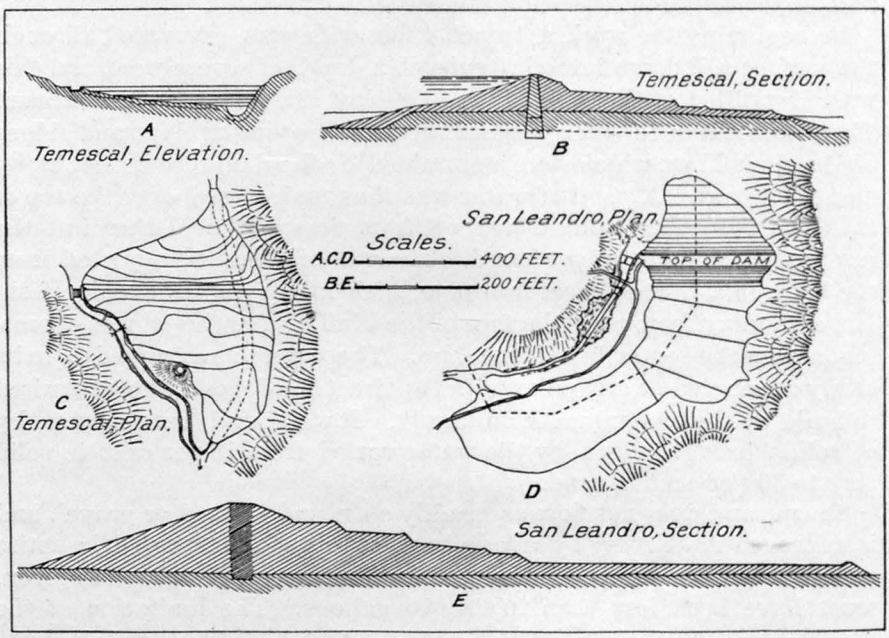



FIG. 96.—Plans and cross sections of San Leandro and Temescal dams.

The San Leandro dam was built in 1874–75, and has a height of 120 feet above the stream bed. It is located 9.5 miles east from Oakland, 1½ miles above the village of San Leandro, at an elevation of 115 feet above tide. The total volume of the dam is 542,700 cubic yards, of which 160,000 yards were deposited by the hydraulic process. The water was brought 4 miles in a ditch, and the sluiced materials were conveyed in a flume, lined with sheet-iron plates and laid on a grade of 4 to 6 per cent. The water used was 10 to 15 second-feet, and the ground-sluicing method was alone employed, as it was not convenient to get water under pressure. The cost was estimated at one-fourth to one-fifth that of putting the earth in place with carts or scrapers. The entire cost of the dam proper was about $525,000, but the outlets, waste

VIEW OF FINISHED DAM AND WASTEWAY OF LA MESA RESERVOIR.

ways, and improvements of various kinds about the reservoir have increased the total to over $900,000, or about $68 per acre-foot of storage capacity. The reservoir covers 335 acres and has a maximum capacity of 13,270 acre-feet, or 4,323,446,000 gallons.

The area of the watershed tributary to the reservoir is 50 square miles, from which the run-off is generally in excess of the storage capacity, and considerable difficulty was experienced in disposing of the surplus, without washing away the dam, until a waste tunnel 1,100 feet long, with a capacity of 2,000 second-feet, discharging into the stream half a mile below the dam, was opened in 1888.

The plans and sections of these dams are shown in fig. 96, in which are represented the restraining levees or banks for holding the sluiced materials deposited on the outer slopes; the deposit on the inside was made by simply dumping the contents of the flume into the water and allowing it to assume its own slope on the surface of the embankment.

## HYDRAULIC FILLS ON THE CANADIAN PACIFIC RAILWAY.

Further examples of the successful employment of hydraulic-mining principles to the work of building embankments are to be found on the Pacific Coast, but none more instructive than the extensive hydraulic fills made by the Canadian Pacific Railway in British Columbia, where trestles of great height are being supplanted by earth and gravel embankments made by the agency of water alone. The methods employed differ materially from those described in the foregoing pages, but will doubtless find frequent application elsewhere in irrigation-dam construction. At trestle No. 374, near North Bend, in Fraser River Canyon, 110 miles east of Vancouver, there is required to fill the chasm an embankment 231 feet in extreme height and containing 148,000 cubic yards. When seen by the writer, in November, 1896, the fill had reached a height of 167 feet and contained 70,000 cubic yards, all of which had been put in place by hydraulic process. The plant used consisted of 1,450 feet of double-riveted sheet-steel pipe 15 inches in diameter, 1,200 feet of sluice boxes or flume about 3 feet wide and the same depth, one No. 3 double-jointed "giant" monitor with 5-inch nozzle, and a large derrick fitted with a Pelton wheel connected with the winding drum of the derrick and operated by diverting the jet of water used in piping the bank upon the wheel when loads were to be hoisted by the derrick. The gravel bank where the material was obtained was 1,130 feet distant from the center of the track, and from this pit the pipe was laid to an adjacent stream, 1,450 feet, in which length the fall was 125 feet. The sluice boxes were laid on a grade of 11 per cent for the first 425 feet, increasing to 25 per cent the rest of the way, partly supported on high trestles. These boxes were paved with wood blocks on the lighter part of the grade and with pieces of old railway rails laid close together lengthwise of the flume where the grade was heaviest.

One of the most serious difficulties here encountered—and each locality develops its special problem—was the fact that about 50 per cent of the materials in the gravel pit were such as to be classed as cemented gravel, 30 per cent as loose gravel, and 20 per cent consisted of large bowlders, which had to be lifted out of the way and handled by a derrick, although unavailable as filling, because of their great bulk, which rendered it impossible to transport them. Notwithstanding this disadvantage, the results which have been accomplished are quite remarkable, as the entire cost of the work, including the plant, was but $5,089, an average of 7.24 cents per cubic yard. The entire force employed consisted of 8 men, disposed as follows: 1 piper at the monitor, 1 at the head of the sluice boxes and in the pit, 2 along the sluice "driving" the material along, 3 men on the dump and making brush mattresses for the slopes, and 1 man, a carpenter and foreman of the gang, repairing the flume. The time occupied was as follows: Sluicing, 95.3 days; removing bowlders from the pit, 50.4 days; repairing flume and plant, 13.5 days; total, 159.2 days of the entire force. The actual working time when sluicing gave an actual working performance of 738 cubic yards per day of ten hours, or at the rate of 1,771 yards per twenty-four-hour run. The water used was approximately 20 second-feet, or 1,000 miner's inches, the duty performed being 1.77 yards per twenty-four-hour inch.

Had the pit been free of the large troublesome bowlders, the work could have been done in two-thirds of the time actually occupied; and had the pressure been greater and the gravel all been loose, instead of being half cemented, requiring the use of explosives to some extent, the duty of water, on the high grades available for the flume, should have been increased more than fourfold, as the ratio of solids carried was less than 3 per cent of the volume of water used. An understanding of all these conditions suggests what might be accomplished by this method with a perfect combination of circumstances, viz, water under pressure of 400 to 500 feet head, loose materials for washing, and heavy grades to the dump. In this case the water was allowed to pour over the faces of the embankment, the slopes being protected from erosion by brush and tree tops woven in alternating layers along the edges of the fill. Old track ties and poles were also used to some extent with the brush. In addition to this protection it was necessary to exercise care to prevent the water from concentrating in channels or from reaching to the sides or flowing down the hill over the natural surface. By keeping the sides of the fill as nearly level as possible the water was spread in a thin sheet over the face and reached the bottom of the slope without washing or doing injury. The slopes are remarkably true and uniform, and the embankment was packed very hard, particularly near the end of the sluice, where the gravel dropped from a great height to the dump below.

The device employed for handling the bowlders in the pit by water power was ingenious and effective, and was similar to those in common

use in hydraulic mines, where the stream issuing from the nozzle is at will deflected upon a tangential water wheel with peripheral buckets. This wheel being attached to a winding drum, the wire hoisting rope leading from the derrick is rapidly wound up and the load handled at will. A friction brake with long lever gave the operator perfect concontrol of the load and enabled him to lower it as swiftly or as gently as desired. Sharp turns in the flume were made by a vertical drop of 2 feet at the turn, and two angles of 90° each were thus successfully made. Bowlders with 1 or 2 square feet of face would sometimes stop rolling, and if not quickly started would cause a jam and overflow, endangering the flume on the gravel hillside. For this purpose it was necessary to detail two men to patrol the portion on which the grade was lightest, to keep all such stones in continuous motion, but on the 25 per cent grade no such attention was necessary.

At the crossing of a stream called Chapman Creek the railway company in the summer of 1894 made a similar fill of 66,000 yards, at a total cost of 7.5 cents per yard, of which 3.2 cents was for plant. The actual work of sluicing cost but 1.78 cents per yard. Some difficulties were encountered, and it was necessary to use a quantity of explosives in the pit for breaking up the material and preparing it for washing. The company is preparing to make another high fill in the Selkirk Mountains by the same methods in the season of 1897, the contents of which will be 400,000 cubic yards. The work has been executed under direction of H. J. Cambie, chief engineer Pacific division, Canadian Pacific Railway, and his chief assistant engineer, Edmond Duchesnay, of Vancouver, British Columbia, by whose courtesy the data have been supplied.

## HYDRAULIC FILLS ON THE NORTHERN PACIFIC RAILWAY.

Work of a precisely similar nature has been in progress for a number of years past on the line of the Northern Pacific Railway, where several high and dangerous trestles have been replaced by hydraulic-made embankments of earth, gravel, and loose rock. Special activity in this direction has been displayed during the current year (1897), and nine high trestles have been filled, requiring from 6,200 to 108,500 cubic yards. Of this amount 377,000 cubic yards in eight of the trestles were moved and put in place, at a total cost of $18,052.70, or an average of 4.79 cents per cubic yard. The detail of the cost of this work is of special interest to those who may be contemplating similar undertakings, and is given as follows, per cubic yard:

| | |
|---|---|
| Sluicing and building side levees | $3.85 |
| Hay used in side levees | .09 |
| Tools | .08 |
| Lumber and nails | .22 |
| Labor building flumes | .44 |
| Engineering and superintendence | .11 |
| Total | 4.79 |

In all the above work the water was carried to the borrow pits and the sluicing done by gravity. In one case, however, pumping was resorted to, and 42,250 cubic yards were moved by water thus lifted, at an average cost of 13.5 cents per cubic yard.

By courtesy of E. H. McHenry, chief engineer, and Chas. S. Bihler, division engineer, Northern Pacific Railway, the writer has been furnished these interesting figures of cost and the following general description of the work under date of September 17, 1897:

The results have been very gratifying, both as to cost and character of the fills made. We are using, or trying to obtain, about 100 inches of water for each nozzle, as with a less quantity the rocky character of the material moved does not give good results. In some cases we have been able to obtain water at the bridge without the necessity of building any considerable length of flumes. In other cases we had to construct several miles of flumes for the water supply. These flumes are constructed in the most temporary manner, of inch and a quarter lumber, 16 to 18 inches square. Where the locality would permit we have sluiced the dirt to the place of deposit, a distance of over half a mile. We use hay for keeping up a levee on the outside and wooden frames, which are easily moved, to deflect the main current from the levees. The waste water is carried off through a waste box, which is taken up through the body of the fill and built up as the filling increases in height. By adjusting the height of the waste gate a larger or smaller amount of fine material can be retained in the fill, as desired. In building up the fill, naturally a separation of the material takes place. The coarser material is deposited right under the sluice boxes, while the finer material is carried along, the finest particles of earth being deposited in the vicinity of the waste gate in the shape of mud. For larger fills it is therefore necessary to have several waste gates, so that coarser material may be deposited, from time to time at those places, and the accumulation of too much of the fine material at any one point may be avoided.

The plant required for the work is rather inexpensive. According to locality, one nozzle would require from 300 to 1,000 feet of light sheet-iron pipe, costing about 27½ cents per foot, and a No. 2 Giant, costing $95. Outside of this nothing is required except picks, shovels, hoes, and axes.

The character of the material that we have available is not very favorable. The pits are very rocky, and the banks overlying bed rock, which can be loosened by the water jet, are not very heavy. The cost given in the table for moving earth and building levee includes all cost of clearing. From five to six men are required with each nozzle to build the levee, move the sluice boxes, and do everything else connected with the work.

## HYDRAULIC CONSTRUCTION ELSEWHERE.

Except in the manner of loosening the materials and putting them in motion, the methods of hydraulic dam construction above described are quite similar to those used in the reclamation work in progress by the Seattle and Lake Washington Waterway Company, although it has a totally different object, namely, the opening of navigable tidal channels by dredging and the reclamation of tide lands adjacent to the business center of the city of Seattle, Washington, by filling them with the fine black sand dredged from the channels. Two powerful dredges are used, each with a capacity of 6,000 to 7,000 cubic yards per twenty-four hours, which is pumped from the bottom of the channel through

18-inch pipes a distance of 2,000 to 4,000 feet and deposited to a depth of 18 to 20 feet over the area to be reclaimed. Some 36,000,000 cubic yards are to be handled in this way and 1,500 acres filled in solidly to a height of 2 feet above high tide. About 1,000,000 yards had been put in place January 1, 1897, the cost of which was 16 cents per yard by contract. The mean velocity maintained in the delivery pipes is 13.5 feet per second and the discharge is 24 second-feet, so that when the work is at a maximum the percentage of solids carried by the water is 9, although tests have shown as high as 20. The bulkhead along the channels which hold the sand in place is made of brush mattresses, while the temporary cross levees or bulkheads are effectively formed by the use of coarse hay, straw, or swamp grass along the margin, similar to the way in which brush was used in the Canadian fills before described.

In the course of a somewhat extended experience in hydraulic mining on the Etowah River in Georgia, Col. Latham Anderson, M. Am. Soc. C. E., demonstrated—and his experience leads him to write—that "gravelly hydraulic tailings could be deposited within sharply defined limits and in any shape desired, limited only by the condition that the slopes should not be steeper than the natural angle of repose of the material."

The experiments made by Professor Fortier, of the Utah Agricultural College Experiment Station, on the mixture of various aggregates for use in construction of earthen dams show that gravel, sand, and clay will occupy less space and become more compact when poured into water, mixed therewith, and allowed to drain and settle, than by any process of tamping, either moist or dry.[1]

Clemens Herschel, M. Am. Soc. C. E., says[2] that "pure gravel, just as it comes from the gravel pit, will make a water-tight stop, when used between planks or in any other position for which puddle is used, as far as my experience goes, better than clay or a clay mixture ever did."

The Holyoke dam across the Connecticut River, a timber crib structure 1,017 feet long and 30 feet high, was reconstructed and filled with a mass of puddled gravel by Mr. Herschel in 1885, the gravel being washed in and puddled by hydraulic streams, of which he writes:[3] "No part of the work gave less anxiety and more satisfaction than this from the day it was started."

These citations sufficiently illustrate the principles and methods that may be employed in many localities for the construction of dams by the powerful and convenient aid of flowing water.

## MASONRY DAMS.

The class of structure for water storage which appeals most effectively to the mind and imagination of the majority as safe and suffi-

[1] Earthen dams, by Samuel Fortier: Bull. Utah Agricultural College No. 46. November, 1896.
[2] Trans. Am. Soc. Civil Eng., Vol. XXVI, p. 684.
[3] Ibid., Vol. XV, p. 568.

ciently enduring to withstand the pressure tending to overturn or destroy it is undoubtedly the solid masonry dam, laid up with good cement mortar, and even though in certain cases it may not in reality be so able to resist the forces acting against it as some other form of barrier, made of earth or loose rock, yet it always looks stronger and safer and is invariably first in popular favor. Undoubtedly fewer failures have occurred in masonry dams than in those of any other type.

## HEMET DAM, CALIFORNIA.

Doubtless the most massive and imposing structure that has thus far been erected in the West for irrigation purposes is the dam built by the Lake Hemet Water Company in Hemet Valley, Riverside County, California (Pls. LXII and LXIII, figs. 97, 98, 99). It is built of granite rubble, laid in Portland-cement concrete, and is now 122.5 feet above the creek bed, or 135.5 feet above lowest foundations, and is to be carried 30 feet higher. It is 100 feet thick at base, and has a batter of 1 in 10 on the

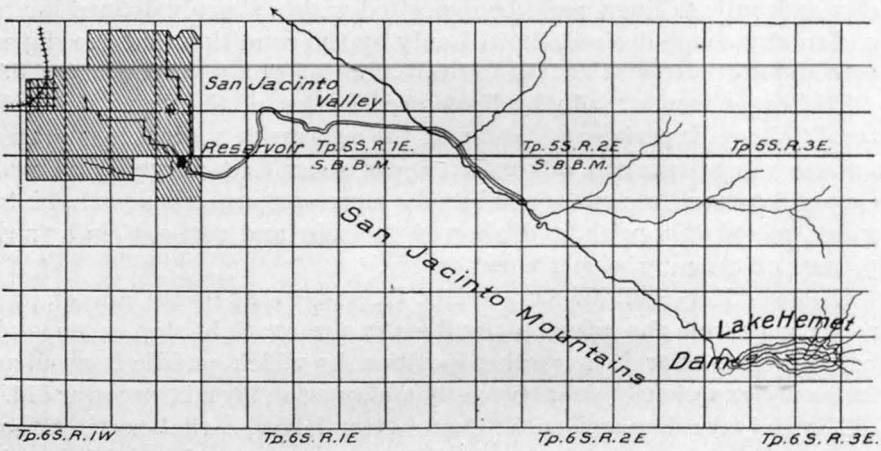
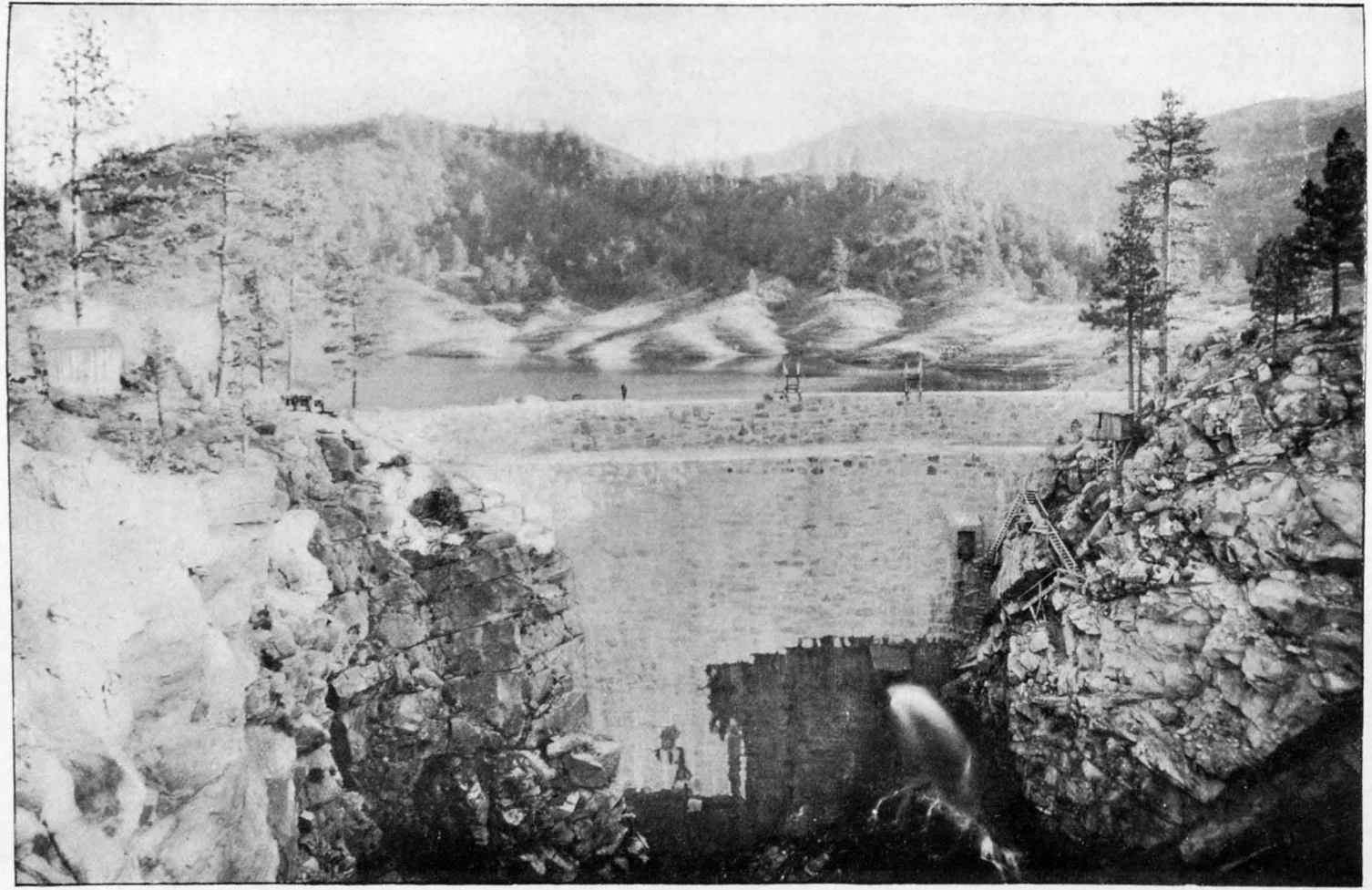



FIG. 97.—Map showing location of Lake Hemet, the main conduit, and irrigated lands.

water face and 5 in 10 on the lower side. Its present crest is 260 feet long, while the length at bottom is but 40 feet. The dam was carried up with full profile to the height of 110 feet above base, at which point the thickness is 30 feet. For the extension to the 122.5-foot level an offset of 18 feet was made and the wall reduced to 12 feet at base and 10 feet at top. A notch 1 foot deep and 50 feet long was left in the center for an overflow or spillway, although it is anticipated that extreme floods may pass over the entire length of the wall, as they did to the depth of several feet in January, 1893, when the dam was 107 feet in height. The dam is arched upstream, with a radius of 225.4 feet at its upper face, on the 150-foot contour, and has a more substantial appearance by reason of this curvature.

The location is in the San Jacinto Mountains, at the foot or outlet of



HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

Hemet Valley, whose altitude above sea level is about 4,200 feet. The South Fork of the San Jacinto River, which passes through the valley, drains the southern flanks of Mount San Jacinto, one of the highest peaks in southern California (10,987 feet), and has a watershed area above the dam variously estimated at 65 to 150 square miles, although no surveys have been made to determine its boundaries.

The outlet to the valley is a narrow canyon in granite, with precipitous walls, through which the stream plunges for 9 miles to its junction with Strawberry Fork, the location of the pick-up weir diverting water into a flume at an elevation of 2,200 feet, the descent from the dam being about 2,000 feet. The dam is located at the head of this canyon at its narrowest point.

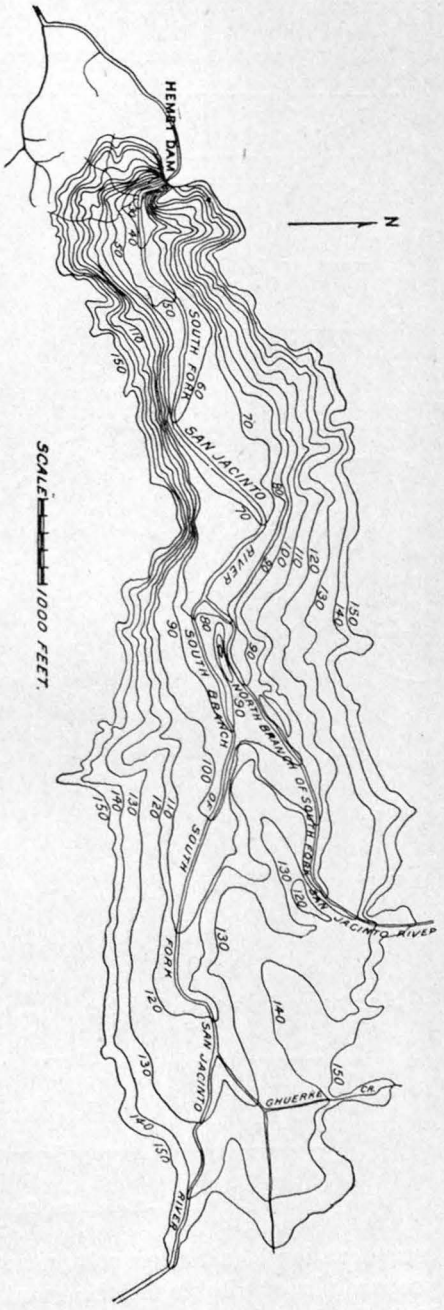



FIG. 98.—Contour map of the Lake Hemet reservoir.

The enterprise was projected in 1886, when the stockholders of the Hemet Land Company, owning a tract of 7,000 acres in the San Jacinto Valley, secured the water rights in the stream and diverted water to their land by means of a 13-inch iron pipe laid from the weir at the mouth of South Fork down the canyon and out to the tract. The storage dam was not then begun, but was in contemplation. Nevertheless, it was found that purchasers were skeptical of the water supply with merely the normal flow as the only visible source, and though the lands were all that could be desired otherwise, they were practically unsalable until the company began the actual building of the reservoir and had finished it so far as to be able to store a considerable body of water behind it.

The site seemed to be most suitable for a masonry structure because of the excellence of the foundations, the abundance of the materials at hand, and the narrowness of the canyon for its location. After due

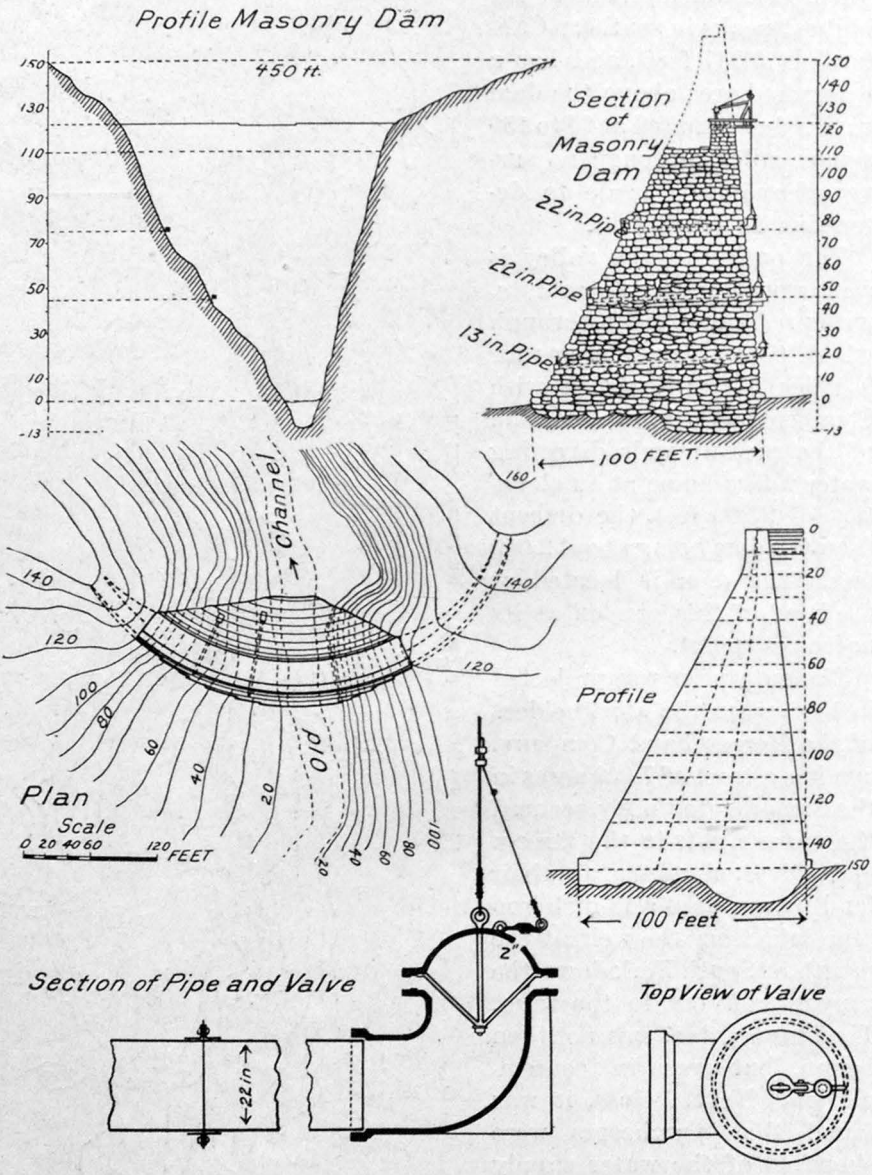



FIG. 99.—Hemet dam, Riverside County, California.

consideration of all alternative possibilities the writer was directed to prepare plans suitable for the maximum height to which a dam could be built to advantage at this site, and in the summer of 1890 the plant was assembled and excavation begun. The stripping of the founda-

HEMET DAM AS FINISHED, SHOWING THE SPILLWAY RIDGE SOUTH OF THE DAM.

tions occupied several months with the aid of a cable way for conveying and dumping the waste below the dam, as a large "pothole" was developed, 13 feet deep, directly under the base of the dam. This was thoroughly cleaned out, and a center trench was cut in the rock all up the sides as a key or anchorage to receive the masonry. Considerable time was also required in hauling sufficient cement up the mountain to make a beginning, and it was the 6th of January, 1891, when the first stone was laid.

The work proceeded thenceforth until January 24, 1892, when severe weather and floods compelled a suspension of construction at the 45-foot contour, and four months elapsed before it could be resumed, when it was carried to the 107-foot level without cessation; but on January 9, 1893, the workmen were driven off again by a storm and freshet that filled the reservoir so rapidly that many of the buildings and tools were submerged and the water ran over the dam in a sheet several feet deep for a short time. Construction was not resumed after the storm, and the work remained at this level until the fall of 1895, when the dam was carried up to its present height and all machinery and tools removed. The dam now contains 31,105 cubic yards of masonry, all laid in Portland-cement concrete, the number of barrels of cement being stated at approximately 20,000. The cost of the cement delivered on the ground was about $5 per barrel, as it had to be hauled up the mountain 23 miles from the nearest railroad station, Hemet, over a grade of 18 per cent maximum and an elevation 500 to 600 feet higher than the dam. The sand used was clean and sharp, and was accumulated in a temporary log dam reservoir as it was brought down by the flowing stream, and conveyed to the mixing platform by an endless wire-rope carrier with triangular buckets placed at intervals of 20 feet, passing over drums in the receiving box below and on the platform above, which hoisted it 125 feet vertically and carried it 400 feet horizontally.

The stone was all quarried within 400 feet of the dam, on both sides of the canyon, both above and below, and was hoisted and conveyed to the wall by two cable ways, each about 800 feet long and 1½ inches in diameter. These were placed up and down the stream, crossing the dam nearly at right angles with the chord of the arch, but diverging from each other and anchored to convenient trees on either side of the gorge. Their position was seldom changed except to lift them higher up into the tree tops and to erect "A" frames on top of the masonry to support the cables when the wall had reached such a height as to require it. Loads of 10 tons could be hoisted and handled with ease, and with the aid of two derricks, one at each end of the dam, the rock brought by the cables was placed on the dam where required. The carriages traveling on the cables and the devices for sustaining the hoisting "fall" as the load moved back and forth were devised on the ground and operated satisfactorily.

The derricks were operated with water power obtained from a 36-inch Pelton wheel, propelled, under a head of 75 feet, by about 80 miner's inches of water, brought from the stream in a flume, and thence in a 13-inch pipe, which was afterwards embedded in the masonry of the dam and can be used as the lowest outlet of the reservoir.

The concrete used to embed the blocks of stone was mixed in the proportion of 1 of cement, 3 of sand, and 6 of broken stone, crushed to pass through a 2½-inch ring. The stones were placed 6 inches apart at the nearest, and the spaces between them were filled with concrete and smaller stone, all well rammed into place with iron tampers. This use of concrete enabled unskilled laborers to do much of the work, and stone masons were employed only in the facings, which were laid in mortar, mixed richer than the concrete and well pointed at the joints.

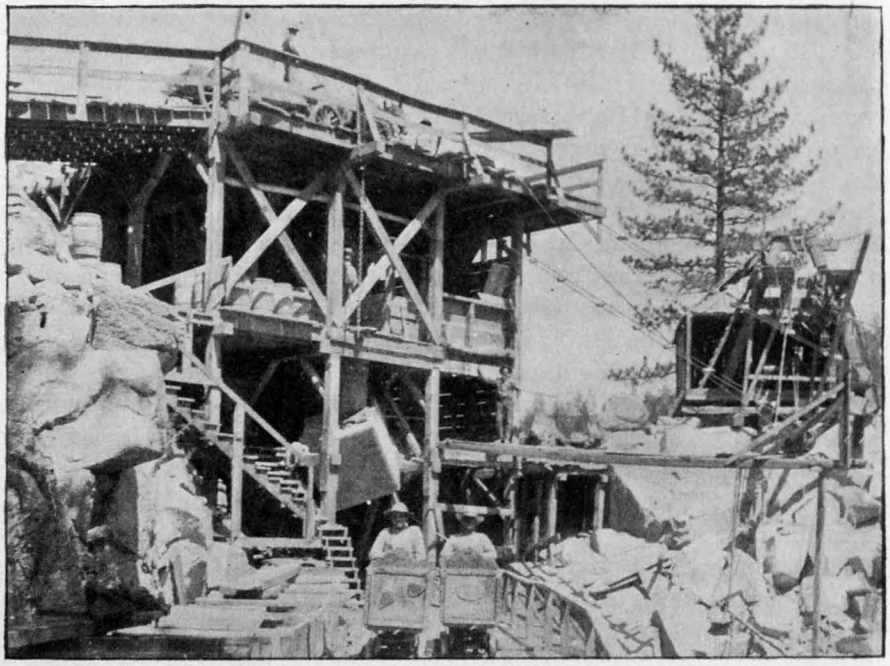


FIG. 100.—Hemet dam construction plant.

The mixing of both mortar and concrete was done by machinery, which is undoubtedly superior to hand mixing in the quality of the output. Fig. 100, from a photograph, shows the plant for crushing the stone and mixing the mortar, and one of the engines of the cable ways, as well as a part of the sand conveyor. A trestle from the mixing platform carried a tramway along the face of the cliff, some 300 feet, to the line of the dam at the 80-foot level, and when the dam reached that level an elevator was built to a higher line of trestle.

The outlets to the dam consist of two 22-inch pipes, at the 45-foot and 75-foot levels, on the upper ends of which are elbows turning

upward and flaring outward to 30 inches diameter, closed by semispherical covers, manipulated by a wire rope passing over a pulley and windlass on a frame resting on top of the dam. These covers are ordinarily removed and replaced by a fish screen standing on the valve seat of the pipe from which water is being drawn, and the main control is had by gate valves set at the lower line of the dam, from which the water falls freely to the rocks below in a fine spray, collecting in a pool a short distance below and passing over a weir for measurement before beginning the plunge down the canyon.

When construction began, the reservoir site was well covered with pine trees, and as it became necessary to clear them from the flowage tract they were sawed into lumber, of which about 1,000,000 feet was used for buildings and stagings about the dam and half a million was hauled to the valley for flumes and trestles. The main conduit is partly built of this mountain lumber, and, although knotty and inferior lumber for general purposes, it has made a remarkably tight and serviceable flume.

This conduit is 3.24 miles in length from the pick-up weir to the mouth of the canyon, where it connects with a 22-inch pipe 2 miles long, from the lower end of which an open ditch, lined with masonry and plastered with cement mortar, 5 miles in length, delivers the water to a distributing reservoir, covering 20 acres at the highest corner of the tract. This reservoir has a capacity of about 90 acre-feet, and from it is distributed the supply to the lateral ditches, covering the tract irrigated. The canyon flume is 38 inches wide inside by 18 inches deep, and has a grade of about 140 feet per mile. The joints are battened underneath and calked inside with oakum, while a triangular strip is placed in the corners, and the whole interior is smeared with asphalt, the outside being whitewashed with lime. The lining lumber is $1\frac{1}{2}$ inches in thickness.

The ditch lining consists of granite cobbles of 10 inches maximum diameter, laid in lime-and-cement mortar, equal parts of each, and plastered with Portland-cement mortar. It is 2.75 feet wide on bottom, 7 feet at top, 2.75 feet deep, and has a capacity of 3,000 miner's inches—60 second-feet.

The distributing system consists of smaller cemented ditches, flumes, and pipes, of which there are 30 miles altogether, covering the tract. The slope of the land is about 40 feet per mile from east to west, which facilitates the distribution of water in conduits of small size.

The dam of the distributing reservoir is of earth, 300 feet long, 14 feet high, and 8 feet wide on top. The reservoir is usually filled to within a foot of the top of the dam. In construction, a trench 10 feet wide and 9 feet deep was excavated under the center line, in the middle of which a tight board fence was erected, reaching to the top of the dam, to prevent the burrowing of ground squirrels and gophers, a function which it effectually performs. The trench was filled with puddled

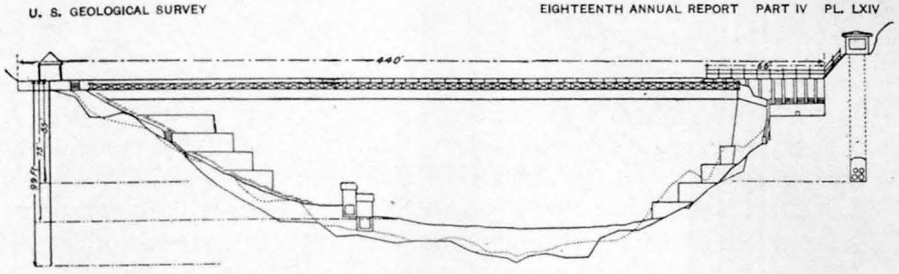
earth on each side of the fence, and the puddle was also brought up to the top of the embankment.

The area irrigated by the system is now 1,092 acres, which is increasing year by year. The planting is chiefly in deciduous fruits, and is divided into 72 tracts, of which the average size is 10 to 20 acres. The rates charged for water are $2 per acre annually, with an additional charge during the nonirrigating season (which is made by the contracts to extend from November 15 to April 15) of $1 per month for each tract for domestic service. In the town of Hemet, which is supplied by the same system, there are 55 taps, paying a uniform rate of $1.50 per month.

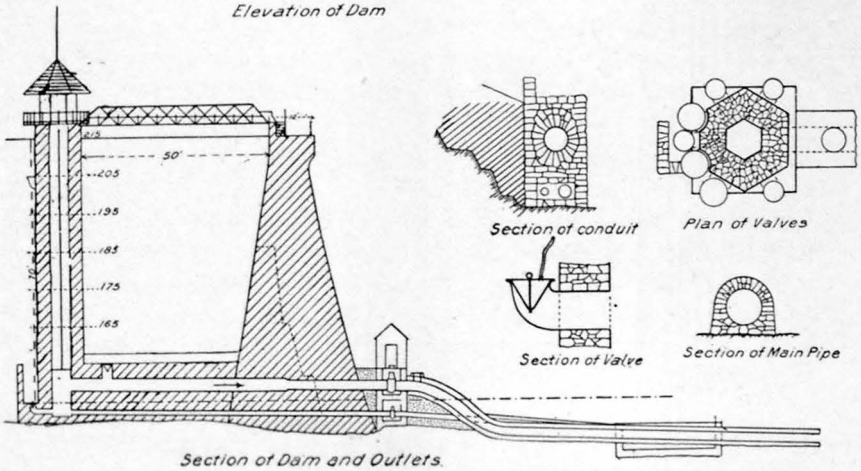
The apportionment of water by the water-right contracts given with the deeds to the land is at the rate of "one-eighth of 1 miner's inch of perpetual flow from April 15 to November 15 of each year for each acre," which is equivalent to 46,224 cubic feet, or 1.06 acre-feet; and the water rate of $2 per acre would therefore be equal to 4.3 cents per 1,000 cubic feet, or 0.57 cent per 1,000 gallons. As at present, while there is an abundant supply, no attempt is made to restrict the use of water to the exact stipulation of the contract, and therefore no special economy is practiced in its application. It is still a matter of uncertainty as to whether the apportionment thus given by the contract is sufficient to thoroughly irrigate the lands, planted to the crops which will there be grown. The consumption during the season of 1896, or the amount measured out of the reservoir by the weir at the foot of the main dam, was 111,600,000 cubic feet—an average of 102,000 cubic feet per acre irrigated, the mean depth of application being apparently 2.34 feet, or over 28 inches. This is not a very exact determination, as it does not take into account the losses by leakage and evaporation in the conduits and distributing reservoir, and as it is not known whether there is a loss or a gain in the flow down the main channel of the canyon.

The measuring weir at the dam is also imperfect, although the velocity of approach, which was neglected in the computation, would tend to increase the total volume stated. These figures indicate in a general way, however, that unless the irrigators are wasting water very extravagantly, now that they are free to use what they like, the apportionment to which they are legally entitled under their water-right contracts is entirely insufficient, and that the probabilities are that the duty of the reservoir when filled annually may be taken at about 1 acre for every 2 acre-feet of reservoir capacity. At the present height of dam the capacity of storage is approximately 10,500 acre-feet.

The winter freshets of the stream are counted on quite reliably to fill the reservoir before the irrigation season begins, and ordinarily the summer showers on this watershed may be relied upon to materially reenforce the volume of the reservoir, and sometimes to completely fill it. With the normal summer flow reckoned as probably offsetting the loss by evaporation, the supply may be regarded as about sufficient for the 7,000-acre tract without further increase in the height of the dam.




Elevation of Dam




Section of Dam and Outlets.

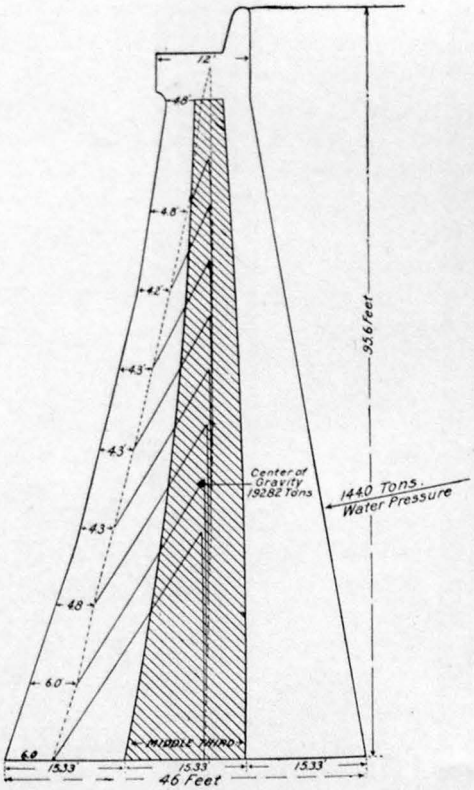
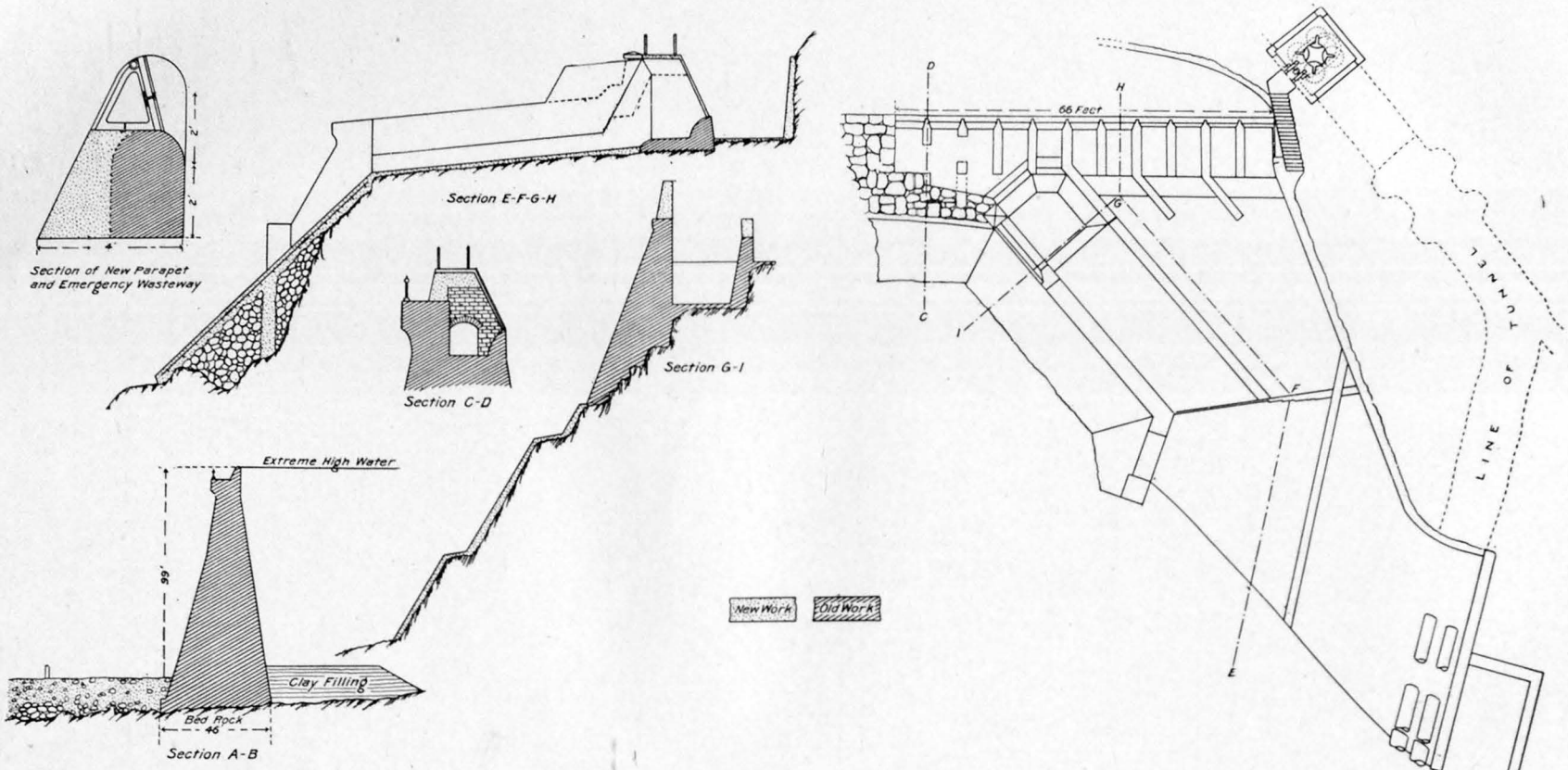



DIAGRAM OF FORCES

ELEVATION AND SECTIONS OF SWEETWATER DAM.




DETAILS OF SWEETWATER DAM.

The cost of the works is withheld by the management, for reasons affecting the public policy of the company and questions of taxation, water rights, etc.

## SWEETWATER DAM.

This structure, located on the Sweetwater River 7 miles from its mouth, on the shore of San Diego Bay, and 12 miles southeast of the city of San Diego, California, has been so frequently described, is so easy of access, and is so generally well known, as it is visited by many thousands of tourists annually, that but a brief general account of its construction is necessary in this report. (See Pls. LXIV–LXXI.)

As originally designed, the dam was to be a slender masonry struc-

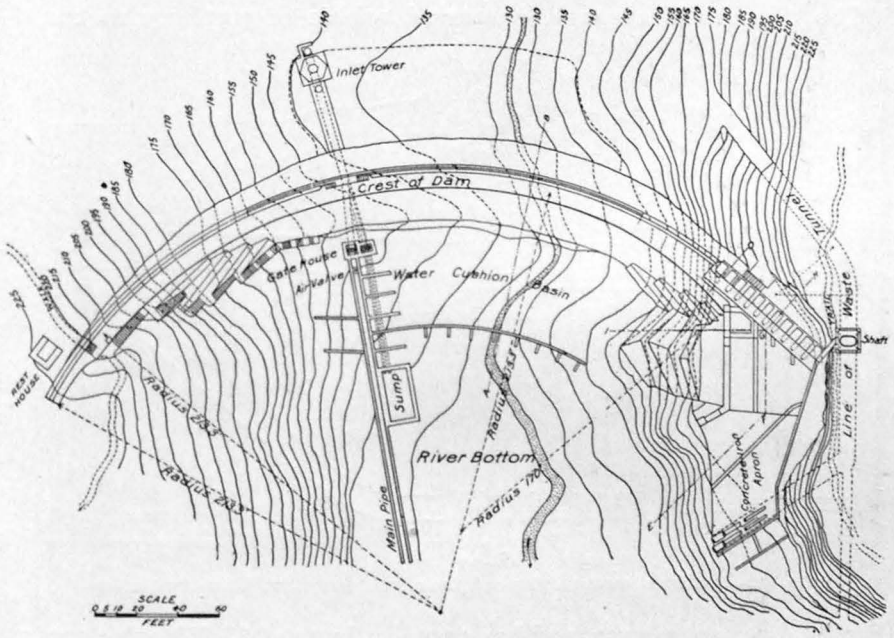



FIG. 101.—Plan of Sweetwater dam.

ture fashioned after the Bear Valley dam by the same engineer who built the latter, and was to be but 10 feet thick at base, 3 feet at top, and 50 feet high, backed on the water face by an embankment of earth. When the structure had reached a height of 15 to 20 feet at the highest part, and its outline and design were fully realized by the management, the plan was disapproved and the author was engaged to construct a more substantial work on the same site, utilizing the masonry already in place. The new plan was drawn to have an extreme height of 60 feet, and the new work enveloped the old. This structure is shown nearly completed in Pl. LXVI, and its profile is shown in fig. 102. It was built in steps on the back with a view to adding to the height, as was subsequently done.

The dam had a maximum thickness at base of 35 feet, and was 5 feet thick at the top. It was fortified by an embankment of clay and gravel 50 feet wide, 10 to 15 feet high, placed against the upper side and well tamped in place.

Shortly before its completion, authority was given for an extension of the dam to 90 feet in height, on the recommendation of the author, whose surveys revealed the fact that the capacity of the reservoir could be increased nearly fivefold by such addition of 30 feet to the height. Accordingly, excavation was renewed at the lower side for an extension of the width of the base, and work proceeded on the final plan without interruption until the completion of the entire structure in April, 1888. The construction occupied sixteen months in all, having been begun in November, 1886.

The masonry is a rough, uncoursed rubble of porphyry rock and

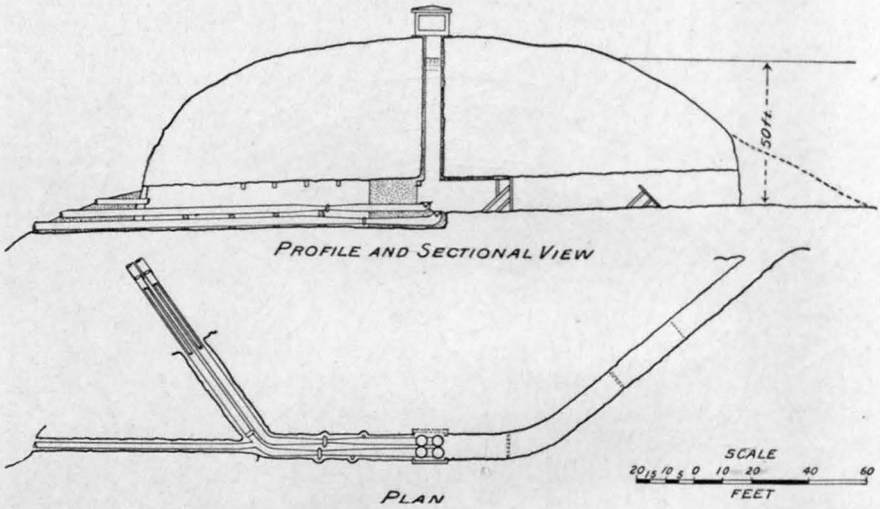
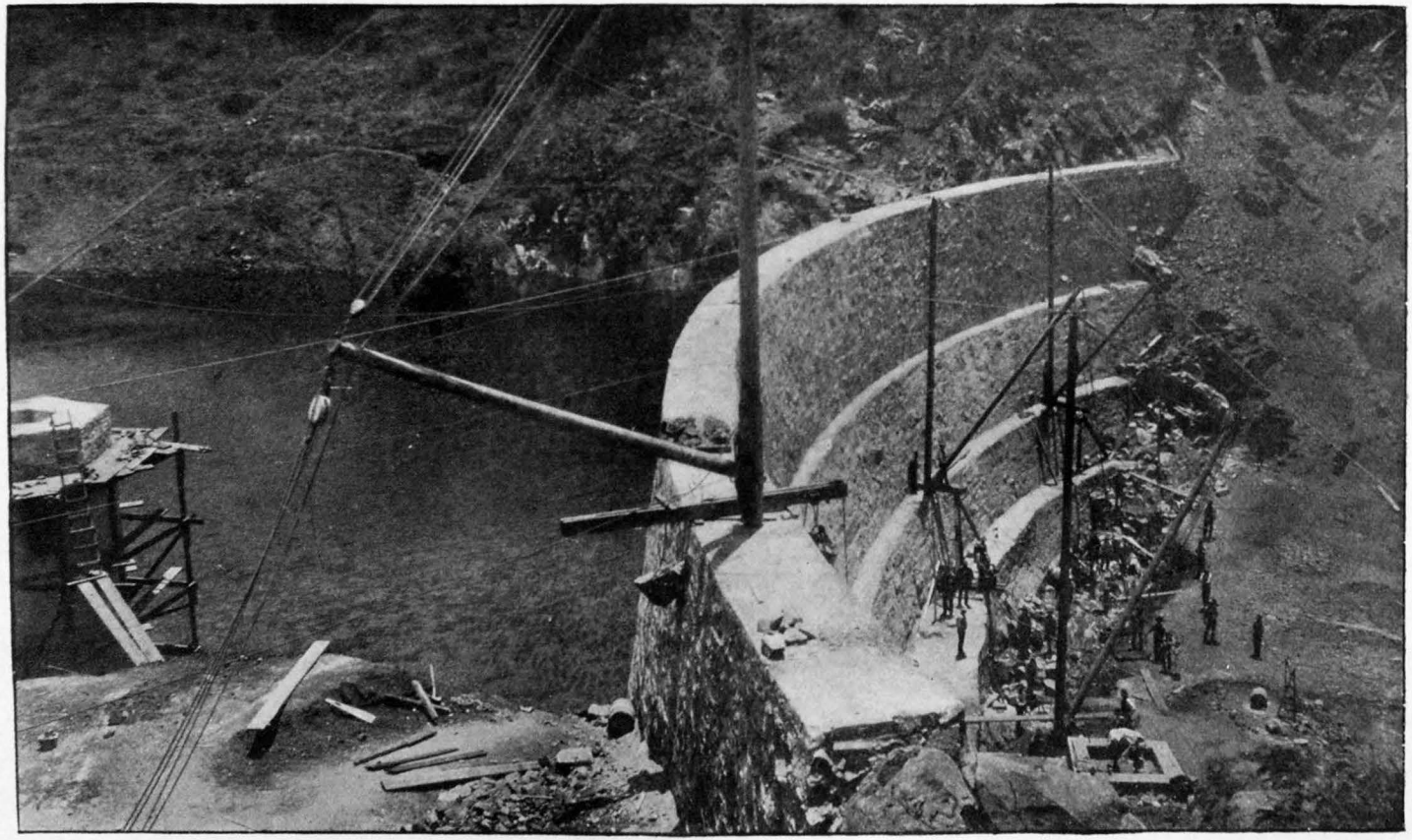



FIG. 102.—Profile and sectional view and plan of waste-way tunnel, Sweetwater dam.

Portland-cement mortar, and has a total volume of 19,750 cubic yards, or, including the tower and other accessories, 20,507 cubic yards, costing in all $234,074, and requiring the use of 17,562 barrels of cement.

Protracted litigation followed the building of the dam, over the condemnation of a tract of land at the upper end of the reservoir, submerged by the impounded waters. The land was comparatively worthless, but a jury gave an exorbitant judgment of its value on testimony given as to its utility for reservoir purposes in a dry country during the height of the southern California "boom." This litigation lasted several years, and was finally compromised, but the effect of it was quite disastrous to the progress of the country depending upon it for irrigation. During the progress of this litigation a tunnel was cut around the south end of the dam, at the level of 31 feet above the



ORIGINAL SWEETWATER DAM AS COMPLETED TO THE SIXTY-FOOT CONTOUR.

lowest outlet, by means of which the flooding of the land could be prevented. In obedience to an order of the United States circuit court, the reservoir, which had been filled, was ordered emptied, and an enormous volume of water was thus wasted when it was needed for irrigation.

With these facts in mind, a summary of results achieved in irrigation development by reason of the existence of the dam can not fail to be of interest. Including the period of retarded growth during the progress of litigation, the dam has been in service nine years, during which time the water it impounds has created values aggregating several millions of dollars, reckoning all the improvements made in the district directly dependent upon it for water supply. The area irrigated from it is now 4,580 acres, chiefly planted to citrus fruits, of which the greater part is devoted to lemons. A population of 2,600 people is also dependent upon the reservoir for domestic water. The distribution for irrigation as well as for domestic use is entirely by pressure pipes, and the agricultural community is as well equipped for fire pressure and general water supply as the average American city of 100,000 inhabitants.

The consumption of water, as determined by the lowering of the reservoir, after deducting evaporation, which is carefully measured, amounts to 500,000 to 550,000 gallons per acre irrigated as the average of the whole, which includes the rather small domestic use, and is equivalent to 1.54 to 1.69 acre-feet per acre. Where water meters are used a variation is recorded of 175,000 to 600,000 gallons on mesa soils, and upward of 750,000 gallons on the sandy bottoms of the Sweetwater Valley.

Estimating the general average use as 550,000 gallons per acre, the total annual consumption would be 2,520,000,000 gallons, and this amount divided into the total gross revenue for 1896, which is given at $29,077.34, would give a mean of 1.15 cents per 1,000 gallons consumed, or $6.35 per acre irrigated. This is not, however, a fair statement of the irrigation cost, as a considerable part of the revenue is derived from the domestic supply of the town of National City, as well as from the farmers, who have to pay for domestic water independently of the irrigation rates. These rates are $4 per acre per annum for orchards in National City limits and $3.50 for orchards outside; $7 per acre for nurseries, alfalfa, and market gardens, and 2 cents per 1,000 gallons when measured by meters at the option of the irrigators, the meters being furnished by the company and maintained at a rental of 35 cents per month by the farmer. The taps on the system number 1,017, from 4 inches diameter to one-half inch, and there are 84 meters in use of all sizes.

### AMOUNT OF WATER USED.

The amount of water required for the irrigation of trees and crops of all kinds under this system proves by experience to be very much greater than was originally expected, and the duty of the reservoir is

restricted to a very much smaller area than was anticipated on the completion of the dam. The requirements of these soils appear to be almost as great for citrus orchards as those of Riverside and Redlands planted to oranges, although the latter, being far in the interior and having a drier climate, were expected to demand very much more water than lands along the coast. The average consumption of the Riverside orchards for ten years has been 1.95 acre-feet per acre, while under the Sweetwater system it is probably now as high as 1.6 acre-feet per acre. In other words, the rainfall is supplemented by irrigation to the extent of 19.2 inches in depth under the Sweetwater system, and 23.4 inches under the Riverside canals, or 22 per cent more than the Sweetwater consumption. The plantings under both systems are chiefly in citrus fruits, and the mean annual rainfall is about 10 inches in each locality.

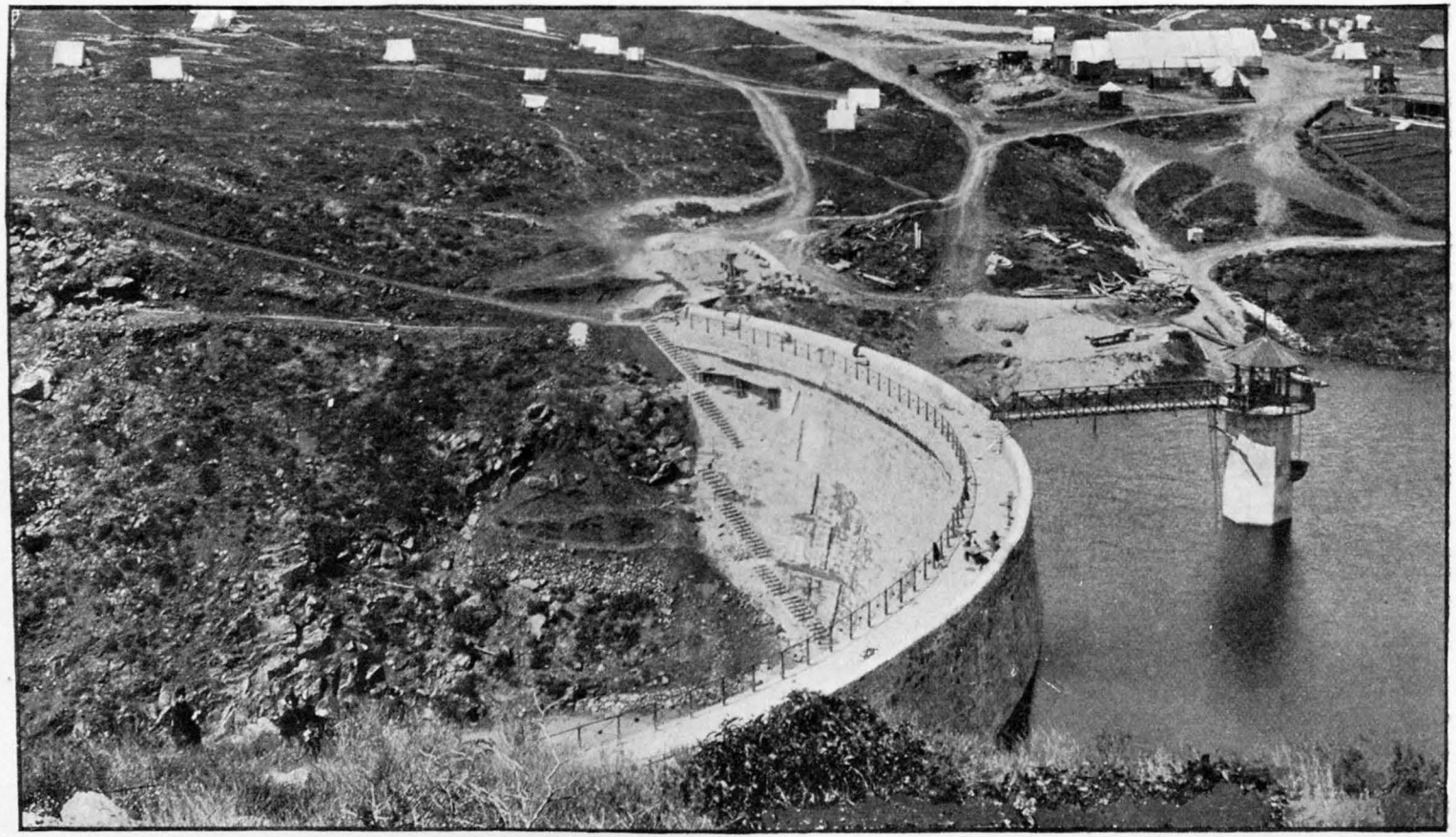
The following tabulated statement of water used for irrigation in Riverside since 1886 is computed from data kindly furnished by G. O. Newman, chief engineer of the Riverside Water Company, and is of special interest in this connection:

*Table of water used in irrigation in Riverside, California.*

| Year. | Area irrigated. | Water used during entire calendar year. | Mean depth applied during entire year. | Water used in irrigation season, May to October, inclusive. | Depth applied in irrigation season. |
|---|---|---|---|---|---|
| | *Acres.* | *Acre-feet.* | *Feet.* | *Acre-feet.* | *Feet.* |
| 1886 | 6,000 | 10,345 | 1 72 | 9,196 | 1.53 |
| 1887 | 6,000 | 12,490 | 2.08 | 8,482 | 1.41 |
| 1888 | 6,000 | 12,540 | 2.09 | 10,590 | 1.76 |
| 1889 | 6,000 | 11,515 | 1.92 | 10,340 | 1.72 |
| 1890 | 8,000 | 13,185 | 1.52 | 10,790 | 1.35 |
| 1891 | 8,000 | 14,310 | 1.79 | 11,730 | 1.47 |
| 1892 | 8,000 | 15,950 | 1.99 | 11,345 | 1.42 |
| 1893 | 8,000 | 13,780 | 1.60 | 11,935 | 1.49 |
| 1894 | 8,000 | 16,943 | 2.12 | 11,905 | 1.49 |

## RUN-OFF.

The volume of supply furnished to irrigators under the Sweetwater system has never been restricted to a definite amount, although constant care and watchfulness are exercised to prevent waste. The area of tributary watershed is 186 square miles, ranging in elevation above sea level from 220 feet, the elevation of the top of the dam, to about 5,500 feet. The extremely variable nature of the run-off from this shed is well exemplified by the following table of the measured results obtained since the construction of the dam.



SWEETWATER DAM AS FINISHED, APRIL, 1888.

*Table of measured run-off, Sweetwater drainage basin.*

| Season. | Rainfall at Sweetwater dam. | Estimated mean rainfall of entire watershed. | Total run-off as measured at the dam. | Percentage of run-off to estimated mean rainfall. | Run-off in second-feet per square mile. |
|---|---|---|---|---|---|
| | *Inches.* | *Inches.* | *Acre-feet.* | | |
| 1887–88 | ..... | ..... | 7,048 | ..... | 0.05 |
| 1888–89 | 13.53 | 21.00 | 25,253 | 12.0 | 0.19 |
| 1889–90 | 16.52 | 25.71 | 20,532 | 14.0 | 0.15 |
| 1890–91 | 12.65 | 23.40 | 20,432 | 9.0 | 0.15 |
| 1891–92 | 9.88 | 17.14 | 6,130 | 4.0 | 0.05 |
| 1892–93 | 11.62 | 20.00 | 15,970 | 8.0 | 0.12 |
| 1893–94 | 6.20 | 14.76 | 1,377 | 1.0 | 0.01 |
| 1894–95 | 16.19 | 27.14 | 70,625 | 26.0 | 0.52 |
| 1895–96 | 7.29 | 16.00 | 1,007 | 0.6 | 0.007 |
| Means | 11.73 | 20.64 | 18,708 | 9.3 | 0.139 |

Of this period of nine years the run-off for five seasons exceeded the capacity of the reservoir, but during the other four it was so far below as to justify the recommendation made by the writer on the completion of the dam that one-half the reservoirful be held over every year as a reserve for possible drought. It is a singular coincidence that the mean annual run-off since the building of the dam is almost exactly equal to the storage capacity of the reservoir. One notable feature of the results indicated by this table is the remarkably small run-off from the watershed, and the small percentage of mean rainfall so represented, in view of the mountainous and rocky character of a considerable part of the drainage basin. The conclusion to be drawn is that in seasons when the rainfall in the lower part of the shed does not exceed 10 to 12 inches the run-off is practically confined to about one-third or one-fourth of the total area covering the higher levels where the precipitation is in excess of 18 to 20 inches. This conclusion is justified by a comparison with the record kept during the same period of catchment in the Cuyamaca reservoir, whose watershed adjoins that of the Sweetwater, as shown by the following table, compiled from data furnished by courtesy of F. S. Hyde, resident engineer of the San Diego Flume Company.

*Table of rainfall, run-off, evaporation, and average draft from the Cuyamaca reservoir, San Diego County, California.*

| Calendar year. | Rain and melted snow. | Run-off. | Percentage of run-off to precipitation. | Run-off per square mile. | Evaporation. | | Average draft from reservoir for irrigation and city supply. |
|---|---|---|---|---|---|---|---|
| | | | | | Total. | Average per day. | |
| | *Inches.* | *Acre-feet.* | | *Sec. feet.* | *Ft. In.* | *Inches.* | *Acre-feet.* |
| 1888..... | 24.05 | 3,076 | 21.75 | 0.385 | 3 9.5 | 0.316 | ..... |
| 1889..... | 52.83 | 5,568 | 17.91 | 0.697 | 4 5.0 | 0.250 | 2,853 |
| 1890..... | 62.91 | 6,214 | 16.79 | 0.768 | 3 9.25 | 0.208 | 2,881 |
| 1891..... | 64.96 | 7,735 | 20.24 | 0.969 | 3 8.75 | 0.203 | 3,084 |
| 1892..... | 42.56 | 5,163 | 20.62 | 0.647 | 3 6.75 | 0.241 | 4,821 |
| 1893..... | 41.51 | 4,098 | 16.78 | 0.513 | 5 3.25 | 0.303 | 5,965 |
| 1894..... | 24.90 | 2,035 | 13.89 | 0.255 | 7 1.0 | 0.341 | 2,939 |
| 1895..... | 58.52 | 11,464 | 33.31 | 1.436 | 5 3.75 | 0.317 | 6,327 |
| 1896..... | 26.44 | 1,158 | 7.45 | 0.145 | 5 7.5 | 0.284 | 5,777 |
| Means... | 44.29 | 5,397 | 19.83 | 0.676 | 4 8.75 | ..... | 4,331 |

Comparing the two foregoing tables of run-off from the Sweetwater and Cuyamaca watersheds, it is seen that the latter, with 11 square miles of drainage, has an average yield of 491 acre-feet per square mile—the territory being all above 4,800 feet in elevation and below 6,500 feet—while the mean of the Sweetwater was but 100 acre-feet per square mile, or one-fifth that of the Cuyamaca. The mean elevation of the Sweetwater drainage basin is estimated at 2,200 feet.

## ENLARGEMENT OF DAM.

The original construction of the dam was of the best class of uncoursed, rough rubble masonry, laid in a rich mortar of Portland cement and sand, and founded on a bed rock of porphyry, which was stripped and cleaned with the utmost care, while every stone that went into the work was thoroughly washed and scrubbed with hand brushes. This painstaking care resulted in a structure which has successfully resisted the normal pressures of a full reservoir for many years, and on the 17th and 18th of January, 1895, withstood a test far more severe than is usually imposed on reservoir walls of such comparatively slender dimensions and beyond any previous calculation or expectation. On those dates the reservoir was filled to overflowing by a flood resulting from a rainfall of more than 6 inches in twenty-four hours, and for forty hours the dam was overtopped to a maximum depth of 22 inches over the parapet wall. This was 5.5 feet higher than the water was expected to rise in extreme floods; it was not considered possible that water could ever reach so high as to flow over the parapet.

This extraordinary freshet, which within a week produced a run-off

SWEETWATER DAM DURING THE GREAT FLOOD OF JANUARY 17, 1895.

of nearly three times the capacity of the reservoir, was gratifying in one respect—it demonstrated the ability of the dam to cope with such emergencies, as not a stone of the masonry was disturbed or moved

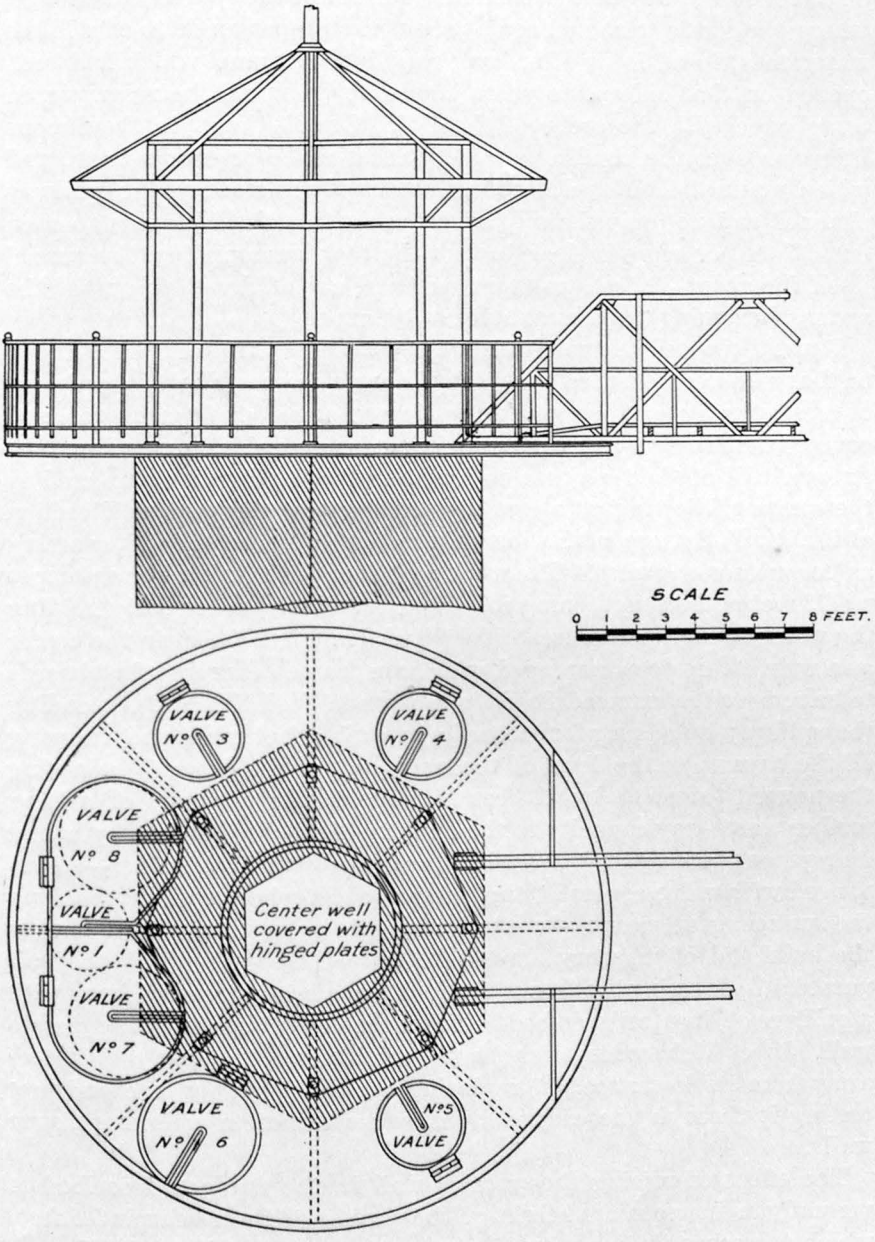


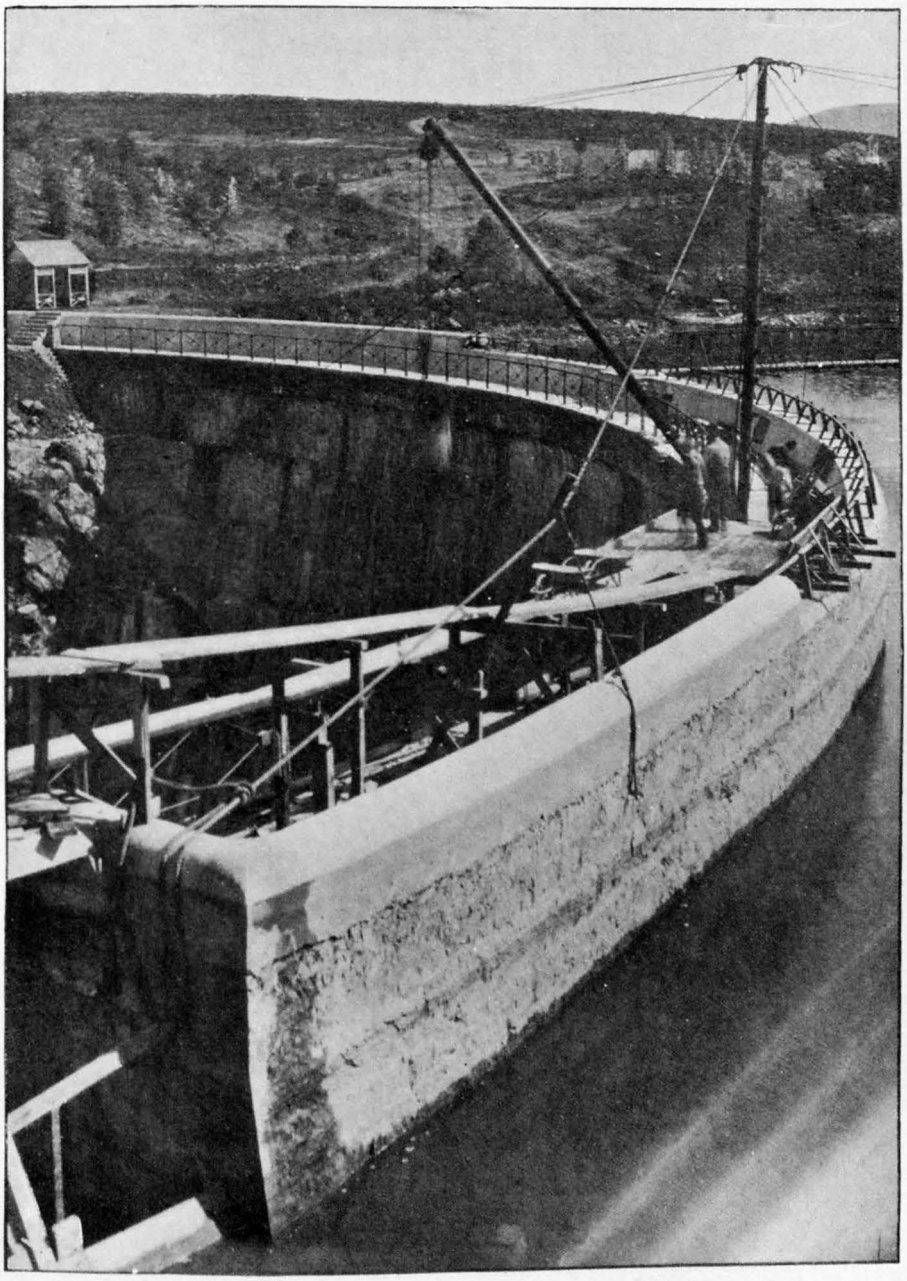

FIG. 103.—Details of tower of Sweetwater dam.

from place, although so much damage was done to the pipes and surroundings as to necessitate considerable expenditure, not only in the

way of repairs, but in the enlargement of the spillway capacity and in preparing the structure to better receive a repetition of the experience in the future. The flood caused a tremendous erosion of the bed rock on either side of the dam, particularly in front of the spillway discharge, where the strata were inclined at about the proper angle to enable the water to strip off layer after layer rapidly. A tunnel which had been opened on that side some years before, to draw off the reservoir, in compliance with the order of the U. S. Circuit Court, in the famous litigation over the condemnation of lands in the reservoir basin, and which was not then used, terminated directly in front of the spillway channel, and not only the approach to this tunnel, which was an open cut, 25 feet or more in length, but the rock surrounding the tunnel itself for about 30 feet, was torn out and cut off by the force of the water, shortening the tunnel by that distance.

It was estimated that not less than 10,000 cubic yards of the solid rock on that side were loosened and washed downstream. The bombardment of these stones upon the pipe line resting on one side of the canyon, and covered with masonry, destroyed it for a considerable distance down the stream. All of the repairs occasioned by the flood were completed in the summer following, at a cost of $30,000, under the capable direction of Mr. H. N. Savage, of National City, chief engineer, the writer acting as consulting engineer. The work consisted of (1) raising the parapet wall 2 feet and strengthening it so as to admit of permanently holding the water as high as its crest, if desired, leaving 200 feet in the center as a weir, 2 feet deep, arranged with iron frames carrying flashboards to be removed in extreme floods, as shown in Pl. LXIX; (2) extending the spillway by adding four more bays, each 5 feet wide, and carrying all the bays up to the level of the new crest of the dam; (3) adapting the unused tunnel, 8 by 12 feet in size, to the purposes of adding further waste-way capacity to the extent of 1,500 second-feet, by laying four pipes through it—two 48-inch and two 30-inch diameter—all arranged with valve covers at their upper ends, where a shaft, reaching the surface, gave means of control, and gate valves immediately below the bulkhead of masonry across the tunnel through which they all passed; (4) covering the face of the rock slope below the waste way with a grillage of iron rails embedded in concrete; (5) erecting a concrete wall, 15 feet high, concentric with the curvature of the dam and 50 feet away from its lower toe; (6) replacing the main supply pipe and protecting it through the canyon by means of concrete collars and spur walls.

The effect of raising the parapet wall in the manner described is virtually to increase the height of the surface of the reservoir 5.5 feet, which increases its capacity 25 per cent, or from 18,053 to 22,566 acre-feet. The dam having shown its ability to withstand this increased pressure, it is now proposed to make this addition to the reservoir capacity a permanent feature of the works.



REPAIRING AND INCREASING THE HEIGHT OF THE PARAPET OF SWEETWATER DAM.

One of the interesting phenomena of the overflow during the freshet was the effect that was observed upon the débris at the foot of the dam, which had been piled up there after construction to the depth of 15 to 20 feet. The sheet of water, falling 90 feet, and in a volume weighing some 10,000 tons per minute, cleared the toe of the dam about 20 feet and expended its energy in excavating a deep hole in the loose débris, thus making for itself a water cushion, although the excavation did not reach to bed rock. It was noticed that the shock of the falling water caused the windows to rattle perceptibly in the keeper's house, 600 to 800 feet away, for several hours, when the rattling ceased, presumably when the pit had become deep enough to make a sufficient water cushion to take up the earth tremor. Profiting by this suggestion, a wall was constructed below the dam across the canyon, which will form a pond 5 to 10 feet deep in time of overflow and save the possibly injurious effects of such tremor upon the masonry.

Concrete was used in all the new work, as preferable to rubble masonry, because of the greater ease with which all the materials can be handled and the work performed by unskilled labor. The concrete was mixed by machinery, and one engine performed all the work of crushing the stone, revolving the mixer, and hoisting the concrete to the top of the dam, where it was distributed by wheelbarrows. Iron, in the form of old rails and scrap bars of all sizes, was embedded in the concrete wherever it would add to the strength, as in the 6-inch floors of concrete covering the waste way and spanning the 5 foot spaces between piers; in the roof of the gatehouse over the shaft in the tunnel from which the heavy gates are suspended; in the thin concrete buttressed wall, 10 to 15 feet high and 18 inches thick, forming the auxiliary water-cushion dam, and in the inclined apron of the waste way. This construction is satisfactory, as the rates of expansion of iron and of concrete are practically identical, so that there is no separation of the two elements by the action of changes of temperature, and the iron supplies a tensile strength to the combined mass which it could not otherwise acquire.

## PROFILE AND FORM OF DAM.

The profile of the Sweetwater dam has been regarded with particular interest by engineers because it is so much more slender than the standard theoretical types of high masonry dams resulting from the formulæ of Sazilly, Delocre, Rankine, Wegmann, and Fteley, although by no means so radical a departure from these theoretically correct forms as is the famous Zola dam of France or the Bear Valley dam of California, both of which depend wholly upon their arched form for their ability to withstand the water pressure against them. In the Sweetwater dam the line of pressure with full reservoir, prior to the recent addition of 5.5 feet, fell about the center of the outer third, whereas the theoretical requirement for a dam which shall be stable

from its own gravity, independent of its form, is that this line of resultant pressures shall fall within the inner third of the base width at any level. With the added height and the increased pressure resulting therefrom the line of pressure still falls within the toe of the dam a few feet, but in the Zola and Bear Valley dams it falls entirely outside the toe, as is illustrated by fig. 104, taken from the Proceedings of the Institution of Civil Engineers (Vol. CXV, p. 151), discussion by Mr. George Farren on "Impounding reservoirs."

That there are no evidences of crushing visible in the masonry at the toe of the dam is doubtless due to the fact that the stone is extremely hard and the mortar of prime quality, and that the tensile strength of the mortar on the upper face has also been of some assistance; furthermore, that the arch of the wall has been called into action from the

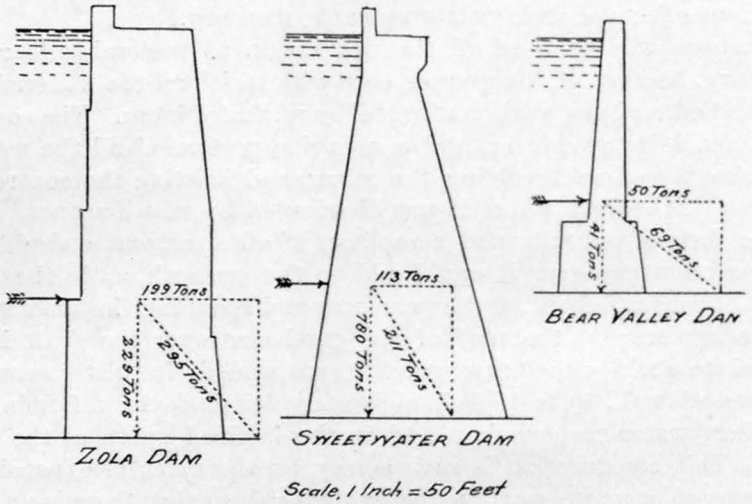
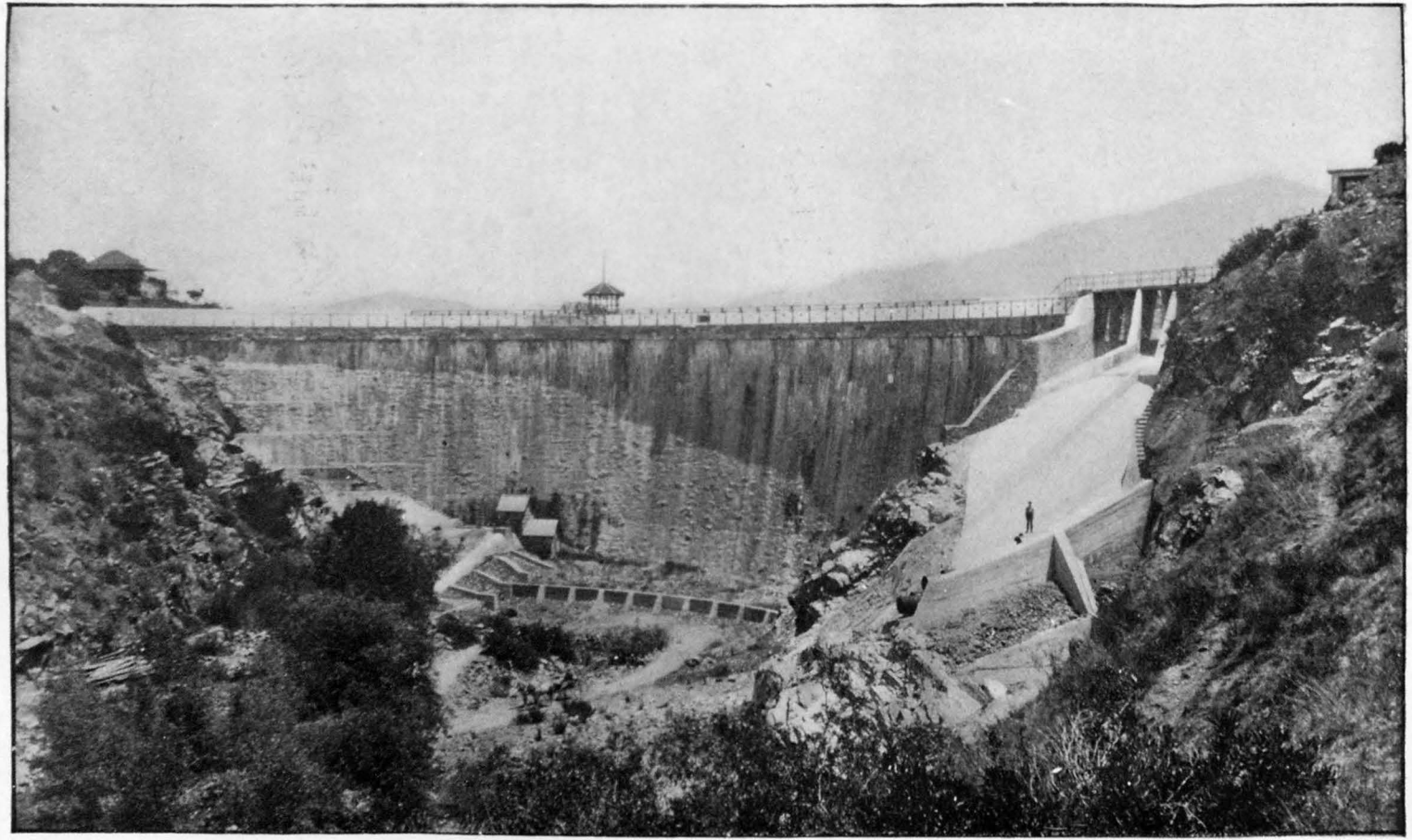



FIG. 104.—Comparison of profiles of Zola, Sweetwater, and Bear Valley dams.

top down to some neutral point, where gravity alone suffices to resist the pressure. There have never been any cracks in the masonry of the dam, nor any spouting leaks to indicate the transmission of an upward pressure through the masonry of the slightest moment. The leakage was never of considerable amount, and has steadily diminished, so that the wall is practically dry over most of its outer face. This result has been accomplished in part by carefully repointing the inside face as far down as the water was lowered in the reservoir and applying successive washes of soap and alum.

While it can not be proved to a demonstration that the Sweetwater dam owes its present existence (after the flood of 1895) to its arched form, there appears, after that experience, to be very good reason for congratulation that it was not built on straight lines, and, without attempting in this paper to discuss the moot question between engineers as to the relative merits of straight and curved dams, it will be of inter-



SWEETWATER DAM, SHOWING NEW APRON OF SPILLWAY AND PROTECTING SPUR WALLS ON PIPE LINE.

est in this connection to quote the arguments in favor of curved reservoir walls advanced by Professor Forchheimer, of Aachen, Germany, in discussing the series of papers on "Impounding reservoirs," above referred to, as follows:[1] "Of even more importance than uplift in dams is the movement due to variation of temperature, especially in countries subject to climatic extremes." Referring to a dam 82 feet high, plastered and rendered over with two coats of asphalt, built by Professor Intze, in Remscheid, Westphalia, he says:

> A backward and forward movement, amounting to $1\frac{1}{16}$ inches, occurred during the filling and emptying of the reservoir, and the movement due to temperature was almost as great as this. The latter was due less to the temperature of the air than to direct solar radiation. The crest of this dam was 460 feet long and was arched with a radius of 420 feet. One side was exposed to the sun longer than the other, and the more exposed part moved to and fro seven-eighths of an inch in the course of the year, while the other part moved only one-eighth of an inch, the crest expanding one nine-thousandth of its length, or five-eighths of an inch. In arched dams such movements do no harm, but in straight dams these phenomena are objectionable. As dams are usually built during the warmer seasons of the year, the masonry has a tendency to contract in the colder weather. In a curved dam this can take place by movement of the structure without cracking, but not in a straight dam. * * * If the temperature is lowered 10° C. (18° F.) and it is not free to contract, tension amounting to between 140 and 280 pounds per square inch is set up, which is greater than the mortar will stand. * * * That a straight, or almost straight, wall incurs considerable danger of fracture is shown by practical experience. The dams of Habra, Grands-Cheurfas, and Sig, in Algiers, have broken, and in that of Hamiz a tear occurred during the first filling. The Habra dam broke in December and the Grands-Cheurfas and Sig dams gave way in the month of February. The Beetaloo dam, in Australia, also developed a crack one-eighth of an inch wide in the middle of winter without any apparent cause. The Mouche dam, Haute Marne, a structure 1,346 feet long and about 100 feet high, exhibits clearly the dangers attending straight dams. In the winter of 1890–91, when the temperature varied between —10° C. and —20° C. (14° to —4° F.) and the water surface was 10 feet 8 inches below the normal level, seven vertical cracks appeared in the dam, situated at uniform distances of about 160 feet apart. They were widest at the top, and died out about 37 feet below the normal water level. Their aggregate breadth was $2\frac{7}{8}$ inches. The cracks gradually closed as the temperature rose, and by the end of February, 1891, four of them had completely vanished, while the others had perceptibly contracted.

## CONDUITS.

The main conduit leading from the dam to Chula Vista is 30 inches in diameter and has a minimum capacity for delivery of 1,260 miner's inches (25.2 second-feet) at an elevation of 90 feet above sea level, which is high enough to cover the larger part of the settlement. This pipe was found to be inadequate to the demands upon it, because in practice the maximum rate of consumption was about double the mean rate, and for the further reason that the company inadvertently became committed to the delivery of water to tracts on higher levels than the

[1] Proc. Inst. Civil Eng., Vol. CXV, p. 156.

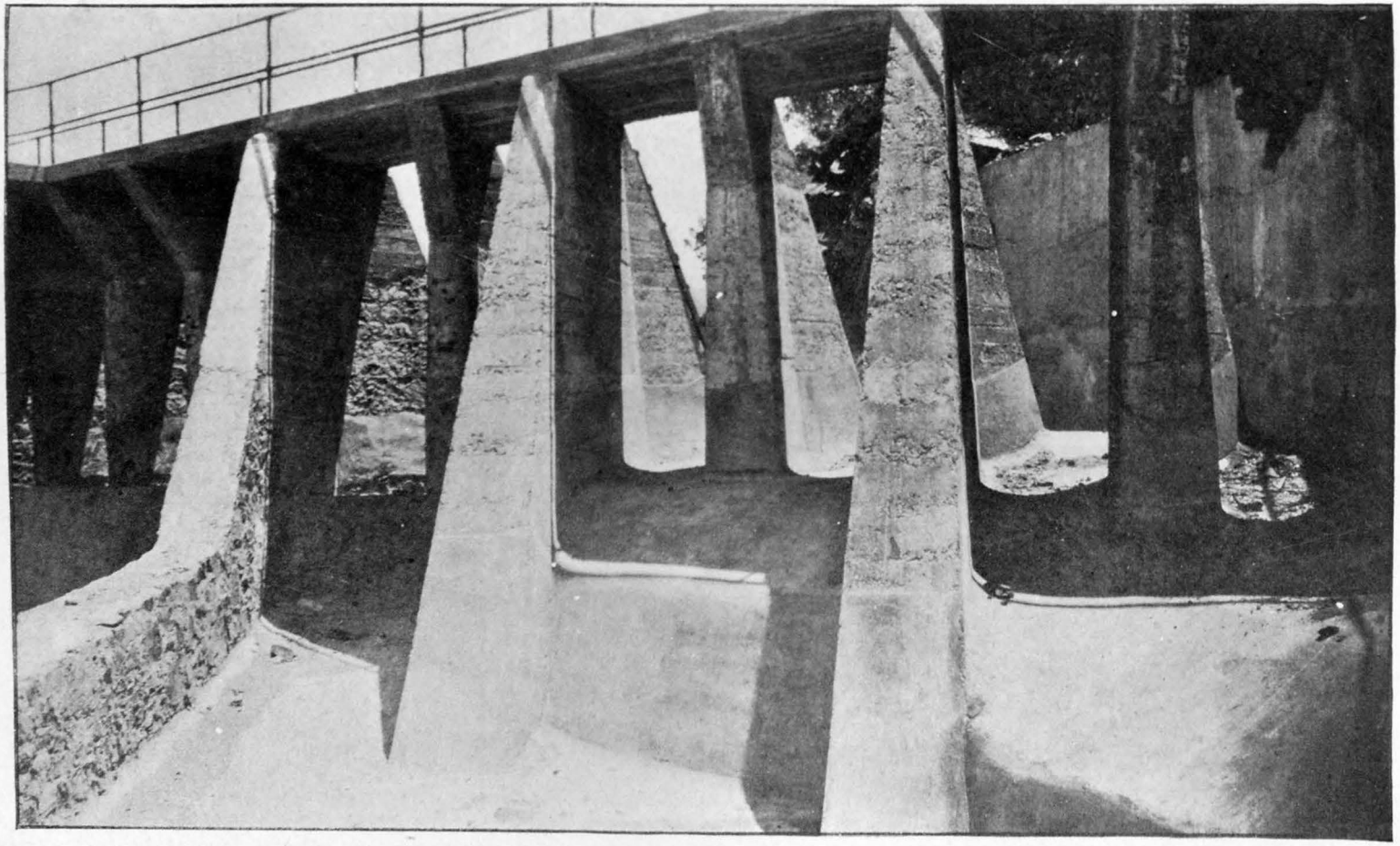
mean pressure in the pipes under full draft could well supply. To better meet the demand and serve the higher lands more efficiently, a second pipe was constructed in 1895. It was located on the north side of the valley of the Sweetwater, is 24 inches in diameter, of mild steel, riveted, is 30,142 feet in length, and cost $65,000. This line has a minimum capacity of 450 miner's inches (9 second-feet), and is used chiefly for high service. It is connected at the dam with one of the pipes laid through the tunnel.

## EVAPORATION.

The subject of the percentage of water lost in storage reservoirs by evaporation is an interesting and vital one, as it is a factor which, though subject to wide variation, due to differences in ratio of exposed surface to volume stored, as well as to differences in mean depth, climatic influence, wind currents, and relative humidity, is yet ever present, and in so large a degree that it may easily reach in some instances 25 to 30 per cent of the entire contents of the reservoir. Careful measurements of evaporation from the Sweetwater reservoir for the last nine years show that the mean annual loss from that source is about 54 inches, ranging from 49 to 60 inches. This causes an annual loss of 15 per cent of the stored water, and as a reserve must always be held back for dry years, so that practically the reservoirful is a two years' supply, the loss is really 30 per cent of the amount actually available for use. At the Cuyamaca reservoir, on the adjacent watershed, the average loss reported during nine years prior to the current season was 56¾ inches per annum, which has resulted in a total loss of 25.5 per cent of the water stored during that time. To illustrate the effect of evaporation upon the general supply, and to show also the variable seasonal run-off, as well as to present a rough check upon the estimated loss and the calculated consumption of water, the following figures of two seasons are given by way of example:

| | Acre-feet. | |
|---|---|---|
| After the flood of January, 1895, the season started with a full reservoir back of the dam, or | | 18,000 |
| Catchment of stream flow during irrigation season, and return water from saturated slopes of reservoir | | 1,850 |
| Catchment during winter season, 1895–96 | | 1,000 |
| Total resources during two years | | 20,850 |
| Loss by evaporation in two years, say 30 per cent | 6,256 | |
| On hand at end of 1896 | 3,422 | |
| | | 9,678 |
| Amount used in irrigation in two years | | 11,172 |

As the mean area irrigated during this period was about 4,340 acres, the result of the above calculation shows that a mean of 1.4 acre-feet per annum per acre was used on the land, which is not far from the estimate previously given (see p. 672) of 1.6 acre-feet as the mean obtained from independent data.



SPILLWAY OF SWEETWATER DAM, SEEN FROM BELOW.

The effect of the increase in storage capacity of the reservoir will be to raise its effective duty to the irrigation of somewhat over 5,000 acres, after deducting all losses and insuring a constant supply, as follows:

| | Acre-feet. |
|---|---|
| Total capacity of reservoir as enlarged | 22,500 |
| Amount below the 30-foot contour required to be left to maintain pressure for delivery to high lands | 1,680 |
| Balance available for use | 20,820 |
| Deduct evaporation during two years, say 30 per cent | 6,246 |
| Net balance | 14,574 |
| Minimum annual inflow | 1,007 |
| Return waters from saturated sides, say 10 per cent | 1,457 |
| Total net supply for two years' irrigation | 17,038 |
| Total net supply for one year | 8,519 |

This net amount may be needed for about 5,300 acres if used at the estimated average depth of application of 1.6 feet, or it may be made to serve 6,000 acres safely if 1.4 feet depth is found on further experience to be more nearly the requirement.

It is apparent, without further demonstration, that the recurrence of occasional dry years places such a limitation upon the mean supply as to restrict the reservoir duty to about half what would otherwise be reasonably expected from it. The development of this limitation by the experience of nine years has necessitated an increase in the water rates to $7 per acre per annum, which the management has attempted to enforce, but which has been vigorously resisted in the courts by the irrigators without a definite result having yet been reached.

## SEDIMENTATION.

Much apprehension was felt (and freely expressed in some quarters, due to ignorance of the facts) prior to the completion of the Sweetwater dam on account of the possibility of the reservoir being speedily filled with sand brought down by the stream, although that apprehension was not shared by the engineer in charge, whose few experiments on the load of sediment carried by the stream in flood led him to the conclusion that the reservoir might be filled 1,000 times before becoming entirely filled with sediment.[1]

Recent observations on the filling that has taken place to the present time afford the basis for the following estimate of sedimentary deposit:

| | Acre-feet. |
|---|---|
| 40 acres at upper end of basin filled 5 feet deep | 200 |
| 528 acres above gage 30 feet with an average deposit of one-half inch per annum for eight years | 143 |
| Total | 343 |

[1] The construction of the Sweetwater dam: Trans. Am. Soc. Civil Eng., Vol. XIX, p. 214.

This filling is at the rate of about 1 per cent every six years, which is not enough to be regarded with special concern or to warrant great expense in attempting to counteract it.

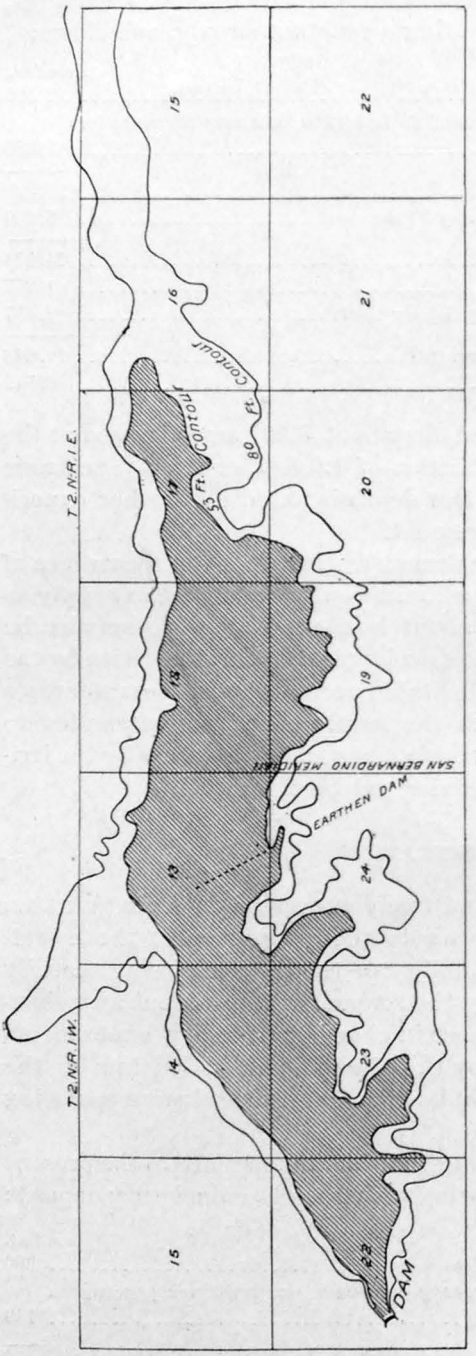
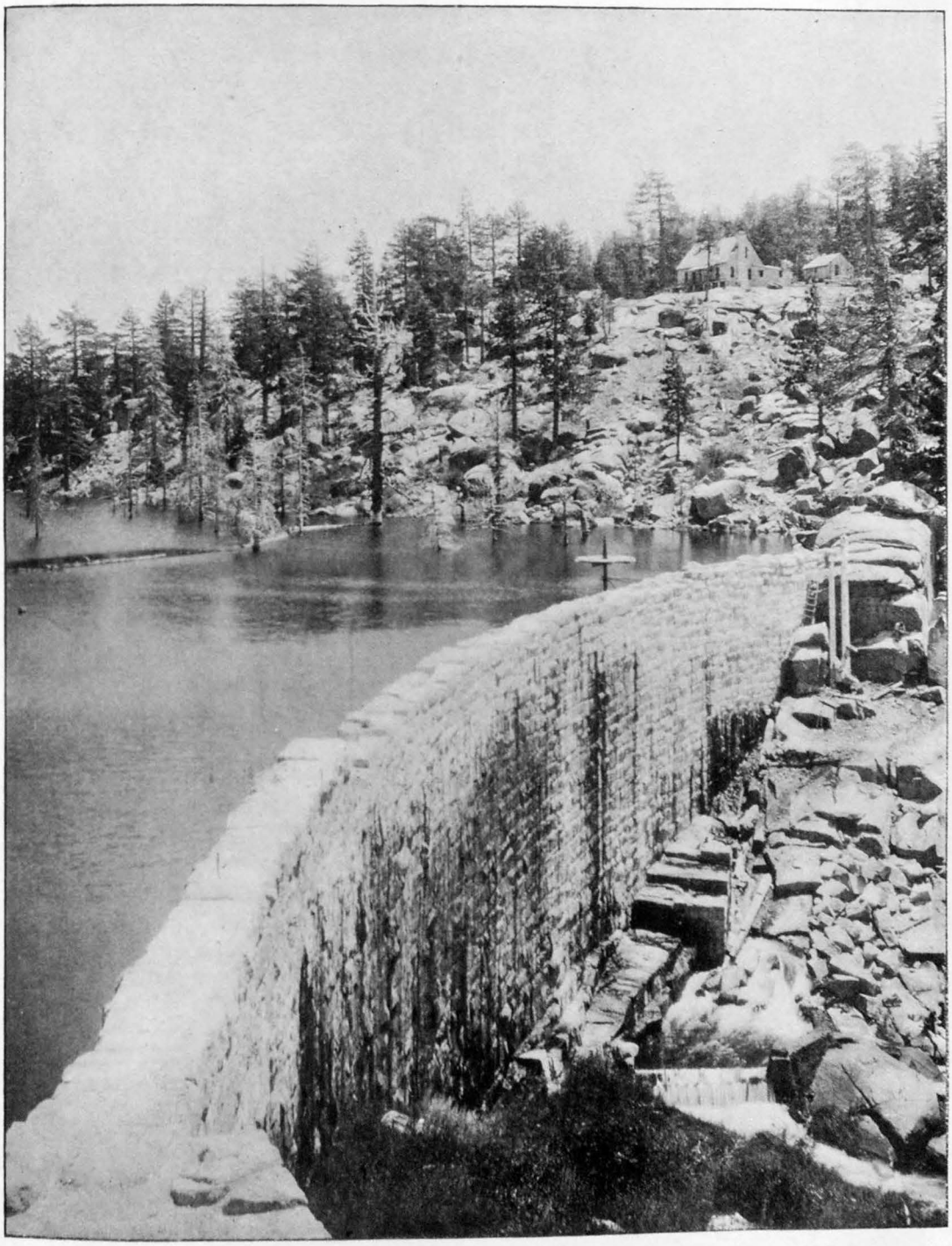



FIG. 105.—Map of Bear Valley reservoir.

## BEAR VALLEY DAM, CALIFORNIA.

Probably the most widely known irrigation system in California is that of the Bear Valley Irrigation Company of Redlands, not only on account of the remarkably slender proportions of the Bear Valley dam, which has been to the engineering fraternity the "eighth wonder of the world," but because the stock of the company was quite widely distributed through the Eastern States and in Europe, and the disastrous financial failure of the enterprise has called special attention to it and provoked much unfavorable comment, to the discredit of irrigation development in general. It is not within the province of this paper to discuss the financial policy of the company or the conditions which brought about its embarrassment, but it may not be out of place to refer to the enterprise in general as a notable example of the creation of great values in landed estates from the storage of water that had hitherto been flowing to waste.

The settlements of Redlands, Crafton, and Highlands—among the



BEAR VALLEY DAM, LOOKING SOUTH, TOWARD SPILLWAY.

choicest of the orange-growing region of California—and the irrigation districts of Alessandro and Perris are the outgrowth of this water storage. Prior to the construction of the dam, in 1883 and 1884, the natural streams of the San Bernardino Valley had apparently reached the limit of their irrigable duty, and all the water in sight was appropriated and used. The creation of the reservoir has more than doubled the area of land irrigated and has increased the valuation of property in still greater ratio.

The construction of the dam was a bold and difficult undertaking, as it was in a remote locality, and cement and all tools and supplies had to be hauled from San Bernardino, over a rough mountain range and across a portion of the Mojave Desert, a total distance of 70 miles. The cost of hauling cement was $10 per barrel, and its total cost delivered was $14 to $15 per barrel. Under such conditions, and with a scarcity of funds for what was considered an experimental and doubtful project, it is not to be wondered that economy in dimensions of the structure was practiced to such a degree that it is without parallel in all the world for extreme slenderness. The dam is curved upstream with a radius of 335 feet, and is 64 feet high from base to top of coping. Its length on top is about 300 feet, and in thickness it is but 3 feet at top and 8.5 feet at a point 48 feet below the crest, where it rests on a base of masonry that is 13 feet wide, making an offset of about 2 feet on each side of the dam at the center; but inasmuch as the lower part, or foundation, was built with a curve of shorter radius than the upper 48 feet, the offset is not uniform, but tapers to nothing on one side and is fully 4 feet on the other. At the foundation of the base the thickness is 20 feet, as shown on fig. 106. The dam contains about 3,400 cubic yards of masonry, in which were used about 1,600 barrels of cement. It is reported to have cost $75,000, or over $22 per cubic yard, of which the cement alone cost but $7.50 for each cubic yard of masonry laid. That the plant and labor could have cost so much as $14.50 per yard, which is several times the ordinary cost of such work, must, if true, have been largely attributable to the lack of adequate machinery, as well as extravagant management. The masonry is chiefly a rough granite ashlar with a hearting of rough rubble, all laid in cement mortar and grout. The work was evidently done slowly and with great care, as it has leaked but little beyond the usual sweating, which has left its marks in an efflorescence or deposit of lime brought

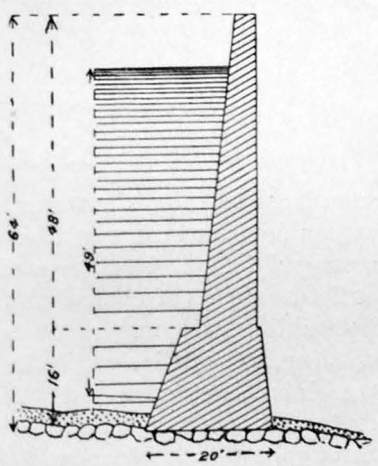



FIG. 106.—Cross section of Bear Valley dam.

out of the mortar by the moisture oozing through. This occurred during the first few years and has almost entirely ceased. In August, 1896, when inspected by the writer, the water in the reservoir was standing within 10 feet of the top, with little or no visible leakage manifest below.

The south end of the dam abuts against a projecting ledge of granite standing boldly out from the side of the canyon 100 feet or more beyond the general line of the side slopes, illustrated in Pl. LXXII. Over the top of this ledge, as far from the dam as it could be placed, a spillway, 20 feet wide, was excavated to a depth of 8.5 feet below the level of the extreme top of the dam (Pl. LXXIII). This was for a time closed with

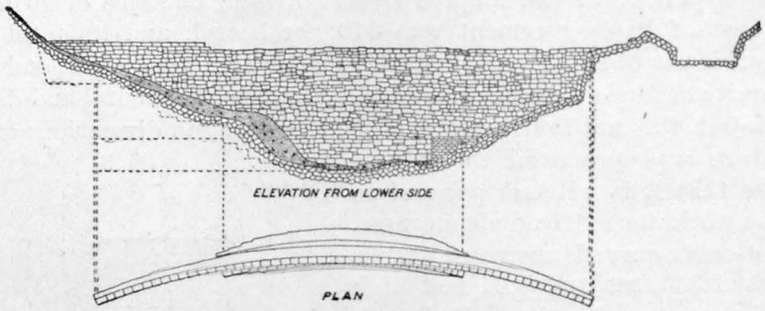
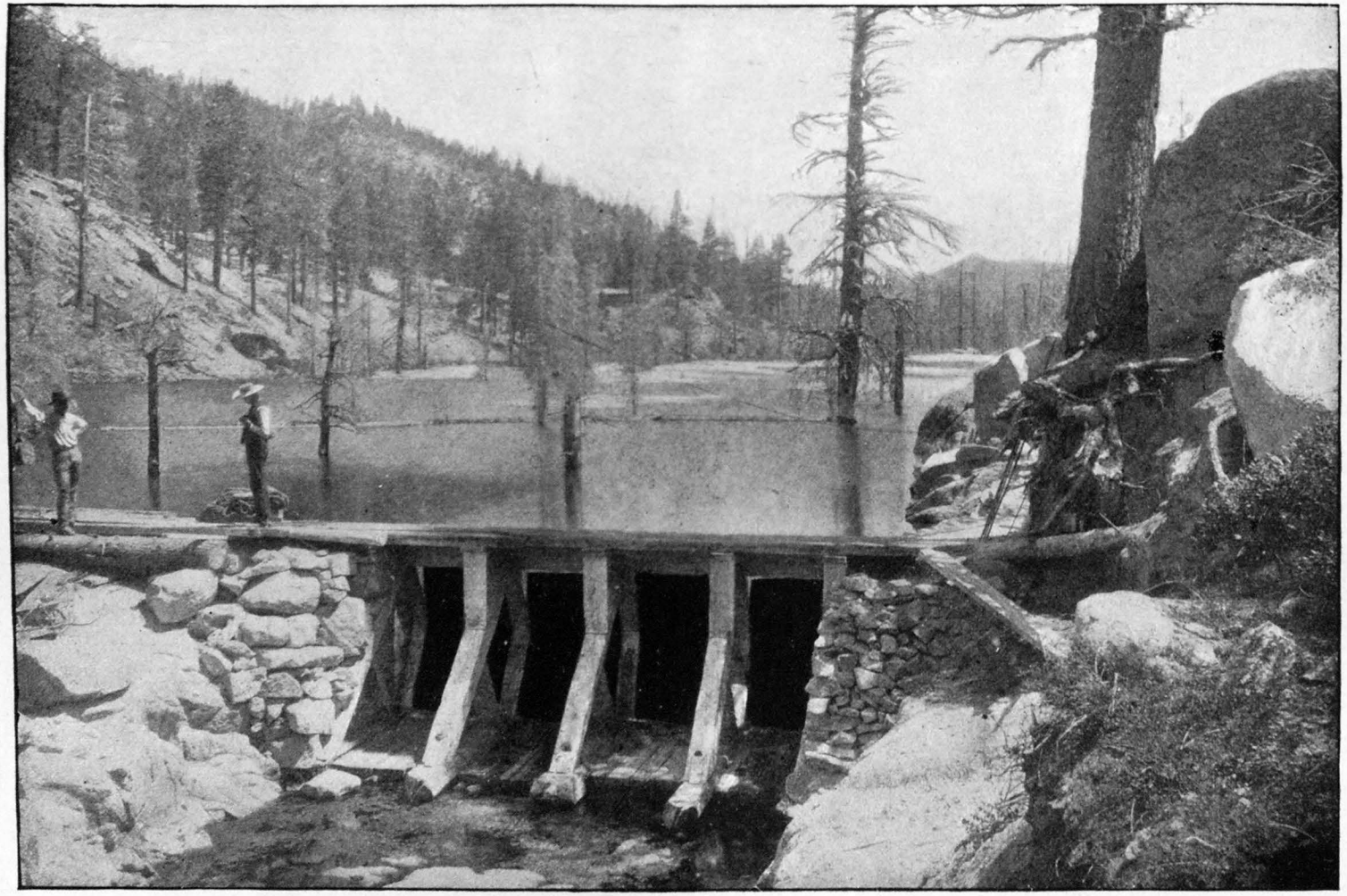



FIG. 107.—Plan and elevation of Bear Valley dam.

sand bags to raise the water above the level of the floor of the spillway, a device which was afterwards replaced by movable flashboards, arranged in four bays, separated by suitable framework. The only outlet or means of control of the water drawn from the reservoir is an iron sliding gate, moving on brass bearings and closing a rectangular opening, 20 by 24 inches, leading to a culvert cut in the bed rock. This trench is 2 feet wide and 3 feet high, arched over the top with concrete, flat on the bottom. The gate is operated by a stem passing up through a 6-inch pipe standing vertical in the water next to the dam and reaching up to a wooden platform placed at the coping line.

The top of the dam is not finished to a true level line, as the coping stones have been omitted over about one-half the length, and this portion is 2 to 3 feet lower than the finished crest. It requires considerable nerve to walk over the top of the dam, because it is so narrow and has no side railing or parapet of any kind, and not many visitors attempt the feat. Water has stood for a considerable time within a few inches of overflowing, although it has never actually passed over the top, as the spillway has thus far been capable of carrying the surplus flood water. The maximum amount stored in the reservoir thus far has been somewhat over 40,000 acre-feet, and in seasons of excessive precipitation the run-off has exceeded the reservoir capacity. In order to be able to impound the entire amount of run-off from the watershed, or at least to greatly increase the duty of the reservoir, the company at one time contemplated the erection of a higher dam, to be built



SPILLWAY OF BEAR VALLEY DAM, WITH FLASHBOARD GATES.

immediately below the existing structure, or not nearer than 200 feet from it. The new dam was designed to carry water to the 75-foot contour, at which level the computed capacity of the reservoir basin is 80,000 acre-feet, flooding a surface area of 3,060 acres to a mean depth of 25.3 feet. This structure was designed as a rock-fill dam, and was to be 80 feet in height above the base of the upper dam, but never was finished beyond the foundations, which were laid in a substantial manner in 1893. It was regarded as impossible to safely add another foot to the height of the present dam, and no engineer cared to risk the responsibility of excavating at the toe of the wall for such an addition to it as would enable it to be raised to the height desired; hence it was deemed best to go a safe distance below to avoid jarring or disturbing the fragile wall, and there begin an entirely independent structure. This would not have been necessary, of course, if the reservoir could have been emptied for a season, but too many interests are depending upon the stored water to permit such a deprivation.

The watershed tributary to the Bear Valley reservoir, as determined from the best available maps, is approximately 56 square miles, the maximum elevation of which is about 1,500 feet higher than the valley, or about 7,700 feet above sea level. On the north and east the shed borders on the desert and the precipitation shades off to a considerably less amount than is recorded at the dam. Following is a table of the annual rainfall and melted snow from the records kept at the dam from 1883 to 1893, the year in each case beginning September 1:

| | Inches. | | Inches. |
|---|---|---|---|
| 1883–84 | 94.60 | 1889–90 | 93.40 |
| 1884–85 | 28.06 | 1890–91 | 78.40 |
| 1885–86 | 65.51 | 1891–92 | 38.00 |
| 1886–87 | 24.00 | 1892–93 | 44.32 |
| 1887–88 | 62.30 | | |
| 1888–89 | 46.03 | Mean for ten years | 57.46 |

The dry years which have occurred since 1893 must undoubtedly reduce this mean very considerably, although the record is not at hand to give the precise amount.

While the company and its representative as receiver are reluctant to give out data of actual measured run-off in the past for publication, it is believed by those who can make a shrewd guess that the minimum is about 15,000 and the maximum 100,000 acre-feet per annum, and that by erecting the new dam to store water to the 75-foot contour, impounding 80,000 acre-feet, a mean annual draft of 25,000 acre-feet, after deducting probable losses by evaporation, could reasonably be expected to be maintained, and no more. This would be equivalent to about 4,860 six-months miner's inches. The annual loss from the reservoir by reason of evaporation may be approximately estimated at 15 per cent of its total capacity.

## LAGRANGE DAM, CALIFORNIA.

This structure (figs. 108 and 109), erected on the Tuolumne River, California, by the Turlock and Modesto irrigation districts jointly in 1890, and sometimes called the "Turlock dam," is designed simply as a diverting weir for the two canals which head at the dam on each side of the river. It is 125 feet high and 90 feet thick at base, with a crest width of 24 feet, the length of which is but 320 feet between the canyon walls.

This structure is also among the class of curved dams of masonry

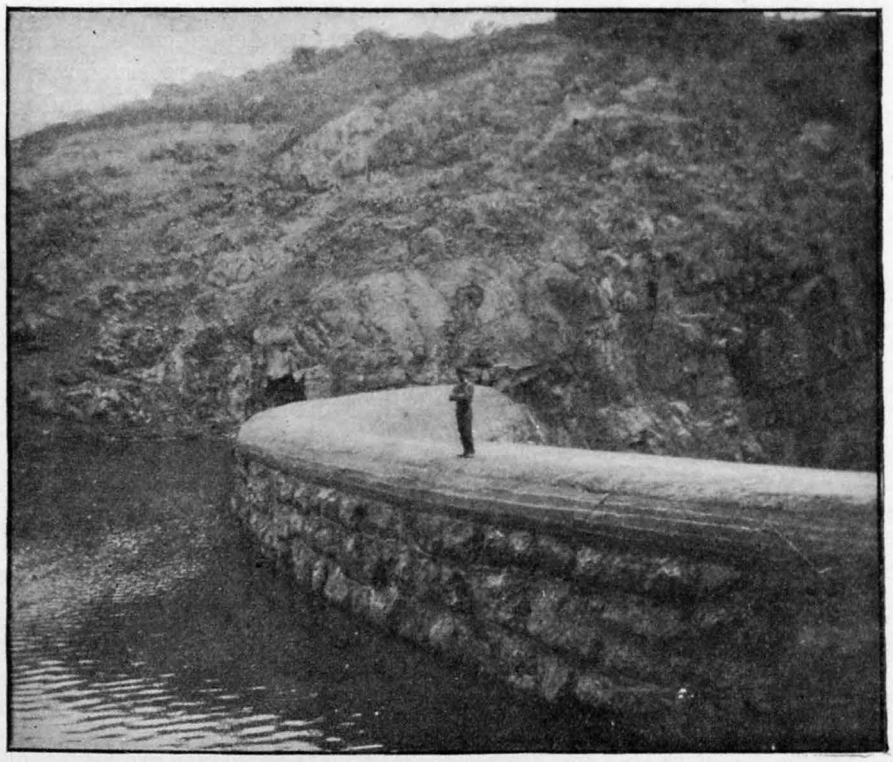
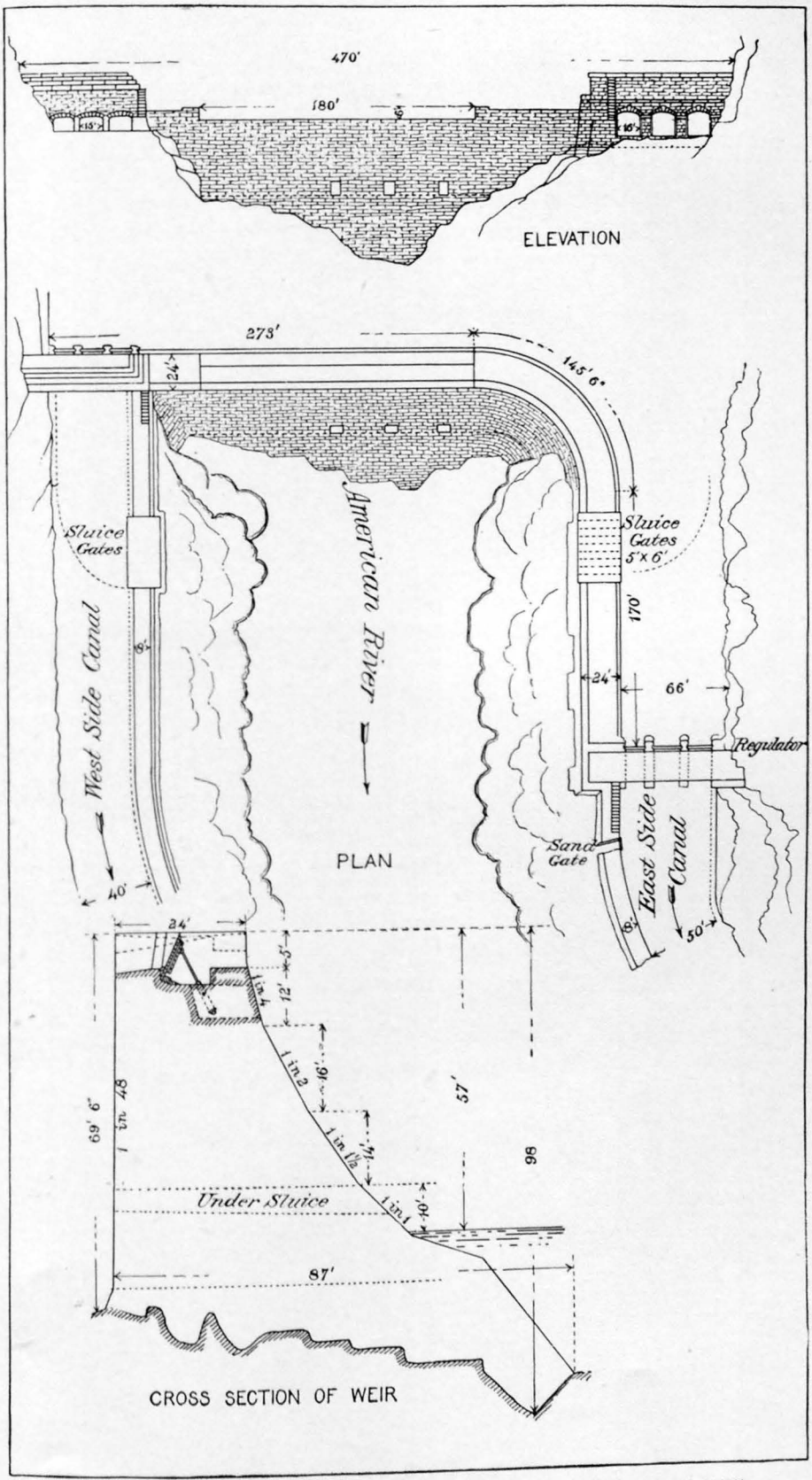
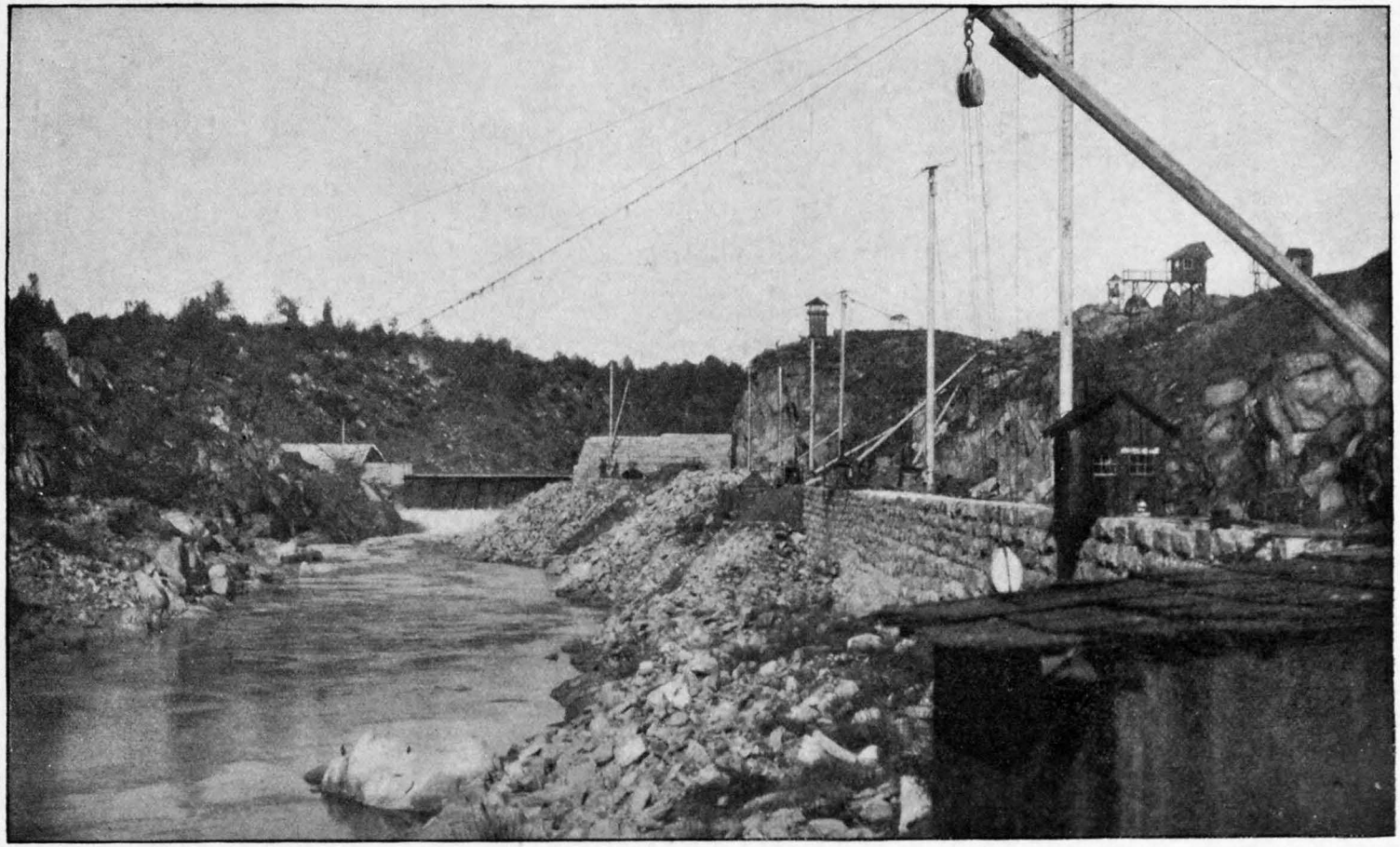


FIG. 108.—Upper face of Lagrange dam.

in which the arch is opposed to the direction of the water pressure, the radius of the arch being 300 feet. It is built throughout of rough, uncoursed rubble masonry, laid in Portland-cement concrete, in practically the same manner as that described in the construction of the Hemet dam. The work was done by contract, the districts furnishing the cement. It is believed to be the highest overflow dam in the United States, considering the volume of water which passes over it in flood, which amounts at times to 100,000 second-feet. The canyon reservoir back of the dam is of no value for storage and is expected to




PLAN, CROSS SECTION, AND ELEVATION OF WEIR AND HEADWORKS OF FOLSOM CANAL.



AMERICAN RIVER DAM AT FOLSOM.

fill with detritus to the top of the wall, no undersluice having been provided for drawing off either water or sediment below the level of the canal grades.

## FOLSOM DAM, CALIFORNIA.

There are many things about the Folsom dam, on the American River, in California, which give it special interest to engineers and all others who have seen it, one of which is that it was built entirely by convict labor, being near one of the State prisons of California, which was located at this site for the purpose of erecting this dam and thereby

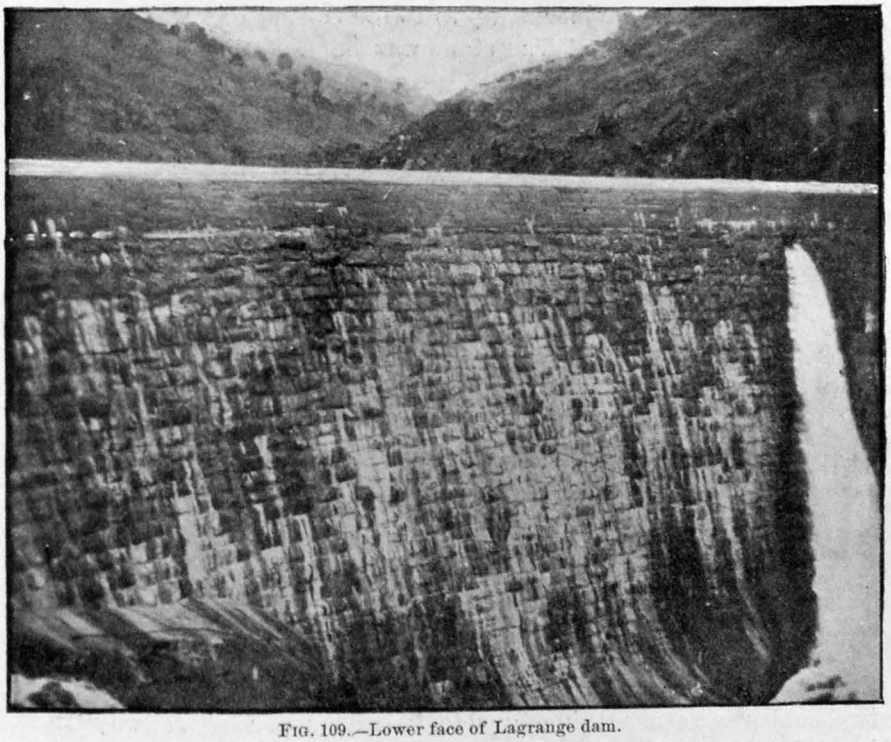


FIG. 109.—Lower face of Lagrange dam.

developing power for use in various industries about the prison, as well as for the transmission of power to other localities. A further purpose which the dam serves is the diversion of the American River out upon the plains of the Sacramento Valley for irrigation. As a masonry dam it is notable as being the only masonry weir of any considerable height or prominence in the Western States which is not arched upstream, and even this is curved in part where it joins the side wall of the canal, although across the main channel of the river it is straight. It serves no purpose of storage, but is designed solely for the diversion of the stream, and, like the Lagrange dam, is so constructed as to permit flood waters to pass freely over its crest. (See Pls. LXXIV, LXXV.)

It is located at the top of a natural fall in the bed rock of the stream, so that the downstream toe is 98 feet below the crest, and at the upper side it is 69.5 feet high. The thickness at the crest is 24 feet; at the base, 87 feet. A movable shutter, 180 feet long, is placed in the center of the dam, the crest of which is depressed 6 feet in depth below the general level for the passage of extreme floods, the shutter at such times being lowered and laid flat, while at low-water stage it is raised to a vertical position by means of hydraulic jacks, shown in fig. 110, operated from the power house at the prison. The entire crest length of the dam, including the curved approach to the canal head gates, is 520 feet. It is a most massive piece of masonry, composed of rough granite ashlar in large blocks, up to 10 tons or more in weight, laid in Portland-cement mortar. The stone was handled from the quarry at

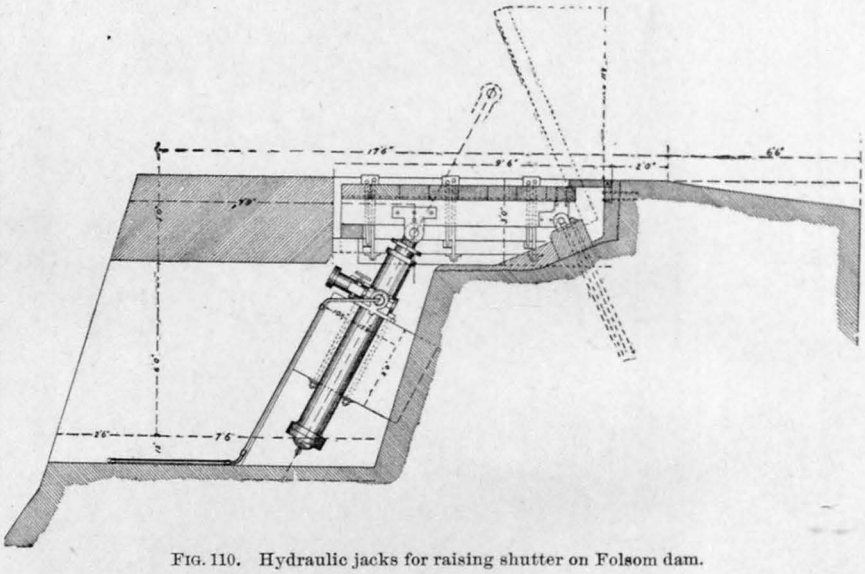
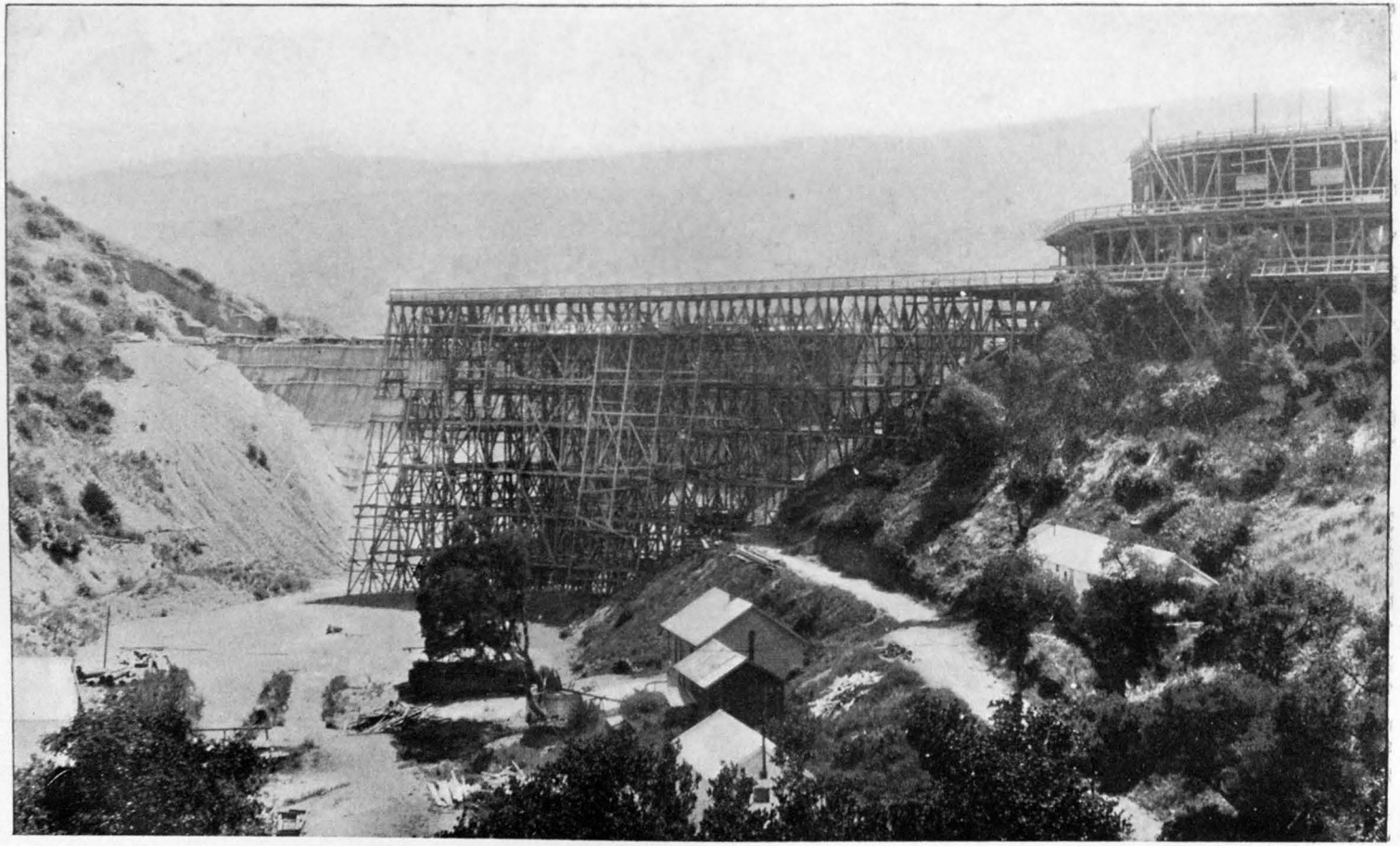


FIG. 110. Hydraulic jacks for raising shutter on Folsom dam.

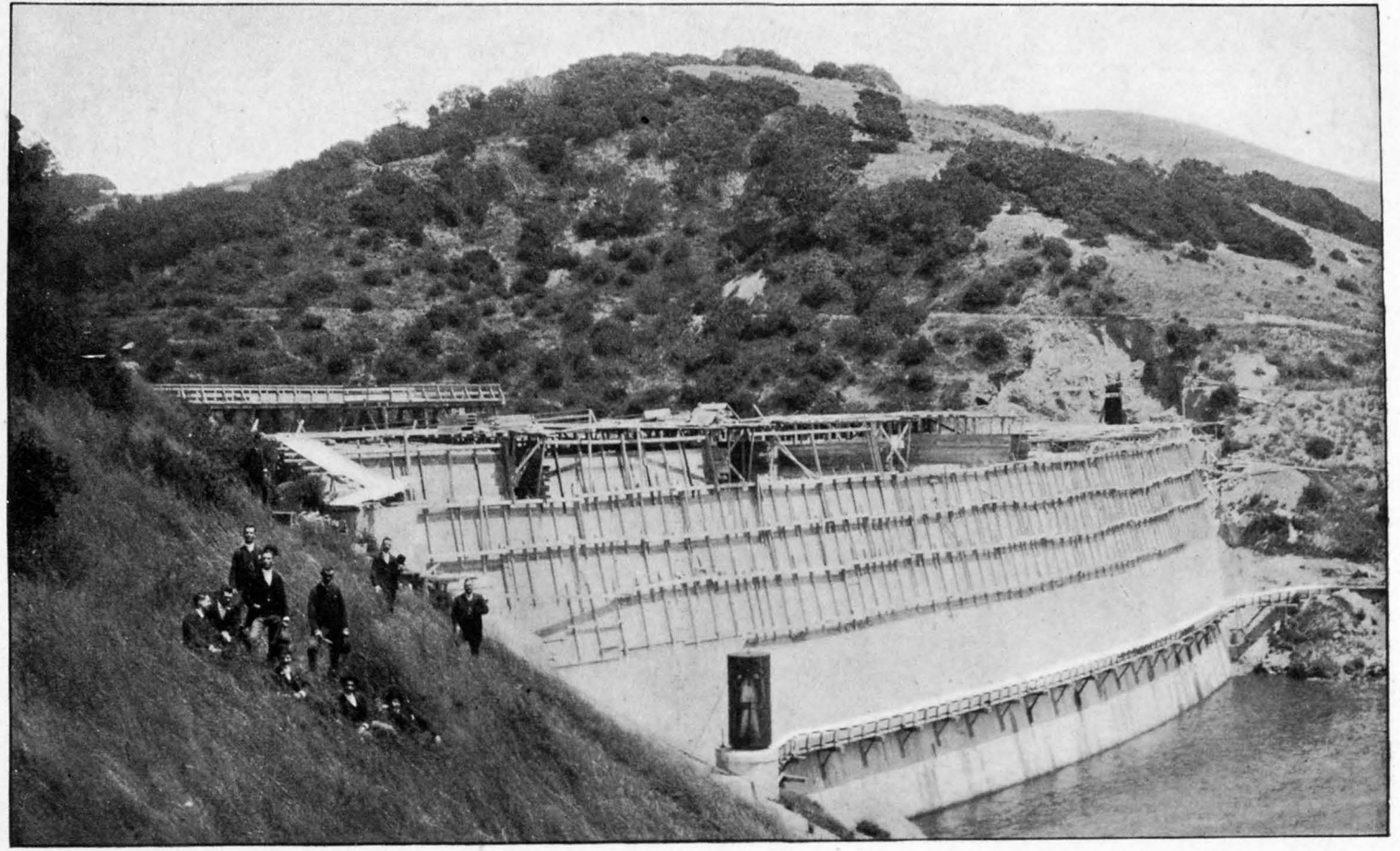
the head of the canal by a cable way of unusual construction, in that two cables were used side by side, like a suspended railway track, instead of one, as is ordinarily employed. The trolley was a 4-wheeled carriage, which carried the loads suspended from it and transported them to their destination. The canal leading from the dam on the left bank through the prison grounds passes through a power house, where a drop of 6 feet is utilized by turbine wheels for creating power.

## SAN MATEO DAM, CALIFORNIA.

Doubtless the most enormous mass of masonry in one solid body in the West, if not on the American Continent, is the great concrete dam erected in 1887 and 1888 near San Mateo, California, for the Spring Valley waterworks, supplying San Francisco. It also ranks among the highest and most costly dams in the world, being now 146 feet in height



PLANT FOR MIXING AND HANDLING CONCRETE AT SAN MATEO DAM.



CONSTRUCTION OF INTAKE OF SAN MATEO DAM.

and designed to be raised to a height of 170 feet when finally completed.[1] It has a thickness of 176 feet at the base, and is to be 25 feet thick on the crest when finished to the top, when the length will be 680 feet.

It is arched upstream with a radius of 637 feet, and is built throughout with artificial Portland-cement concrete. This material was chosen because of the difficulty of securing rock in the vicinity suitable for rubble masonry. The stone at hand was quarried in small irregular nodules, frequently coated with clay and serpentine, and requiring to be thoroughly washed before it was fit for use, even for concrete. After crushing, the stone was passed through revolving cylindrical tumblers, where it was washed by means of a constant stream of water, the tailings passing off through a flume and dropping to the stream channel below the dam, where the deposit was so great in amount as to cover several acres to a considerable depth, partly shown in Pl. LXXVI. The sand used was brought from San Francisco. It was loaded into cars at the sand dunes of North Beach, hauled a mile and dumped into barges, then towed 25 miles up the bay to a landing opposite San Mateo, and thence hauled in wagons 6 miles to the dam.

The concrete was mixed in a battery of six cubical iron mixing machines, revolved by steam power, and it was delivered to the work by a double-track tramway and small cars pushed by hand along a high trestle, built halfway across the canyon to the top level of the dam, as shown in Pl. LXXVII. Vertical iron pipes, 16 inches in diameter, were placed at intervals between the rails of the tracks, extending down to platforms placed from time to time at a level with the top of the work as it progressed, and the concrete was dropped down these pipes, striking on steel plates, from which it was shoveled into wheelbarrows and wheeled to the place of use. The height of this drop was sometimes as great as 120 feet, but no injury resulted to the concrete or to the men shoveling it as it fell.

The concrete was molded in huge blocks of 200 to 300 cubic yards each, with numerous offsets ingeniously dovetailing the blocks together, and every possible precaution was taken in the joining of the successive portions to secure an absolute bond and complete monolithic construction throughout. The result has been very satisfactory; the dam is almost absolutely water-tight, although some moisture does find its way through and appears in spots on the lower face. No settlement or expansion cracks are visible, and the work has the appearance of being absolutely homogeneous. Pls. LXXVIII and LXXIX show the general method of forming the blocks and preparing them to receive fresh concrete, and Pl. LXXX is a general view of the top of the dam as it is at present, taken at the time of the visit of the American Society of Civil Engineers in annual convention, July, 1896. Plans and sections of this dam are shown in Pl. LXXXI. The reservoir at the 170-foot level will

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, p. 320. Plans and cross sections on Pl. CXLIV.

have a capacity of 31,000,000,000 gallons, or 95,140 acre-feet. Even at its present height it submerges the old Crystal Springs reservoir and dam, the latter being an earthen embankment which did service for many years, located in the South Fork of San Mateo Creek; and in the North Fork of the stream a smaller reservoir, that formerly supplied the town of San Mateo, is obliterated from view, while the water extends nearly to the base of the San Andreas dam.

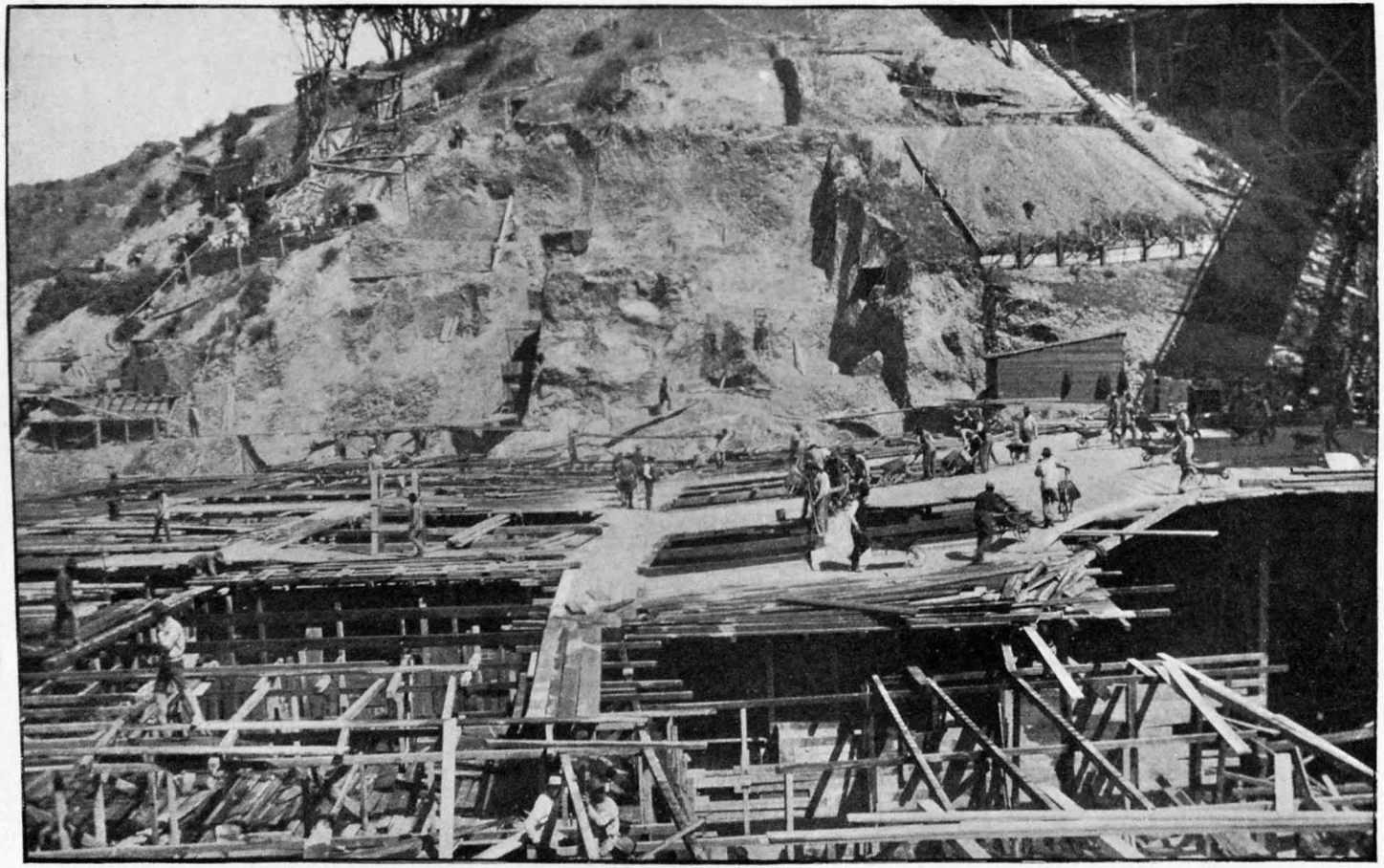
### RUN-OFF OF THE SPRING VALLEY WATERSHEDS.

The Crystal Springs reservoir had a watershed tributary to it of 14 square miles in area, and during the eight years from 1878 to 1886 it yielded a mean annual run-off of 0.44 second-foot, or 319 acre-feet, per square mile, as the result of a mean rainfall of 34.95 inches. This is equivalent to a mean of 14.4 per cent of the rainfall, the maximum being 34 per cent and the minimum 0.5 per cent. The Pilarcitos and San Andreas watersheds, adjoining, with an area of 12.5 square miles, but with a more direct exposure to the saturated wind currents from the ocean, recorded a mean annual precipitation of 47.41 inches during the same period, resulting in a mean yearly run-off of 1.18 second-feet, or 860 acre-feet, per square mile. This run-off is 34.2 per cent of the mean rainfall, the range being from 23 to 44 per cent. The maximum yearly run-off did not, however, occur in the years of greatest rainfall, although the minimum was naturally in seasons of least precipitation, which illustrates the variable nature of the relation between rainfall and run-off generally, and emphasizes the fact that when storms come gently, with intervals of dry weather between them, the percentage absorbed by the earth and evaporated is very much higher than when a series of soaking rains follow one another in quick succession, though the total precipitation of a season may be less in the latter case.

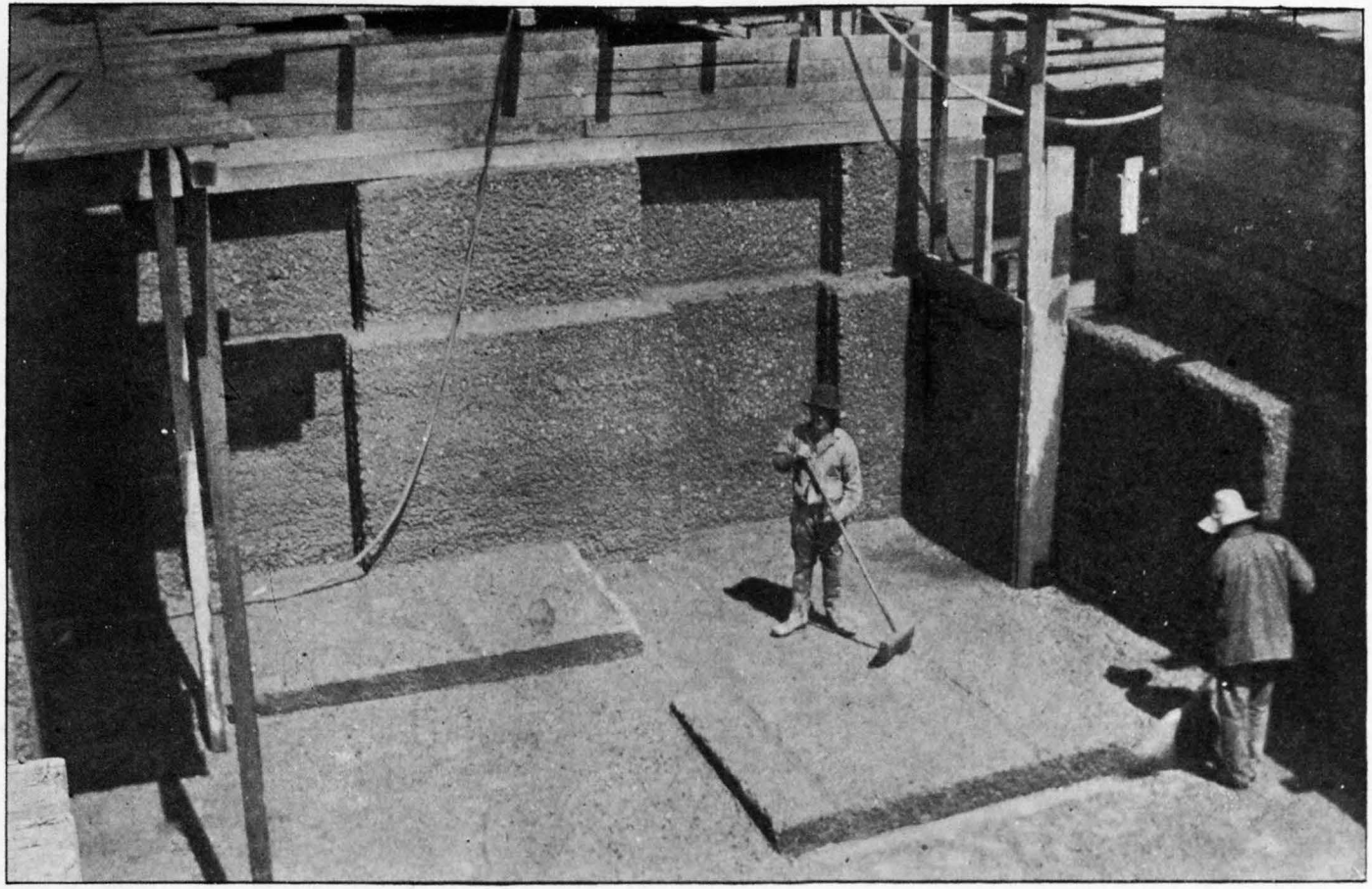
These watersheds are partially wooded, undulating, pasture lands, covered with deep soil and clothed with the native grasses of California that spring up annually from seed and have little sod. The result of the measured catchment from these areas indicates that, in general terms, on watersheds of this character, from 20 to 35 inches of rainfall is annually taken into the soil and absorbed in plant growth and evaporation. Pl. LXXXII is a diagram, called the "Newell Curve," expressing the relation between mean rainfall and mean run-off, as determined from the measurements of a large number of streams by the Geological Survey, upon which have been platted a number of actual measurements of run-off on California watersheds, and some others, which will be of convenience for general reference.

### LITTLE BEAR VALLEY DAM AND RESERVOIR, CALIFORNIA.

The Arrowhead Reservoir Company, of San Bernardino, has in process of construction a dam of large proportions which is to store water in a mountain valley at the headwaters of the Mojave River—water



MOLDS FOR CONCRETE BLOCKS, SAN MATEO DAM.



ROUGHENING SURFACE OF CONCRETE BLOCKS TO RECEIVE FRESH CEMENT, AT SAN MATEO DAM.

that now runs to waste and sinks in the desert, but which is to be diverted across the San Bernardino Mountains and utilized for irrigation in the San Bernardino Valley. (See Pl. LXXXIII.) This dam, of which the foundations only have been laid, is designed to be carried to a height of 175.5 feet above the bed of the stream at the dam site, or 160 feet above the bottom of the outlet tunnel, at which height the reservoir will impound 60,179 acre-feet of water. This will cover a surface area of 884 acres to a mean depth of 68 feet. The dam is intended to be a monolithic structure of Portland-cement concrete, arched upstream, and having a strong gravity profile of modern type.

The company has been at work on the main conduit leading from the reservoir since 1892, their efforts being directed chiefly to the opening of the principal tunnels on the line, of which there are a number. The longest of these is the outlet to the reservoir, 4,957 feet in length (exclusive of approaches), which was made necessary as an alternative to 10 or more miles of mountain-side canal, to round a long ridge. This has been completed, as well as two others, one 1,844, the other 1,792 feet long.

The total length of conduit required to turn the water over the summit of the mountain divide is 13 miles. Thence the vertical descent to the grade of the canal line skirting the upper slopes of the valley is 2,700 feet, which will permit of the development of great water power. Ten miles of canal and pipe, including the descent of the mountain, are needed to carry the water to the west side of Lytle Creek, where the main body of the lands to be irrigated will be reached, and these extend some 10 or 15 miles farther west. The main canal is planned to have a capacity of 6,000 miner's inches—120 second-feet—which is the amount the company believes it is certain to obtain and develop. To deliver this average flow for six months will draw from the reservoir 43,440 acre-feet. The determination of the volume of supply which can be safely sold from the system, and the resultant size of the conduits for carrying the same, have been the result of six years of continuous measurements of stream flow and precipitation. The company maintains 26 rain gages, located at different parts of their watersheds, and a number of self-registering devices for measuring the depth of overflow on their weirs. No such systematic and intelligent study of the probable available water supply from the catchment of flood run-off prior to the construction of works has ever before been attempted in the West, and such preliminary care can not but yield satisfactory results.

The area of the watershed directly tributary to the Little Bear Valley reservoir is but 6.6 square miles, and the entire area from which the supply of the system is to be derived is 77 square miles. This is all above 5,000 feet in altitude, on a mountain crest, and is among the most productive areas in southern California in run-off. The greatest precipitation and yield of stream flow comes from the drainage basin of

the Little Bear Valley, which in the period of observation has given a minimum of 600 and a maximum of 2,200 acre-feet of run-off per square mile per annum. An intercepting canal 13 miles in length, to gather the stream flow from 61.43 square miles of watershed lying east of Little Bear Valley and empty it into the main reservoir, is an essential part of the general system. This canal will have a capacity of 200 to 400 second-feet, increasing as it takes in each successive stream on its way.

Two other reservoirs are contemplated, one at Grass Valley, 4 miles west of Little Bear, elevation 5,108 feet, where a dam 175 feet high will give 27,547 acre-feet of capacity on a reservoir area of 382 acres; the other at Huston Flat, 5 miles west of Grass Valley, elevation 4,450 feet. The 175-foot contour at the latter site will give a capacity below

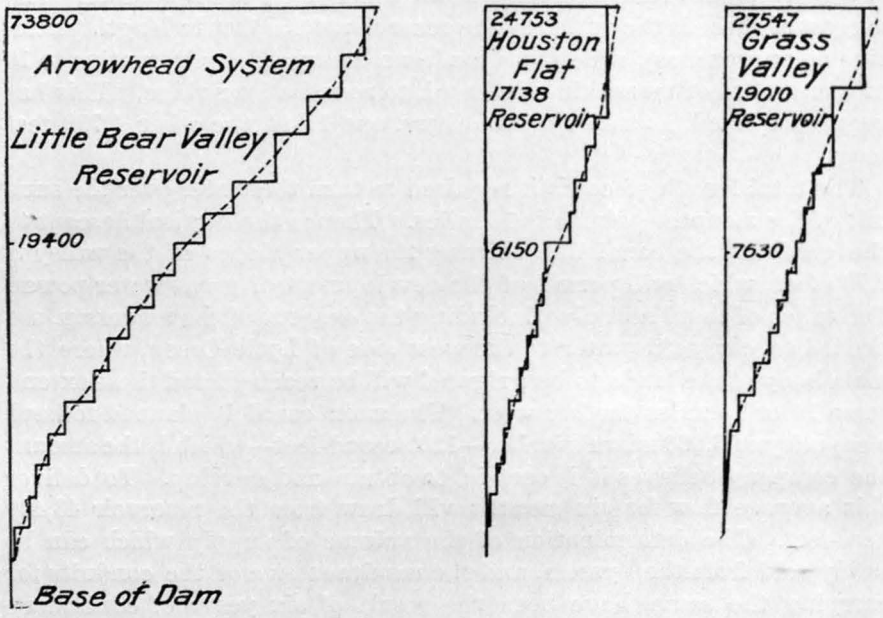
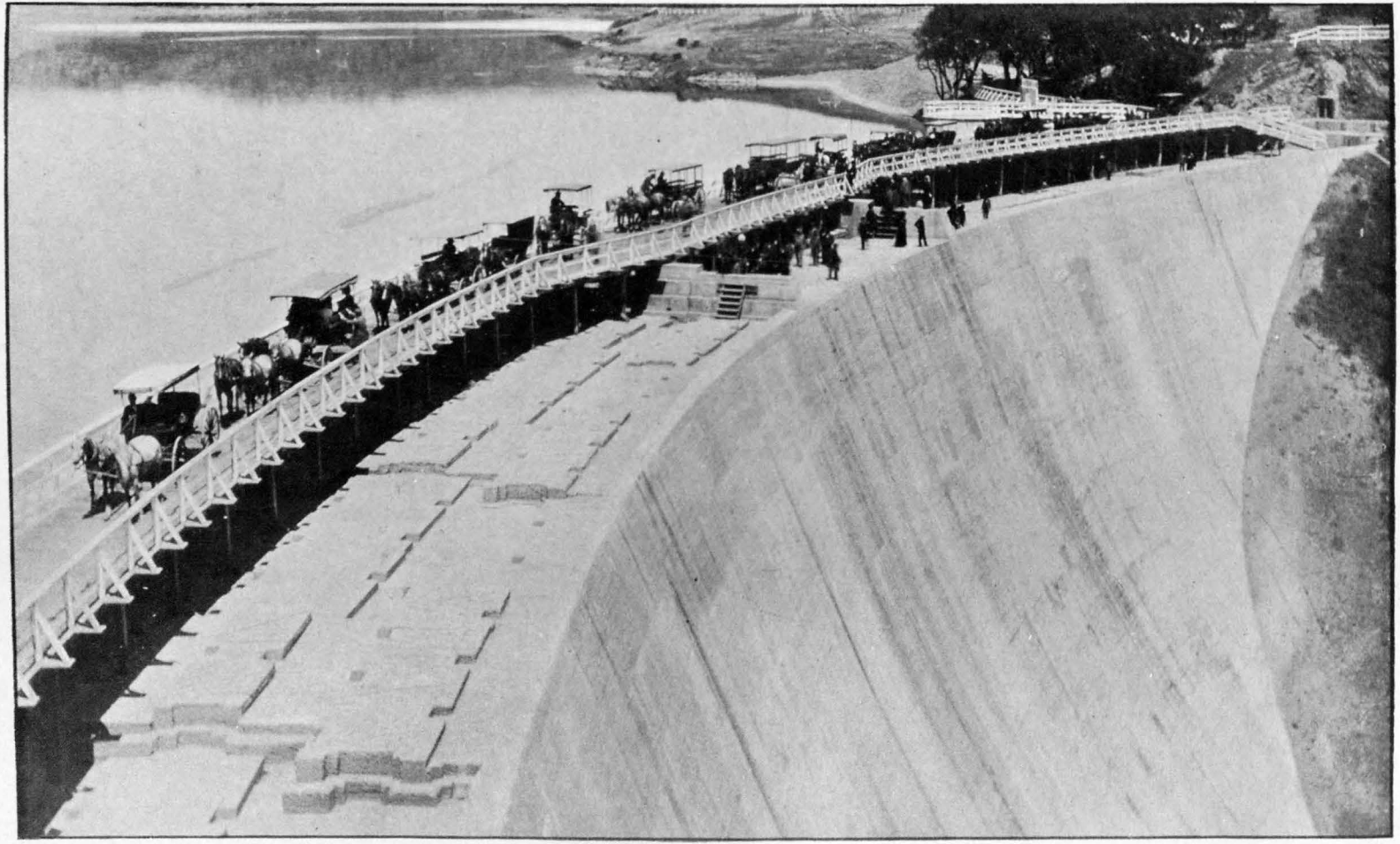
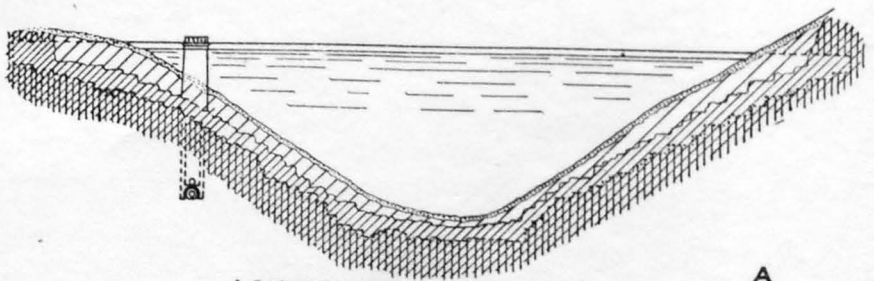



FIG. 111.—Comparison of contents of Little Bear Valley, Huston Flat, and Grass Valley reservoirs.

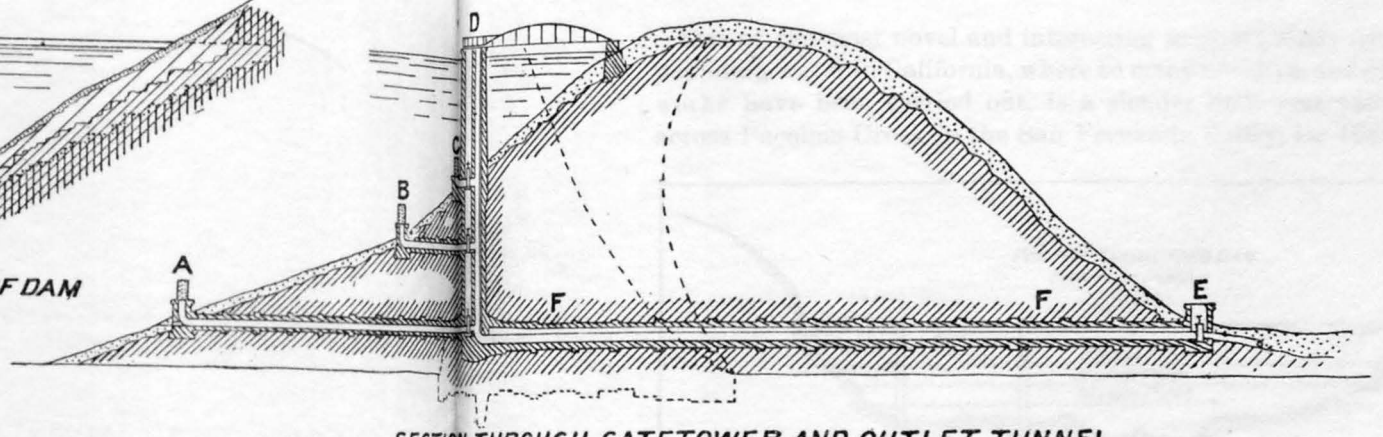
it of 24,753 acre-feet. This dam, being near the line of the conduit from Little Bear reservoir, which would pass the dam site at an elevation of nearly 300 feet above the 175-foot contour, could be built advantageously by the sluicing and hydraulic jet process, as an abundance of material for the purpose can be had conveniently on both sides of the canyon where the dam would be located. To utilize this reservoir will necessitate a tunnel outlet 5,900 feet long, and it has been proposed to make this tunnel a part of the main conduit, by which means 4½ miles of canal would be saved, the cost of which would be about 60 per cent of the cost of the tunnel. These plans are, however, still somewhat indeterminate. The cost of the entire system, not including the Huston Flat reservoir dam and outlet, is estimated in round numbers at $1,600,000.



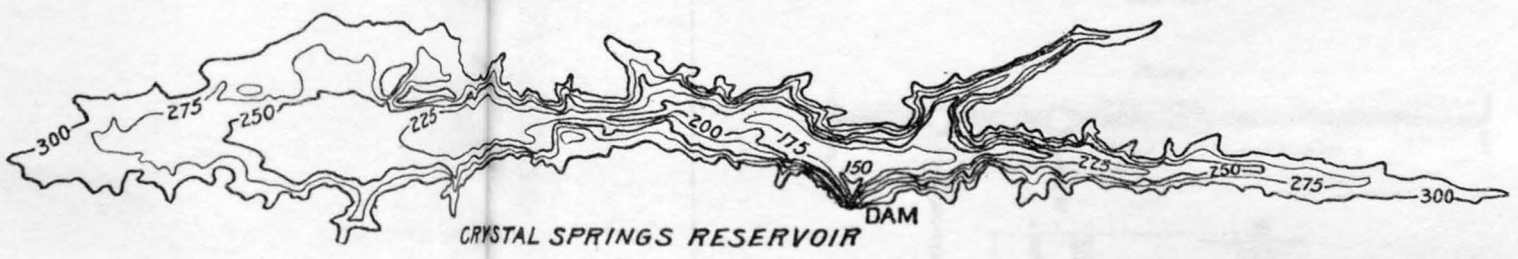
SAN MATEO DAM BEING INSPECTED BY AMERICAN SOCIETY OF CIVIL ENGINEERS IN JULY, 1896.



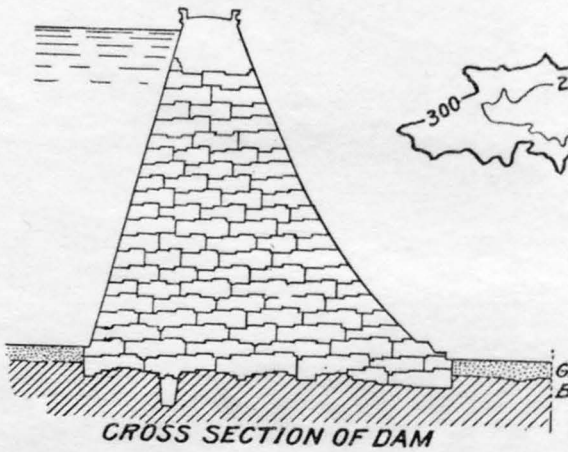
LONGITUDINAL SECTION OF DAM




SECTION THROUGH GATETOWER AND OUTLET TUNNEL

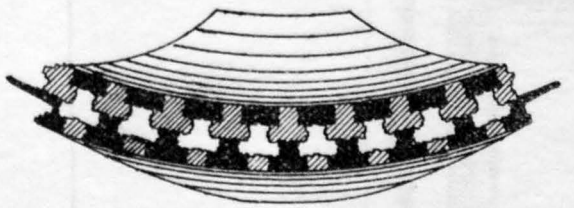



CRYSTAL SPRINGS RESERVOIR

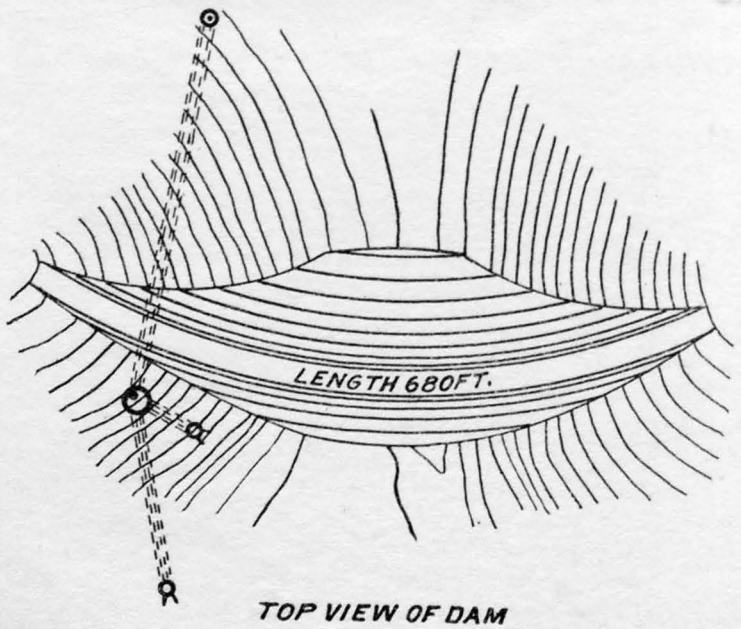



CROSS SECTION OF DAM

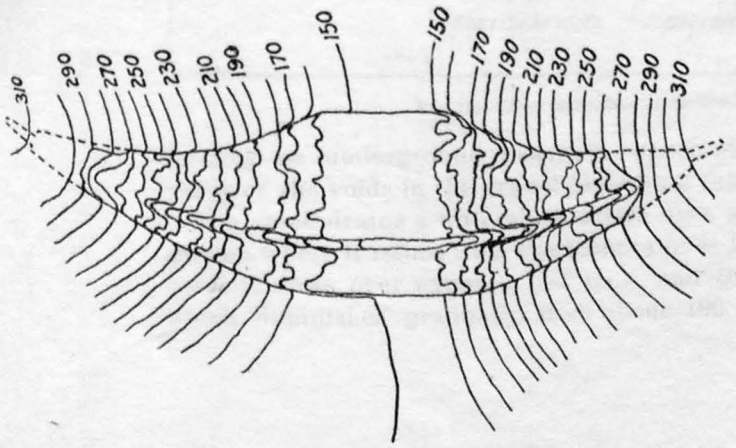
OUTLET TUNNEL F-F



PLAN SHOWING LAYER OF CONCRETE BLOCKS

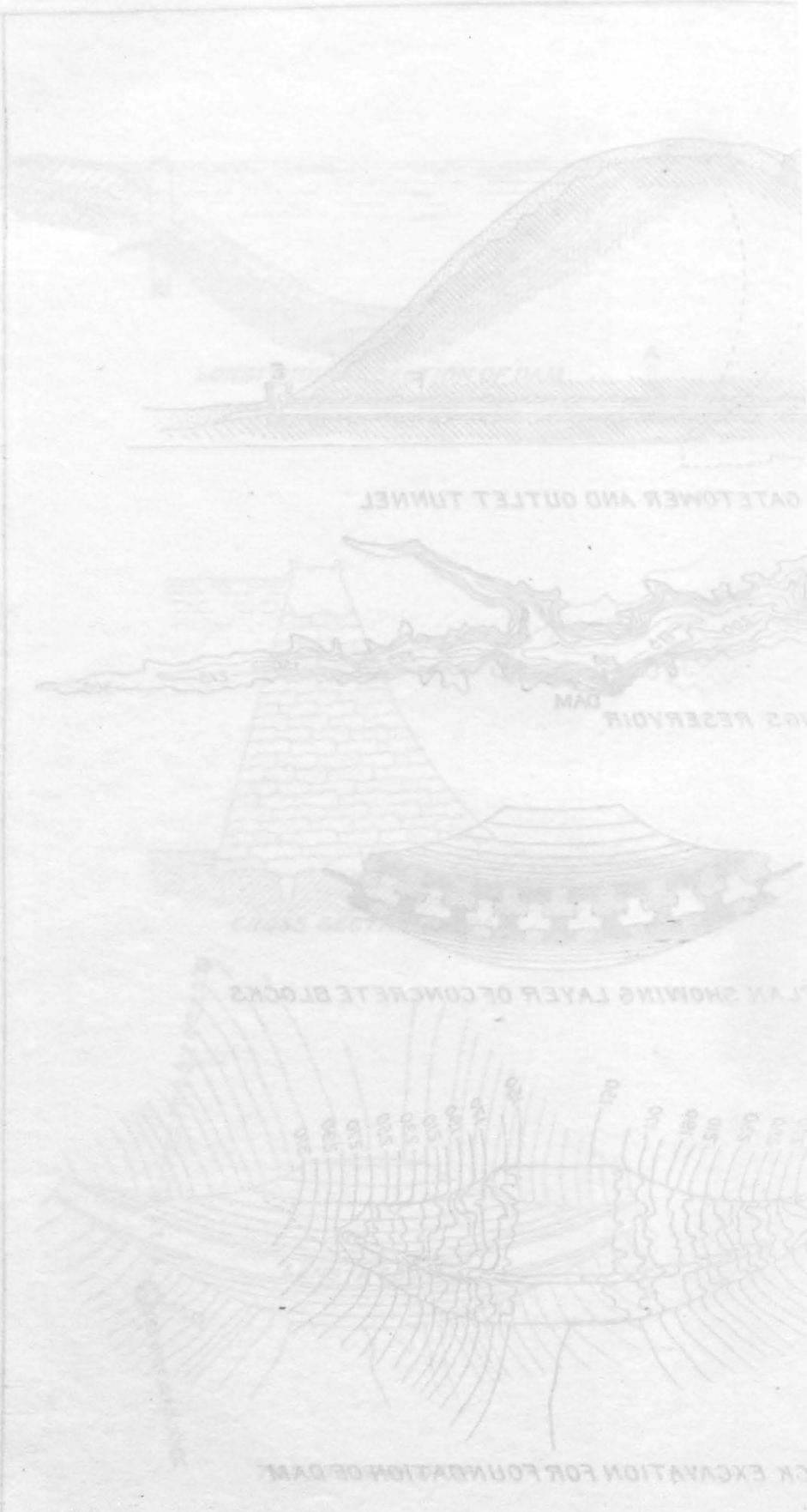



TOP VIEW OF DAM




ROCK EXCAVATION FOR FOUNDATION OF DAM

PLANS AND SECTIONS OF SAN MATEO DAM AND MAP OF CRYSTAL SPRINGS RESERVOIR.



## PACOIMA DAM, CALIFORNIA.

One of the most novel and interesting masonry dams erected for impounding water in California, where so many novelties and experimental works have been carried out, is a slender little reservoir wall built across Pacoima Creek in the San Fernando Valley, for the purpose of

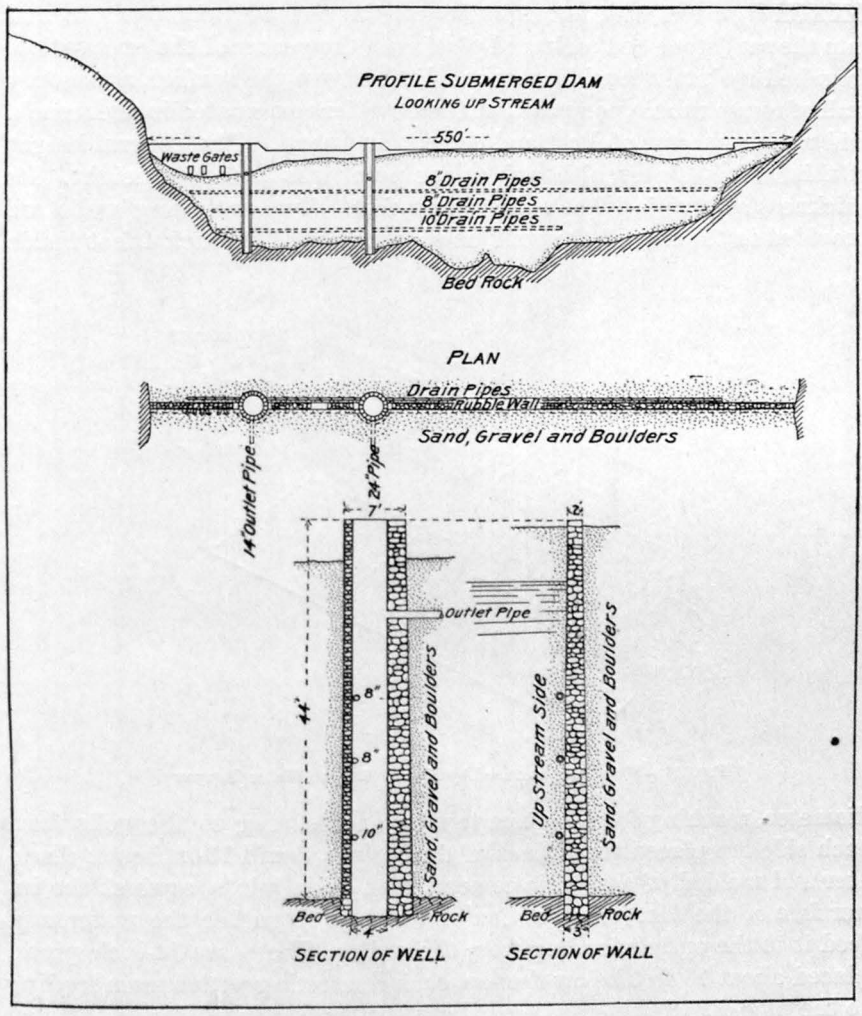



FIG. 112.—Plan and profile of Pacoima dam.

forming an underground reservoir, whose storage capacity consists solely of the voids in the gravel bed filling the valley of the stream.

The creek drains a watershed whose area above the mouth of the canyon where it issues from the mountains is 17 square miles. At this point it flows over exposed bed rock, and the normal summer flow, which diminishes gradually from about 100 to 15 miner's inches, is

entirely diverted by a pipe line and used for irrigation in the valley below. The dam is located 2½ miles below the head of this pipe, at a point where the valley is contracted by a ledge of sandstone to a width of 550 feet, the ledge crossing the channel about at right angles. Between the dam and the mouth of the canyon is a continuous bed of gravel, in places more than half a mile in width, which constitutes the reservoir. The dam was constructed by excavating a trench (Pl. LXXXIV), 6 feet wide, straight across the channel and down to and into the sandstone bed rock, and placing in the center of the excavation, from bed rock to a level line at or a little above the surface, a masonry wall of rough rubble, composed of the bowlders excavated in the trench, laid up in a mortar of Portland cement and sand. The general height of this wall is 40 feet, although at one point it is 52 feet in height. Its thickness at base is 3 feet and at top 2 feet. Two gathering wells are provided in the line of the wall, as shown in fig. 112, each 4 feet inside

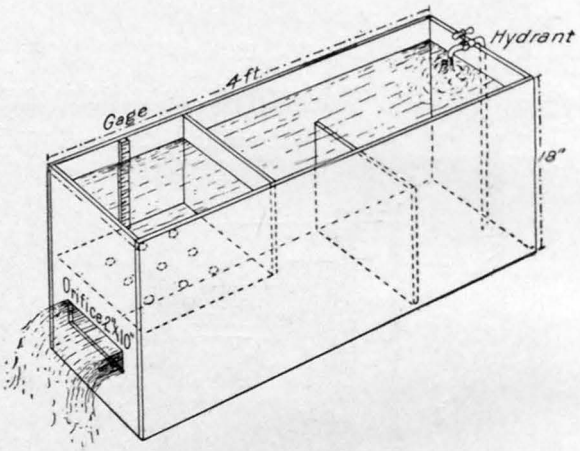
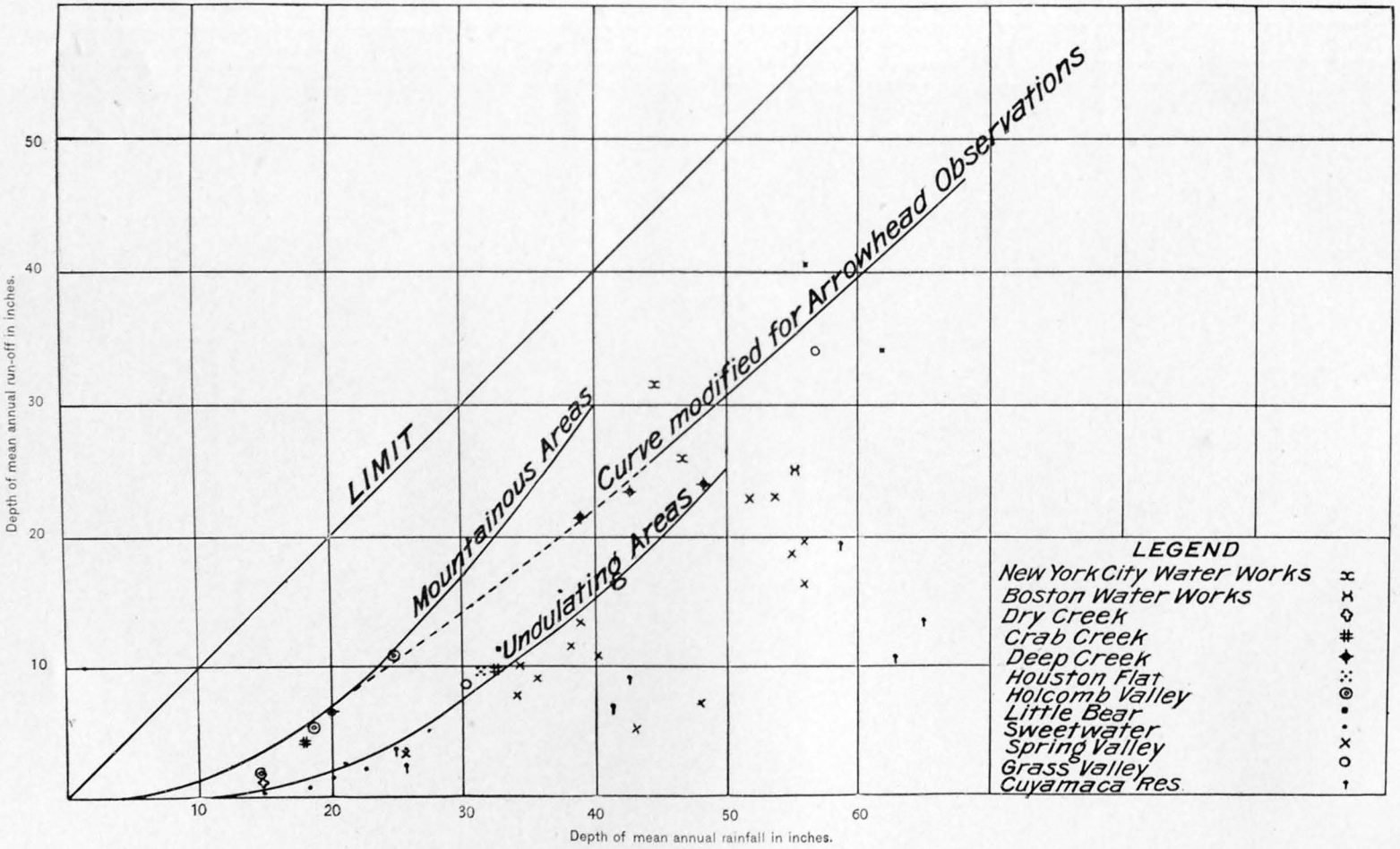


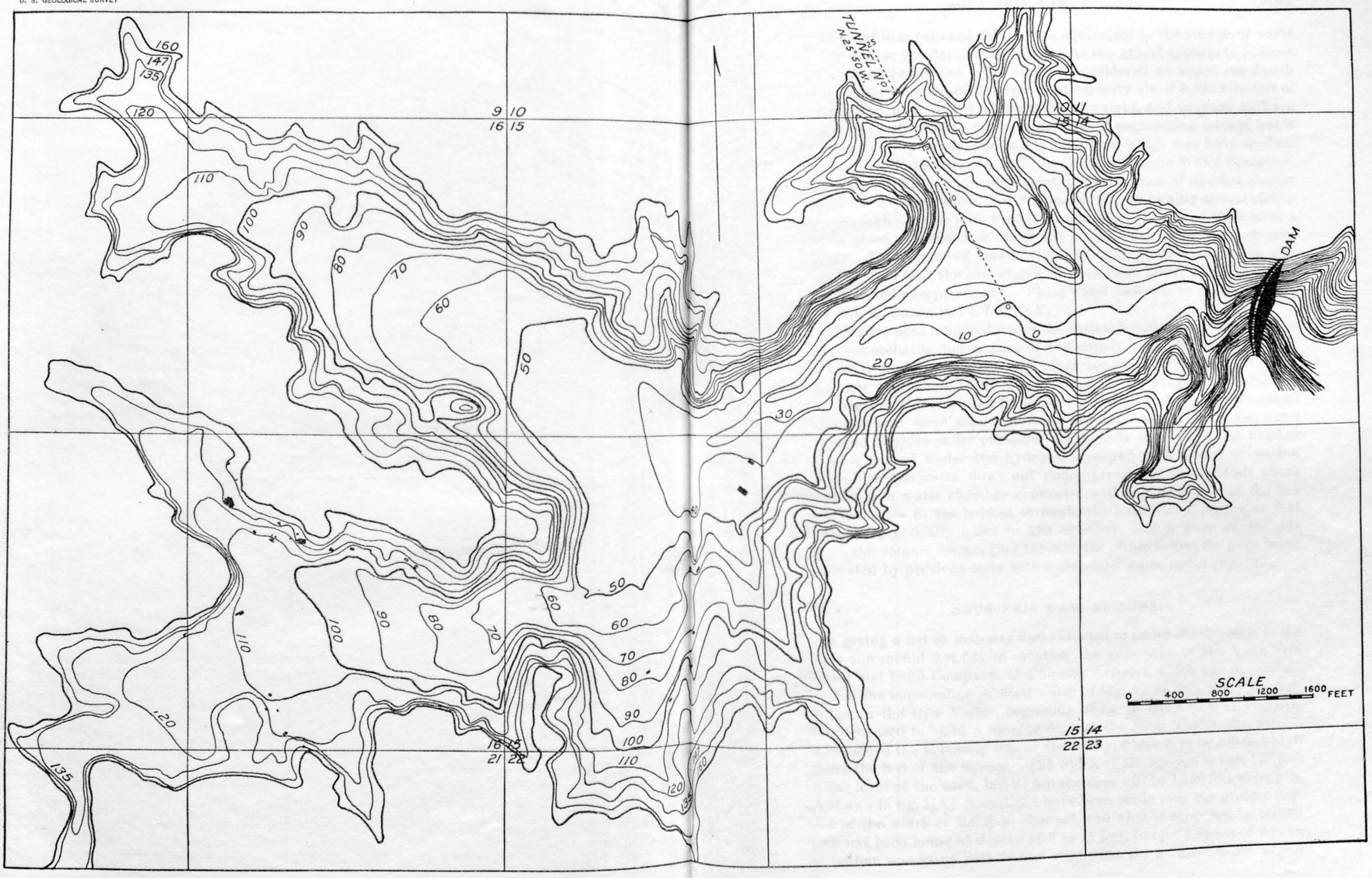

FIG. 113.—Measuring box used by Maclay Rancho Water Company.

diameter, reaching from bottom to top; and leading to the wells from each side are placed three lines of drainpipes, 8 and 10 inches in diameter and molded of asphaltic cement, with open joints, against the inner face of the dam, the function of which is to gather the water and feed it to the outlets leading from the wells. These are 14-inch pipes, placed about 13 feet below the top, each connecting with a main leading to the pipe-distributing system supplying the irrigated lands. When the reservoir is drained down to the level of these outlets, further draft from the reservoir is made by pumping, which is carried on for about one hundred days during the summer and fall.

The dimensions and capacity of this novel reservoir have not been definitely determined, but in round numbers it covers an area of 300 acres and has a mean depth of 15 to 20 feet, and, although it lies on a slope of 100 feet per mile, the water passes down through the gravel so




THE NEWELL CURVE.




MAP OF LITTLE BEAR VALLEY RESERVOIR.

slowly that it is believed the yield is equivalent to the volume of voids in this area to the depth mentioned. As the gravel appears to be loose and rather coarse, the voids may be considered as about one-fourth of the entire volume, and the resultant capacity about 1,300 acre-feet of water. The dam is not absolutely water-tight, and appears to have been a piece of amateur work, built without engineering advice, but it serves a useful purpose, and is a type of dam which may have application to other localities. In fact, the Maclay Rancho Water Company, the owner of this dam, is contemplating the erection of another similar one on the Tejunga wash, 2 or 3 miles south, in a locality almost identical, although a longer dam would be required. The cost of the Pacoima dam is given at $50,000, or about $38 per acre-foot of probable storage behind. The volume of masonry is only about 2,000 cubic yards, and it would seem that the cost stated is somewhat large, as all materials were at hand except cement. Flood water passes over the dam unobstructed, as shown in Pl. LXXXV.

The entire area irrigated under the system is 900 acres, chiefly orange and olive orchards, but a part of the supply, possibly 40 per cent, is derived from artesian wells and other sources. The irrigation water rates are equivalent to $9 per acre-foot, or 3 cents per 1,000 gallons. The measuring device used for apportioning the water to the irrigators is simple and more than ordinarily accurate as a module for water delivered in pipes under pressure. It consists of a box, either fixed or portable, placed under the hydrant, arranged with a slot at one end from which the water flows out under pressure. Immediately above the slot is a water chamber connected with the main part of the box by a few holes in the bottom through which the water passes, so that it stands practically quiet in the chamber, and a gage on its side shows the volume discharging through the orifice below, the gage being graduated by previous tests with a standard water meter (fig. 113).

## AGUA FRIA DAM, ARIZONA.

In giving a list of masonry dams erected or under construction in the West one should not fail to mention the enterprise of the Agua Fria Water and Land Company, of Phœnix, Arizona, which has in contemplation the impounding of flood water of the Agua Fria River for irrigation in the Gila Valley, beginning some 20 miles west of Phœnix. It is proposed to build a storage dam at the Frog Tanks site, some 3 miles above the northerly line of the valley, which is to be 120 feet high above the bed of the stream. The width of the canyon is here 298 feet at the level of the sand, but at top the dam will be 1,160 feet in length, as shown in fig. 114. Soundings have been made over the greater portion of the width of the river channel, and what is supposed to be bed rock has been found at depths of 9 to 15 feet, but for a space of 50 feet no bottom was found with 24-foot rods. As the greatest depth to bed

rock at the diverting dam below was found to be but 40 feet, this depth has been assumed for the maximum of the unexplored 50 feet at the upper site, thus making the maximum height 160 feet from lowest foundations.

The reservoir closed by this dam will be 5 miles in length and will cover an area of 3,200 acres, impounding 108,000 acre-feet. With a gravity profile of dam having a breadth of 124 feet at base and a top width of 8 feet, the volume of masonry required is computed at 128,650 cubic yards. The enterprise is designed for the irrigation of 50,000 acres of land in the valley to the northwest of the contiguous territory irrigated under the canals of the Arizona Improvement Company, and for that purpose a main canal 25 miles long, with a capacity of 300

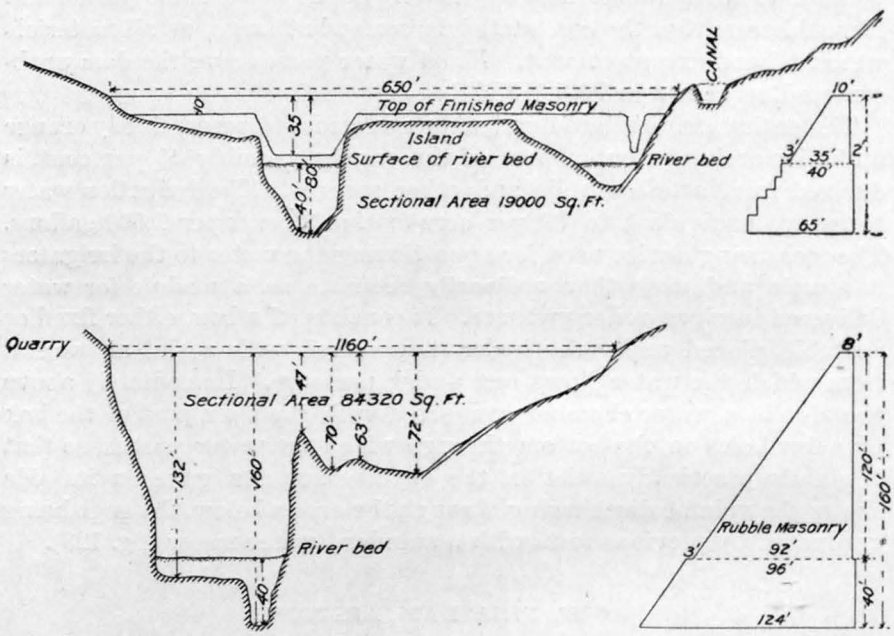
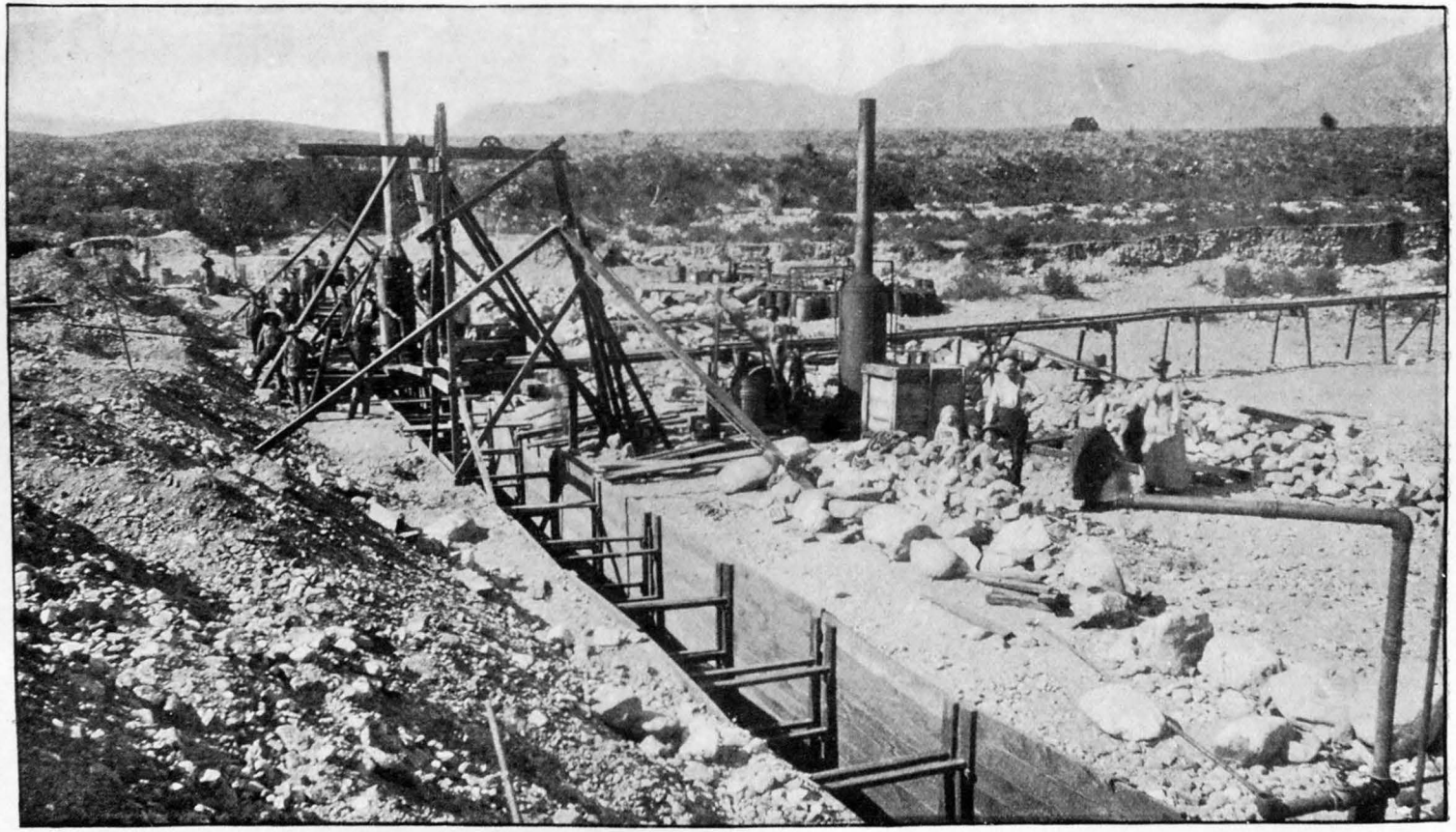



FIG. 114.—Cross sections of Agua Fria diverting dam and storage reservoir dam, Arizona.

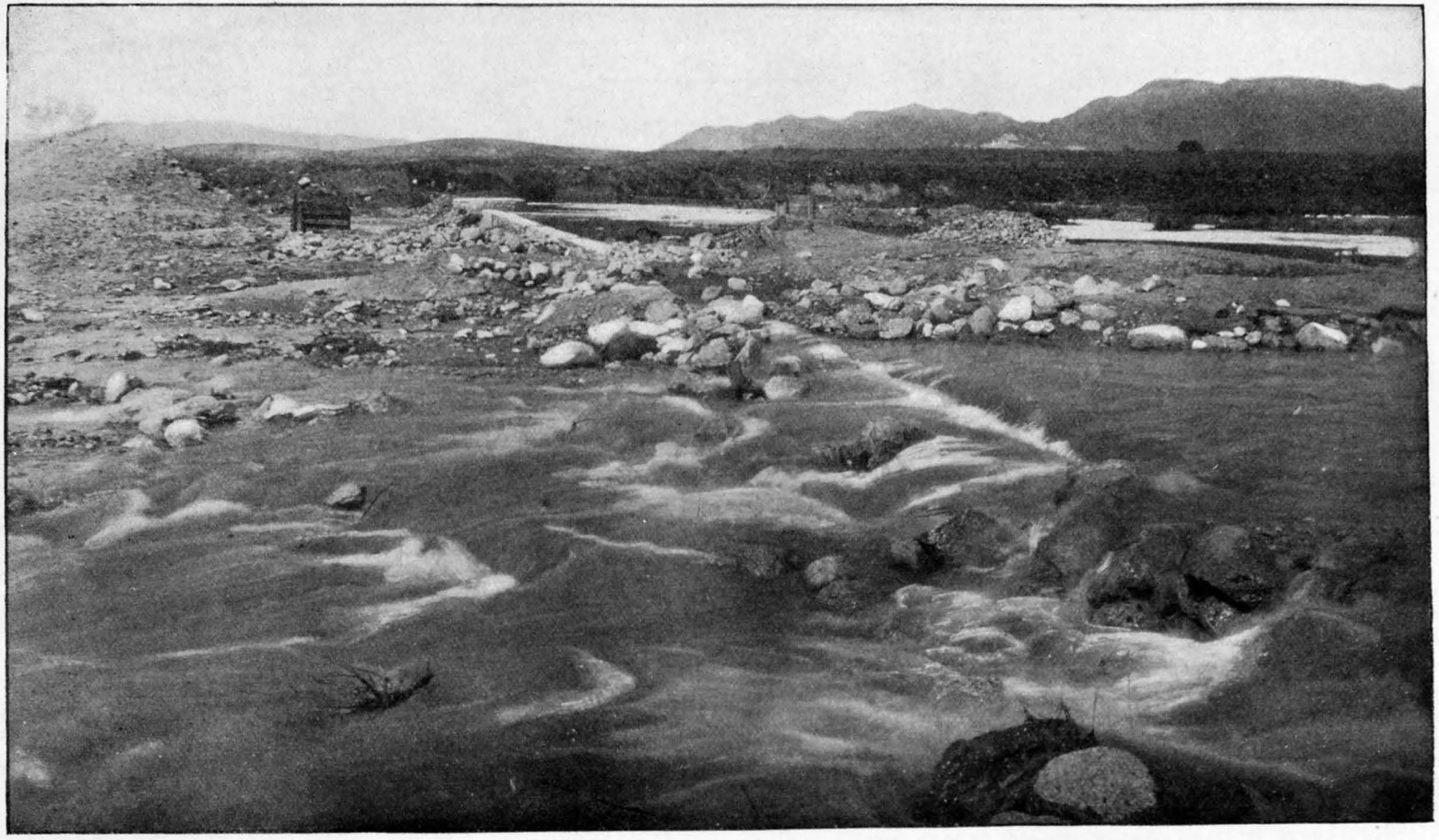
second-feet, is required. It was decided at the outset to begin this canal 1¼ miles below the reservoir, and at this point to erect a pick-up weir of masonry, upon which about $100,000 had been expended at the time work was suspended, in the fall of 1895. This work has been done on the lines of the sections, fig. 114, and is well along toward completion, as shown in Pl. XXV (p. 70) of the report on Irrigation near Phœnix, Arizona, by Arthur P. Davis.[1]

The maximum height of this weir when completed will be 80 feet, and its length on top 640 feet. It has a base of 65 feet, and will be 10 feet wide on top. When finished it will contain 17,200 cubic yards of masonry, and will have cost in the neighborhood of $150,000—a

[1] Water-Supply Paper No. 2, U. S. Geol. Survey, 1897.



EXCAVATION OF TRENCH FOR PACOIMA SUBTERRANEAN DAM.



VIEW OF FLOOD PASSING OVER PACOIMA SUBTERRANEAN DAM.

very large outlay for a work whose only function is to save 1¼ miles of conduit, extending up the canyon to the storage dam proper, which dam must be built before the scheme is of any value. The reasons which led to this error in judgment were, first, a misapprehension as to the depth to bed rock at the lower site, where the construction was apparently a simple and inexpensive work, and a considerable expenditure had been made before the extreme depth to bed rock that was finally reached was known or suspected, when it was too late to abandon the work; and, second, the confident expectation that the amount of underflow that would be thrown to the surface by the dam would reach from "500 to 1,000 miner's inches," which, if realized, would have enabled the management to use the canal at once in the reclamation of the desert land entered under the United States desert-land act, before the reservoir could be made available. This "underflow" development was a sore disappointment, as the flow, when finally secured, amounted to less than 15 miner's inches. The cross-sectional area of the two channels in which the underflow was passing beneath the surface is approximately as follows:

| | Square feet. |
|---|---|
| East channel | 504 |
| West channel | 2,635 |
| Total | 3,139 |

If the voids in the coarse sand with which the channels are filled be assumed to be 28 per cent of the entire area, which they are approximately, the rate of flow established by the discharge of 15 inches (0.3 second-foot) would be precisely 1 mile per annum, a velocity which coincides with the observations of several authorities on the rate of flow through sand.

The character of masonry used in the diverting dam is a rough rubble, faced with coursed ashlar, laid in a mortar of hydraulic lime of good quality, manufactured about 20 miles distant. (See Pl. LXXXVI.) For a portion of the work a small amount of cement made in Colton, California, was used. The rock was handled by a Lidgerwood cable way with a span of 700 feet. The excavation of foundations, amounting to about 12,000 cubic yards, was accomplished by teams and scrapers, the water being handled by centrifugal pumps kept constantly running. The large amount of water thrown by the pumps may have led to the extravagant estimates of underflow, but as the discharge from the pumps was led but a short distance below the dam a considerable part of it returned through the sand to the pump pit.

The area of watershed tributary to the Frog Tanks reservoir is approximately 1,400 square miles, extending north and east of Prescott and draining the east slopes of the Bradshaw Mountains, whose summit elevations reach 6,000 to 8,000 feet. With a mean annual precipitation of 16 inches and a run-off of 15 per cent of the precipitation, the flow of the stream would fill a reservoir of twice the capacity of the one proposed.

A second site, 9 miles above the Frog Tanks dam, has been selected by the company for future utilization of the waste water of this stream.

### CONCRETE DAMS OF THE PORTLAND, OREGON, WATERWORKS.

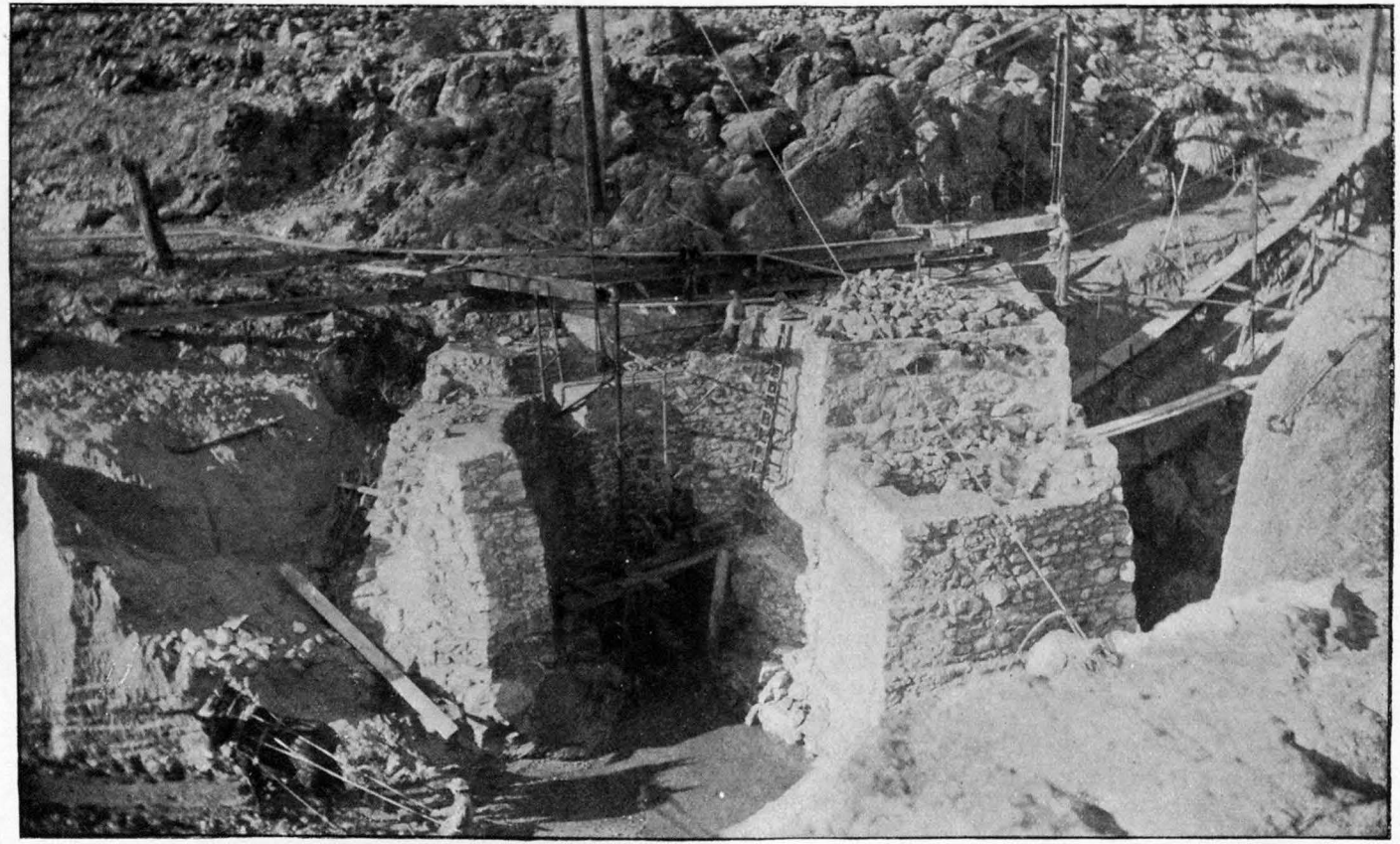
Among recent constructions of concrete masonry the most notable are three dams erected in 1894 for the formation of distributing reservoirs in the system of waterworks supplying the city of Portland, Oregon. They are thrown across ravines and natural depressions, or embayments, in the hills, which were excavated behind the dams to true lines and slopes and covered with a concrete lining for water-tightness, and to preserve the slopes. One of the dams (Pl. LXXXVII), which closes reservoir No. 1 on the side of Mount Tabor, is 35 feet high and 300 feet long, and impounds 12,000,000 gallons of water. Its base is 18 feet wide, top width 6 feet, and behind it is a heavy embankment of earth and gravel excavated from the interior of the reservoir, having a top width of 100 feet. This is such an immovable barrier that the chief function of the concrete wall is as a retaining wall for the inner slope of the embankment. Reservoir No. 3 has a dam 200 feet long, which is arched upstream against the water pressure with a radius of 300 feet. The height of this dam is 60 feet; it is 40 feet wide at base and 15.5 feet at top, where it carries a driveway of the City Park, in which it is located. This dam is the only one of the three which is curved, and the only one which does not exhibit some slight expansion cracks. The dam to reservoir No. 4, low service, which impounds 17,700,000 gallons when full, is 50 feet high, 350 feet long, and 40 feet wide at base. The faces of these dams (Nos. 3 and 4 in the City Park, Pls. LXXXVII and LXXXVIII) are molded and chiseled to resemble stone, and considerable ornamentation has been done on the parapets and about the gatehouses, to which the concrete and iron construction lends itself to good advantage.

## EARTHEN DAMS.

### CUYAMACA DAM, CALIFORNIA.

In the foregoing pages a full description has been given of La Mesa hydraulic dam, built by the San Diego Flume Company, and of the other constructions of the same type that have been projected by the same company for adding to the general storage supply; and under the heading of earthen dams of a different type from any heretofore described, attention should be called to the Cuyamaca reservoir, which for nine years has been the main source of domestic water supply for the city of San Diego and the chief reliance for the irrigation of the mesa lands traversed by the flume. The entire system of storage and distribution has been described by Mr. H. M. Wilson.[1] Since the pub-

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, p. 184.



FOUNDATIONS OF WEST CHANNEL OF AGUA FRIA DIVERTING DAM

INNER FACE OF CONCRETE DAM AT PORTLAND, OREGON.

lication of that paper the dam has been increased in height from 35 to 41.5 feet, at a cost of $3,400. This needed addition has increased the capacity of the reservoir to 11,410 acre-feet, covering an area of 959 acres to a mean depth of nearly 12 feet. Two spillways, of 41 and 90 feet width, have been excavated at either end of the dam, the floors of which are at the 35-foot contour.

Referring to the table (p. 674) of precipitation and catchment on the watershed of this reservoir, the resident engineer, Mr. F. S. Hyde, explains that as the rain gage is located at the dam between two high, wooded peaks, which act as condensers of the moisture-laden clouds, the recorded precipitation is undoubtedly far heavier than the average of the watershed, which a few miles east of the dam borders on the desert, where the rainfall is known to be much less. The correctness of this opinion is borne out by comparing the results of actual catchment with the "Newell Curve" of run-off, which would indicate that if the precipitation given were a mean of the entire area the yield should be very much greater—from two to three times as great. This Cuyamaca record of rainfall is frequently, but erroneously, used as a criterion for the general precipitation of the mountain region of San Diego County, although in reality it probably represents a maximum applicable only to the highest areas and those most directly exposed to the direction of the saturated wind currents flowing in from the ocean. The mean run-off of this watershed, as well as the mean rate of evaporation as actually measured at the reservoir, is a matter of more general interest and value than the precipitation, unless the observations of the latter were taken so generally over the drainage basin as to be fairly representative of the mean rainfall; for the reason that much of that mountain region, which is to be more largely drawn upon in future for the water supply of a large area of highly fertile lands, may be expected to yield even a larger average run off than the mean of the Cuyamaca of 500 acre-feet per square mile, the minimum being 200 and the maximum 1,000. These figures give better data for estimates of run-off on adjacent watersheds of similar character than any possible collection of rainfall statistics without such empirical knowledge of actual yield in stream flow produced by any given rainfall.

Cuyamaca reservoir does not afford the entire supply of the Flume Company's system, as it is not drawn upon during the winter and early spring until the regular flow of San Diego River at the pick-up weir is so diminished as to require it. This may often be as late as April or May, consequently the effective duty of the stored water can not well be determined for this dam, as it can be for the Sweetwater dam. The annual draft from the reservoir since its construction in 1887 has been from 2,853 to 6,327 acre-feet—a mean of 4,331—while the mean run-off has been 5,397 acre-feet. The difference between these figures, or 1,066 acre-feet, represents the mean annual evaporation, or 19.75 per cent.

The area irrigated by the system is not definitely known, but is estimated at 5,700 acres, the basis for the estimate being the amount of water sold and delivered to irrigators, which has reached a total of 380 miner's inches. Part of this is used at the rate of 1 inch to 10 acres and part at the rate of 1 inch to 20 acres, the mean of 15 multiplied by 380 inches delivered and used giving 5,700 acres as the total irrigated. A constant flow of 380 inches for one year would amount to 5,500 acre-feet, or 0.965 acre foot per acre. This is only about 60 per cent of the water used per acre under the Sweetwater system, an economy which is doubtless due to the exactness with which the irrigators are restricted to the allowance called for by their contracts. These water-right contracts permit a continuous flow to be drawn throughout the year, and if a man buys an inch of water it is supposed to flow in perpetuity, so long as the rentals are paid semiannually. Each irrigator (with few exceptions) has a small reservoir of 10,000 to 150,000 gallons capacity into which his quota is allowed to run when he is not actually irrigating.

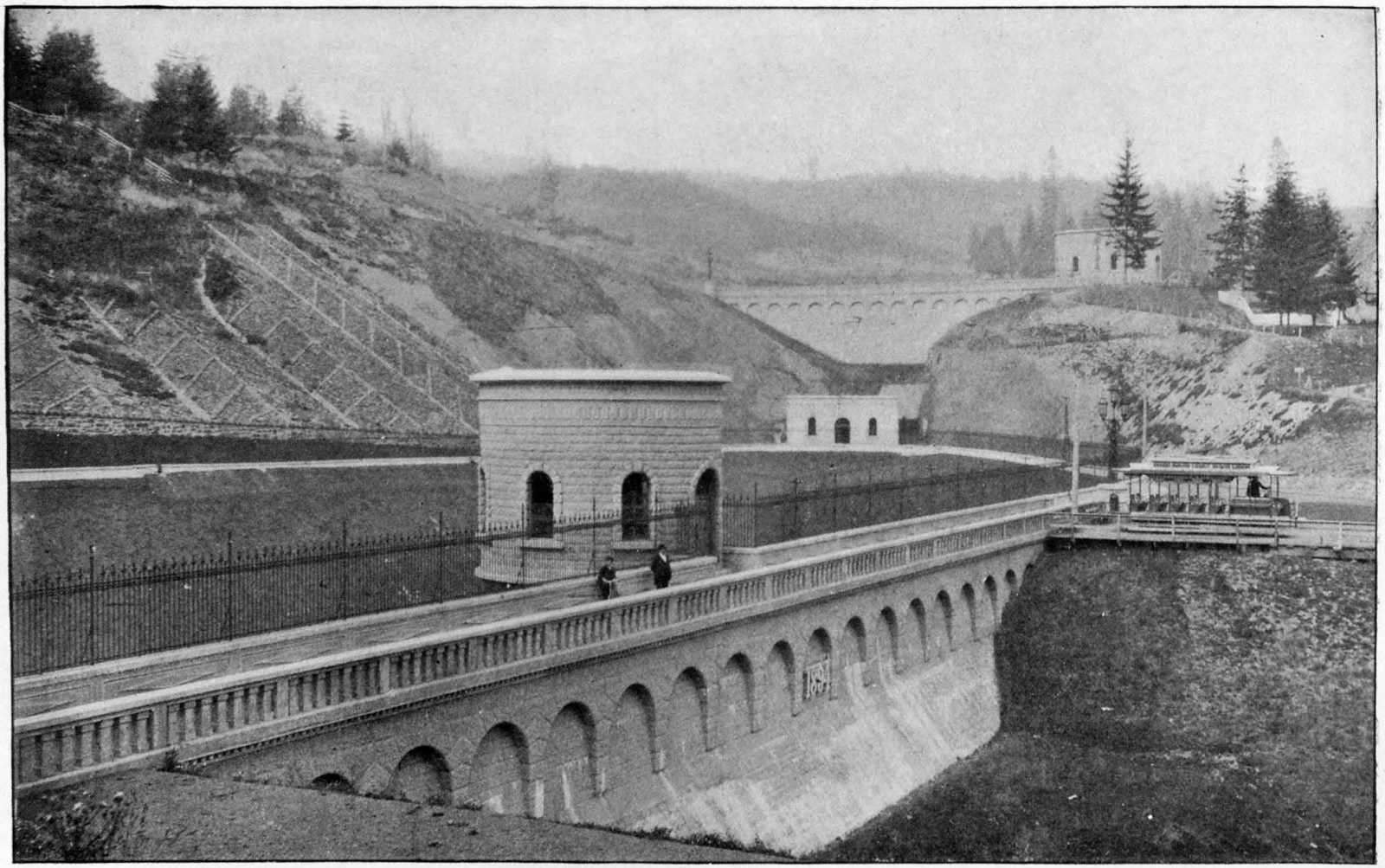
The water rights are sold at $600 per inch for water taken directly from the flume line, and $800 per inch if delivered in pipes beyond the reach of the flume or from the 15-inch conduit leading from the end of the flume to the city. Some of the rights carry an annual rental of $30 per inch, which applies to some of the earliest rights disposed of during construction, but the majority of the rights sold have a rental of $60 annually, and a few pay as high as $120 per inch. The inch is specified as 1,728 cubic feet flow in twenty-four hours. Where water rights are not sold the annual rates for water furnished are 10 cents per 1,000 gallons in the country, and for all water furnished to the San Diego Water Company for city consumption a rate of 5 cents per 1,000 gallons is collected. The latter company charges 6 cents per 1,000 gallons for irrigation on tracts exceeding 2 acres.

The annual cost of maintenance of the Cuyamaca reservoir is about $600 per annum, including watchman's salary, and the cost of maintaining the 37 miles of main flume is stated as $2,700 per annum. The amount of water supplied to the city of San Diego in 1896 averaged 144 miner's inches, of which 96 inches was supplied from the flume and 48 inches was pumped by the city waterworks pumps from wells.

The delivery of 96 inches to the city and 380 inches to the country throughout the year would require a total of 6,890 acre-feet of water, and as the draft from the reservoir was but 5,777 acre-feet, the difference of 1,113 acre feet must have been supplied from the stream below the reservoir.

### MERCED RESERVOIR, CALIFORNIA.

The highest and longest earthen dam closing a reservoir chiefly devoted to irrigation in California is that which forms the so-called "Yosemite reservoir," 5 miles northeast of the town of Merced, constructed in 1883–84 by the Crocker-Hoffman Land Company as a part



EXTERIOR VIEW OF RESERVOIR DAMS AT PORTLAND, OREGON.

of its general system of irrigation, by which some 150,000 acres of valley land are commanded for irrigation. The dam has a maximum height of 54 feet, and is built entirely of earth, composed of a sandy clay, with inside slopes of 3 to 1 and outside slopes of 2 to 1, paved with 12 inches of loose rock for 15 feet down from the top on the inside for wave protection. The entire length of the dam is 4,000 feet, of which 1,400 feet is less than 10 feet in height. It was built up in thin layers by scraper teams, without any puddling or moistening of the material or the making of anything like the conventional "puddle wall," to which English engineers appear to be so wedded in constructing reservoir banks. The base width is 290 feet and the top 20 feet.

The reservoir covers a surface area of 500 acres and has a capacity of 15,000 acre-feet, of which about 20 per cent is annually lost by evaporation. It is fed by a canal 27 miles in length, leading from a diversion weir placed in the Merced a short distance above the town of Snelling. For the first 7 miles the canal has a maximum capacity of 1,500 second-feet, which makes it the largest in California. Most of this water is diverted into laterals and used in irrigation of lands lying to the westward of the canal before it reaches the reservoir, which acts as a convenient receptacle for the accumulation of all surplus not required in the laterals, storing a supply for irrigation around the city of Merced, and yielding a gravity, domestic, and fire-pressure supply to the city pipe-distributing system. The outlet is a 24-inch cast-iron pipe, laid in a brick-lined tunnel, 4 feet in clear diameter, the walls of which are 12 inches thick.

The Merced River at the head of the canal has a catchment area of 1,076 square miles, in which is included the famous Yosemite Valley. The mean annual flow from this stream, as determined by six years of daily measurements by the State engineering department, is about 1,600 second-feet, the maximum being 6,510 second-feet, in the month of June, and the minimum 65 second feet, in the months of November and December. During the three months of May, June, and July, when the greatest amount of irrigation is done, the mean flow is about 4,000 second-feet. Aside from a few comparatively small ditches irrigating the bottom lands for 10 miles or more below Snelling, the great canal feeding the reservoir is the only extensive utilization of the stream.

## BUENA VISTA LAKE RESERVOIR, KERN COUNTY, CALIFORNIA.

Of vastly greater area and capacity, although of less mean depth, than the Merced reservoir is the large storage tank formed of Buena Vista Lake, in the southern end of the San Joaquin Valley, by the construction of a dike or levee 5.5 miles in length on the township line passing the east end of the old lake bed, and between it and what was formerly Kern Lake before its bed was drained and cultivated. This reservoir now receives all the surplus water of Kern River and the waste at the tail end of all of the Kern Island canals. The water thus

stored is of no benefit to the irrigated district around Bakersfield, nor to the arid plains north, south, and east of that place, but there are large areas of arable lands which are low enough in elevation to be reached from it and parts of which are being irrigated to the extent of 30,000 acres. This area is increasing from year to year. It is devoted to alfalfa and grain, and is located in the belt of "swamp and overflowed lands" lying between Buena Vista and Tulare lakes that was periodically overflowed prior to the establishment of the extensive systems of irrigation which now absorb the major part of the water before it can go to waste.

The maximum height of the dam is 15 feet, tapering out to nothing at either end. This levee is 12 feet wide on top, and slopes 4 to 1 inside and 3 to 1 outside, the top being 4 feet above the highest water level of the reservoir when full. On account of the constant erosion of the waves against this bank it was found necessary to riprap the face with stone over a long section from the south end northward, where there were no tules growing, to serve as a breakwater to lessen the effect of wave action, as was the case at the north end for a considerable distance. A narrow-gage railway was laid some 10 miles to the mountains on the south to procure the material for this riprap, the cost of which brought the entire construction account up to about $150,000. The reservoir was first filled in 1890, and has been in use ever since. This work and the creation of this mammoth reservoir were the result of the compromise of the most extensive and costly litigation over water rights that has ever arisen in California—the famous case of Lux *v.* Haggin—in which the supreme court of California, by a majority of 1, established the English common-law doctrine of riparian rights as applicable to the streams of California—a doctrine which is believed to have been a serious drawback to irrigation development in that State.

The bottom of the outlet canal is 10 feet below high water mark, and the volume which can be drawn out is approximately estimated at 170,000 acre-feet, covering 25,000 acres to a mean depth of nearly 7 feet. The annual loss by evaporation from the surface of the reservoir will probably exceed 120,000 acre-feet, which seems an enormous waste, but is due to the vast area of surface exposed to the action of sun and wind.

The reservoir is filled generally from about May 1 to July 20, during the melting of the snows, after which time to September 1 the inflow is about sufficient, ordinarily, to offset evaporation. Thus during the five hottest months, when nearly 70 per cent of the evaporation of the year takes place, the loss is supplied by the river, and therefore, if the flow is sufficient to fill the reservoir by September 1, in addition to the evaporation, the net amount available for irrigation would approximate 125,000 to 135,000 acre-feet. Even if this be the case, although the data are not at hand to determine that point, it is unfortunate that this storage could not be transferred to the mountain sites, where the enormous loss by evaporation could be saved or reduced to a minimum.

## PROJECTED RESERVOIRS.

### KERN RIVER RESERVOIR SITES, CALIFORNIA.

A number of available sites for impounding a considerable volume of the flood waters of Kern River have been surveyed in the mountains near the sources of that noble stream—the "Rio Bravo of the South," as it was known to the native Californians—the largest of which is in the Manache Meadows, on the South Fork of Kern River, at an elevation of 8,200 feet above sea level (fig. 115). A rock-fill dam at this site,

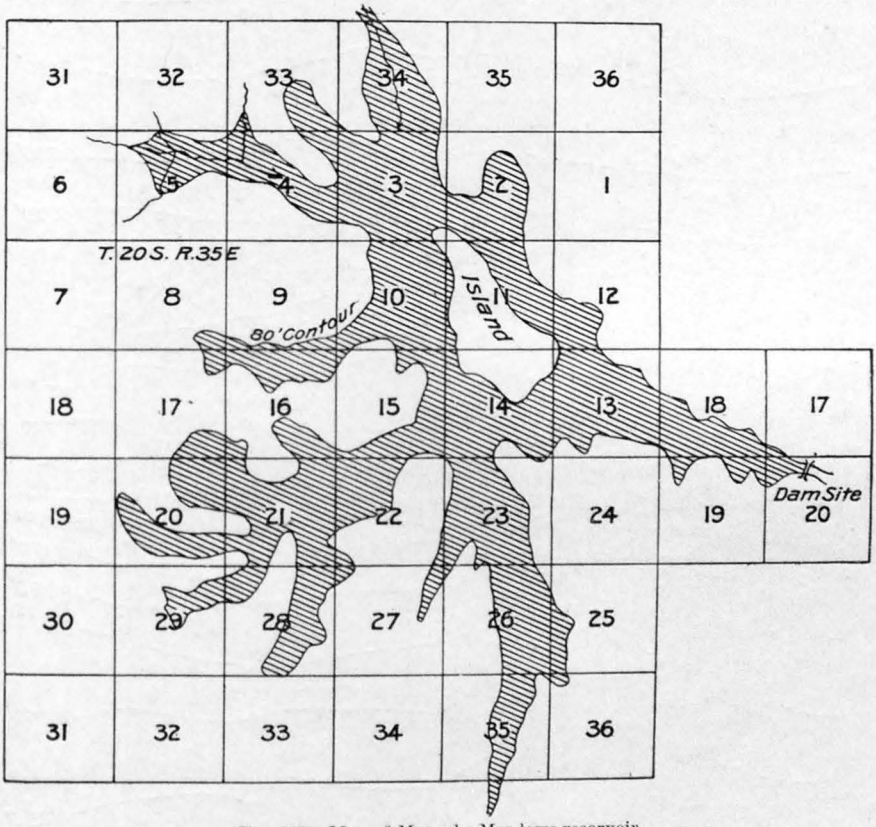



FIG 115.—Map of Manache Meadows reservoir.

estimated to cost $150,000, will create a reservoir of 5,830 acres and impound 248,850 acre-feet, from which it is apparent that the site takes front rank among the most capacious sites that have come to public notice in the West. The locality has the appearance of having been a large lake in a comparatively recent geological period, and the basin is so flat that it was classed, and has been surveyed and segregated, as "swamp and overflowed land." The highest peaks in the catchment area are over 13,000 feet high, and Mount Whitney, 15,000 feet in altitude, is drained on one side by Whitney Creek, the water of which can

be diverted into the reservoir by an inexpensive cut. The area of drainage naturally tributary is 155 square miles.

The dam site (fig. 116) shows solid ledges of granite on each side, and soundings indicate that bed rock is but 8 to 10 feet below the surface

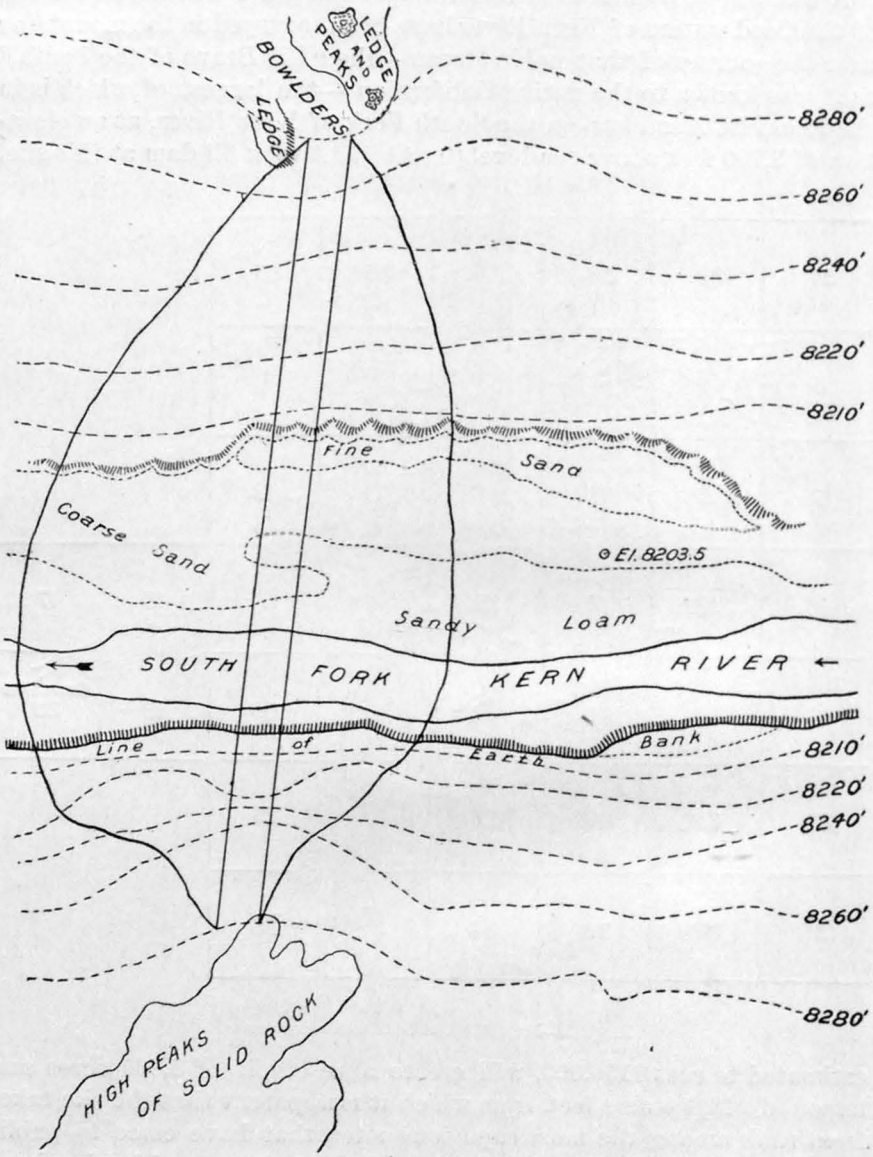



FIG. 116.—Map of Manache Meadows dam site.

across the canyon bed, which is but 160 feet wide at the bed of the stream and 460 feet wide at a height of 85 feet. Lime can be burned for use on Whitney Creek, 20 miles distant, and there is a great abundance of timber which clothes all the surrounding mountains.

If the duty of the reservoir be estimated as equal to the delivery of 50,000 acre-feet to the valley in the neighborhood of Bakersfield, after allowing for all losses by evaporation in the lake and en route, as well as the compensation flow required to be turned out to maintain the rights of the prior users and appropriators in the South Fork Valley in the mountains, where a large area is irrigated, and the irregularities of precipitation and run-off which would be equalized by a reservoir so much larger in capacity than the estimated duty, and on the basis of a use of 2 acre-feet per acre irrigated, the reservoir may be considered as capable of adding 25,000 acres to the area irrigable, at a cost of $6 per acre for construction, aside from the cost of the lands for the reservoir site.

The mountain valley of the South Fork, above its junction with the North Fork, has an altitude of about 3,600 feet, and contains some 25,000 acres of good arable land, of which about 15,000 acres are irrigated, chiefly for alfalfa. There are 30 ditches, each from 1½ to 3 miles in length, 5 to 6 feet wide on bottom, and carrying 1 to 2 feet depth of water. The reservoir in the Manache Meadows would interfere with the supply to these ditches only during the last half of July and the months of August and September. During the remainder of the year the streams below the Meadows are adequate for this service. In fact, the Manache is but one-fifth the total area of the South Fork drainage above the South Fork farming community, and probably does not supply more than 40 per cent of the flow of that stream.

The main characteristics of the North and South forks of Kern River are as widely different as though the streams were in separate States. The North Fork rises in very high, rugged, and precipitous mountains, on which the snow lies late in summer. Its canyon is a deep, narrow gorge throughout its entire length, from its source to Kernville, near its junction with South Fork, with only here and there a narrow strip of meadow land along the stream, not in any way resembling the expansive meadows and open plains which characterize the South Fork for so great a part of its course. The North Fork drains 1,069 and the South Fork 754 square miles of watershed, but the precipitation and run-off of the two sheds vary so greatly that the normal flow of the former is ten to twelve times greater than the latter at their point of junction. Unfortunately the relative advantages of the two forks respecting sites for storage seem to be in inverse ratio to their volume of flow and capacity for filling reservoirs.

One of a large number of sites surveyed in 1881 by the State engineering department of California is at the "lake" on North Fork, where a landslide has filled the canyon some 20 feet and created a pond 40 acres in area. This place has been viewed with the idea of constructing a high rock-fill dam, to be formed by a few huge blasts from the cliffs that tower almost vertically above it for 2,000 to 3,000 feet. The capacity of a reservoir at this place would be 46,600 acre-feet at the

220-foot level, covering about 600 acres. The outlet would be made by means of a tunnel of sufficient capacity to carry the river during construction of the dam. The plan suggested contemplates filling the canyon for several hundred feet with such an enormous mass of rock as to give it unquestionable stability, and, after it is thrown down, to lay up a dry wall on its upper face and cover it with asphalt concrete, excavating a spillway entirely around the dam so created. The canyon width at the site is but 100 feet at bottom and 400 feet at a height of 230 feet. The work is estimated to cost $225,000.

One of the advantages of the reservoir in this locality would be that it could be filled twice a year or oftener. Experience has demonstrated that the usual shortage in supply to the Kern Valley canals occurs twice each year—in February and March and in August and September. In these months a reenforcement of the stream is very much needed. Between each of these periods the North Fork reservoir could be filled and its contents made available for the next low stage.

It may be considered, therefore, that the reservoir, if built and operated in the manner suggested, would practically add 46,000 acres to the irrigable area of the valley, at a cost of about $5 per acre.

Located on Salmon Creek, a branch of the North Fork of Kern River, at a point known as Big Meadows, is a site where a dam of 75 feet height will form a reservoir of 870 acres that would impound 31,150 acre-feet of water. The dam site is in a granite canyon with clean bed rock on bottom and sides, the width at bottom between walls being but 25 feet, while the top width at the 75-foot level would be 390 feet. A rock-fill dam is estimated to require 26,000 cubic yards of material, and to cost $80,000. The area of watershed is estimated at 14 to 25 square miles.

Throughout the higher Sierra Nevada are innumerable lakes of considerable area and capacity, generally so high as to be above the timber line, which can be utilized as storage reservoirs at small expense. They may be counted by the hundreds on the headwaters of Kings, San Joaquin, Merced, and Tuolumne rivers, although it can not be said that any of them are so extensive or capacious as to be distinctly noticeable or require special description. Preparations are being made by people living in Visalia to utilize two such lakes on the headwaters of the Kaweah River during the season of 1897 in a somewhat novel manner. By means of a number of 10-inch pipes they propose to siphon the water out of the lakes to a depth of about 20 feet, and as one of them, called Moose Lake, is about 300 acres in area, it is expected to draw from it in the season of greatest shortage about 5,000 to 6,000 acre-feet of water. The other, known as "Big Lake," has almost as large an area. This method of utilizing the lakes without the expense of building dams may have more than a local application.

On the eastern slope of the Sierra, near the town of Independence, a high mountain lake of this sort has been tapped by a cut about 10 feet in depth, which has given a flow, as reported, of several hundred inches more than customarily came from it before.

R.5.W. R.4.W. R.3.W. R.2.W. R.1.W. R.1.E. R.2.E. R.3.E. R.4.E. R.5.E. R.6.E. R.7.E.

T. 9 S. T. 10 S. T. 11 S. T. 12 S. T. 13 S. T. 14 S. T. 15 S. T. 16 S. T. 17 S. T. 18 S.

SAN LUIS REY WATERSHED

WARNER'S RANCH RESERVOIR

MOOSA RESERVOIR

DISTRIBUTING RESERVOIR

DAM

PAMO WATERSHED

PAMO RESERVOIR

SANTA MARIA WATERSHED AND RESERVOIR

DYE VALLEY RESERVOIR

FLUME COS WATERSHED

SAN DIEGO FLUME COS RESERVOIR

EL CAPITAN RESERVOIR

PINE VALLEY WATERSHED AND RESERVOIR

LINDA VISTA IRRIGATION DISTRICT

SAN DIEGO FLUME COS RESERVOIR

SWEETWATER WATERSHED

TECARTE WATERSHED

SAN DIEGO

BAY OF SAN DIEGO

JAMACHA IRRIGATION DISTRICT

SWEETWATER RESERVOIR

BARRETT RESERVOIR

MORENA RESERVOIR

MOUNT

UPPER OTAY RESERVOIR

LOWER OTAY RESERVOIR

TECARTE RESERVOIR

SCALE

0 2 4 6 8 10 MILES.

MAP OF SOURCES OF WATER SUPPLY IN THE VICINITY OF SAN DIEGO, CALIFORNIA.

## SOUTHERN CALIFORNIA RESERVOIR SITES.

The last few years have been fruitful in the projection of numerous storage enterprises throughout the arid region which are yet awaiting the necessary capital for their construction. The map of San Diego County (Pl. LXXXIX) shows the position of a number of capacious and favorable sites which have been surveyed, in addition to those already described, for storing the storm water of that region. The topography of the country is more favorable for storing water than many parts of the State better supplied with permanent streams. Cross sections of several of these sites are given in fig. 117 and tables of capacity of the reservoirs to be inclosed by them will be found in the Appendix. The Linda Vista Irrigation District, covering an area of 44,000 acres,

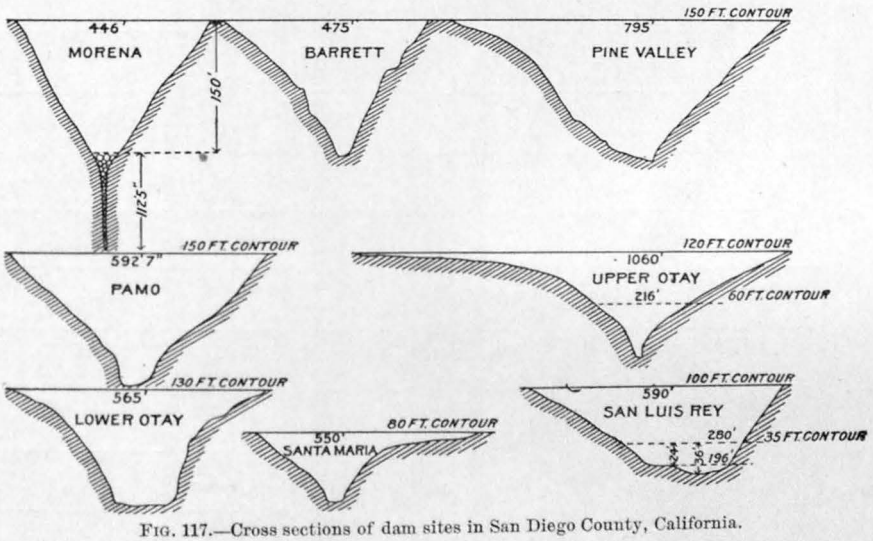



FIG. 117.—Cross sections of dam sites in San Diego County, California.

embracing a part of the corporate limits of San Diego, owns the Pamo, Santa Maria, and Dye Valley sites, and has projected rock-fill dams for each of them. The Pamo is considered most favorable for immediate construction, as it is also the most capacious.

In Riverside County a masonry dam has been planned to span a narrow canyon on the Pauba Rancho at the outlet to a large valley on Temecula Creek which drains a catchment area of 372 square miles. The elevation of the dam is 1,350 feet at the base, and it commands an extensive territory of valuable agricultural and horticultural lands. The dam is projected to a height of 130 feet, at which it will have a capacity of 61,500 acre-feet, covering 1,214 acres. Its cost has been estimated at $400,000, and the 28 miles of canals for distribution to 40,000 acres of land at $230,000, an average cost for the system of about $16 per acre.

The capacity of the drainage basin for run-off has been demonstrated in a striking way on two notable occasions when floods from this section destroyed the Southern California Railway through the Temecula Canyon, causing enormous loss and destruction of property. The track has not been restored since the last time it was destroyed, in 1890–91.

## VICTOR DAM, CALIFORNIA.

Doubtless the most capacious reservoir projected in California is that of the Columbia Colonization Company, located on the Mojave River in San Bernardino County, at the Upper Narrows, near the town of Victor

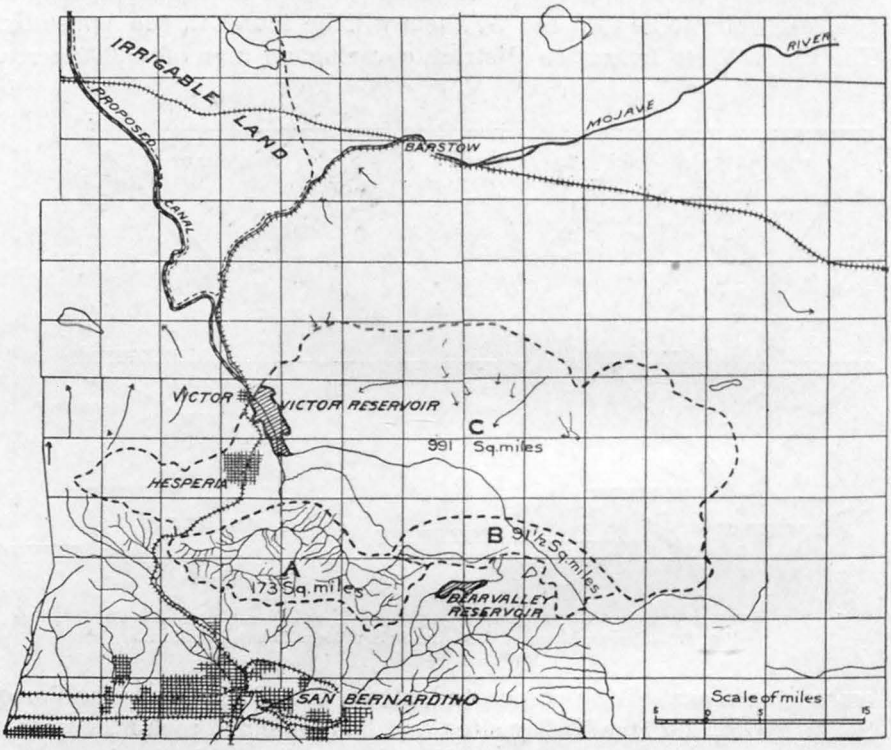
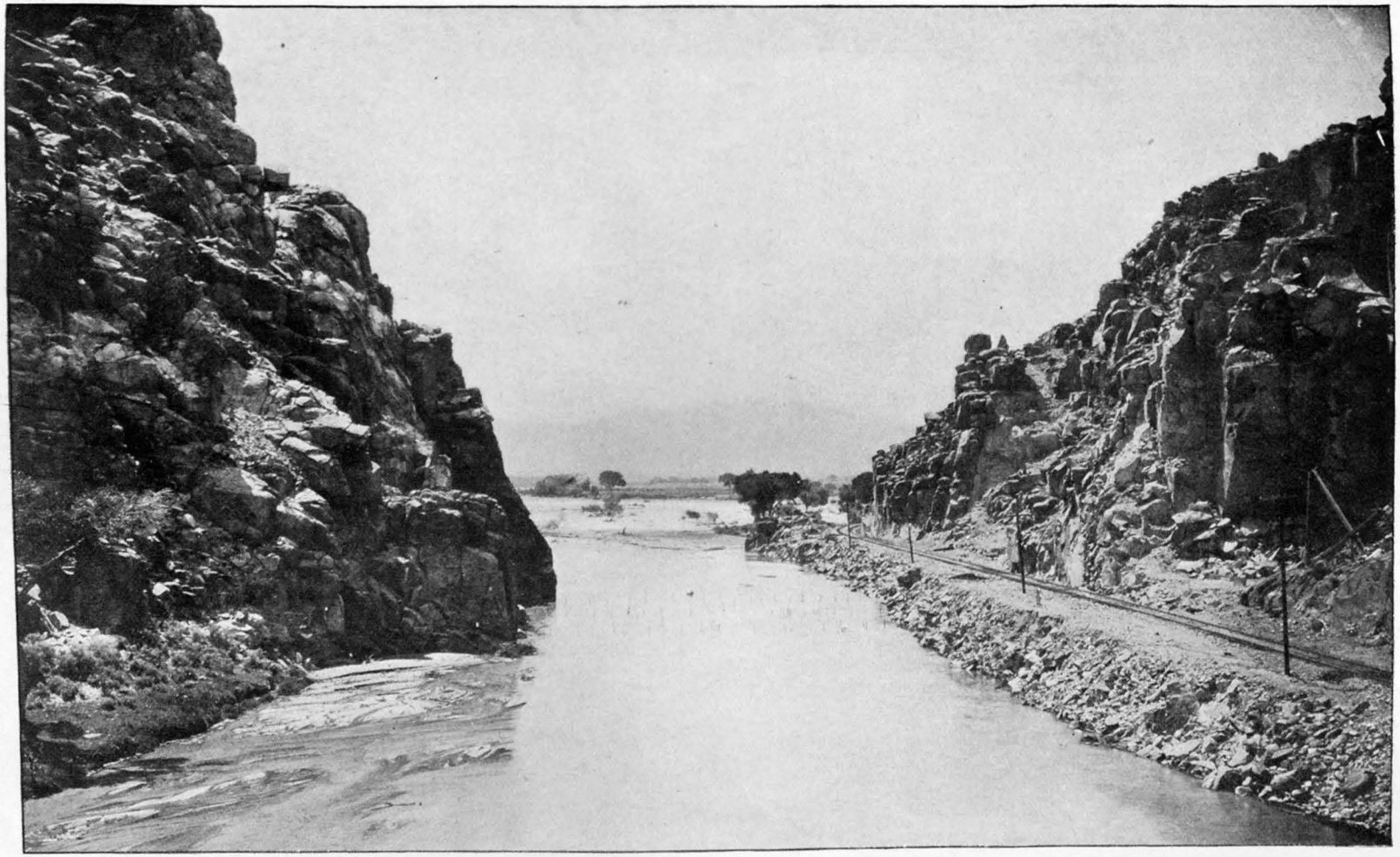



FIG. 118.—Map of watershed and the lands to be irrigated from Victor reservoir.

(fig. 118), on the line of the Southern California Railway, which now passes through the site of the dam, and will have to be rebuilt for 5½ miles to clear the reservoir. The pass at the Narrows is in a granite ridge, which affords most admirable buttresses for a masonry dam, and is a remarkable one, favorable in all respects for such a structure. The width at the stream bed is but 140 feet, while at the height of 150 feet the walls of the canyon are but 360 feet apart. Soundings have been taken with steel rods driven through the sand, which show the maximum depth to what is believed to be bed rock at 52 feet. Fig. 119 is a cross section of the site, showing the soundings, and Pl. XC is a view looking upstream from the county bridge through the dam site, the



VIEW OF VICTOR DAM SITE, LOOKING UPSTREAM.

stakes shown in the water marking the positions of the various soundings. The reservoir basin is shown in Pl. XCI; and fig. 118 is a general map of the watershed and the lands proposed to be irrigated.

As planned, the dam will contain about 70,000 cubic yards of masonry, including the filling of a narrow gap in the rim rock above the 105-foot contour, some 500 feet west of the dam proper. On the opposite side a natural spillway of ample dimensions exists at a height of 145 feet, by

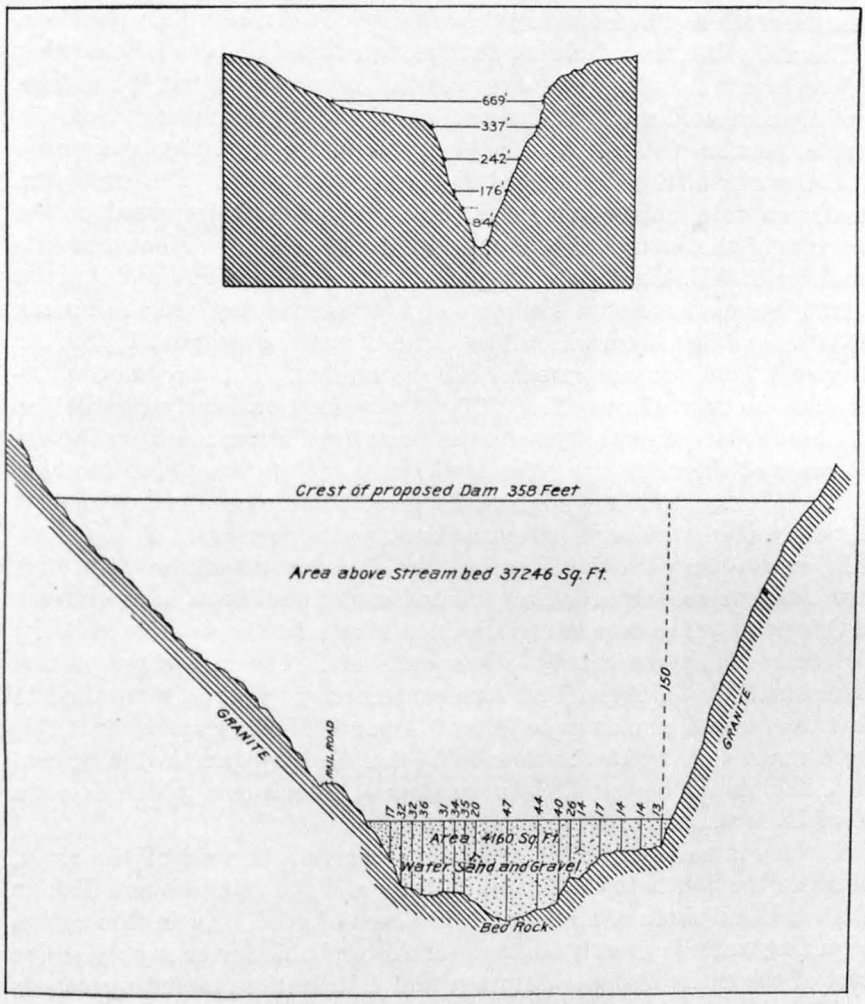



FIG. 119.—Cross section of Victor dam site.

which the waste will be returned back to the channel at a safe distance below over a ledge of solid granite. The reservoir at the 145-foot contour covers an area of 7,718 acres, and has a capacity estimated at 17,000,000,000 cubic feet, or 390,000 acre feet, the mean depth being 50½ feet, or 34.86 per cent of the maximum. The ratio between mean and maximum depth in all large, commodious reservoir basins which

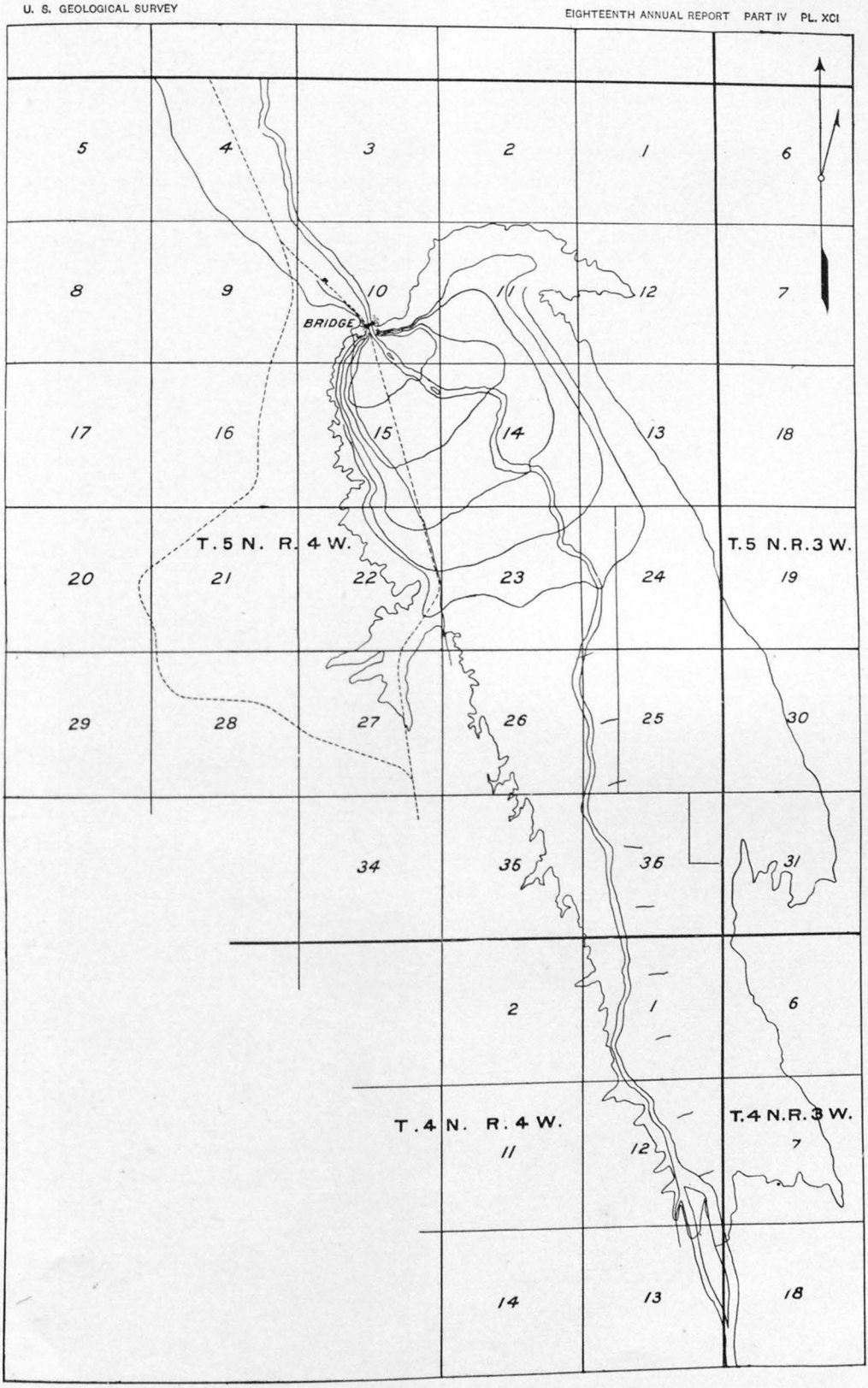
have a fairly uniform slope of stream bed from the dam site up, and do not show a series of rapids for a distance above the dam, is found to range from 32 to 38 per cent, and it is often customary on preliminary estimates, after determining the area of the highest contour embracing the reservoir, and before making detailed survey of the interior of the basin, to apply such a percentage of the height of the dam for computation of contents as the engineer may consider safe within these limits, taking into consideration the general topography of the site. Such has been the method of determining the capacity of the reservoir in question.

The watershed area draining out through this dam site is somewhat indeterminate from lack of surveys in the eastern part, but it has been roughly computed as 1,250 square miles, of which the drainage from the greater portion of 77 square miles on the mountain crest may be diverted by the works of the Arrowhead Reservoir Company. The precipitation has a wide range of variation, from 60 inches and upward on the summits of the mountains to 5 or 6 inches at the dam. Measurements made by F. W. Skinner, civil engineer, between January 1 and August 1, 1893,[1] gave a maximum discharge of 8,500 second-feet and a minimum of 38 second-feet, from which the mean flow from August 1, 1892, to August 1, 1893, was computed as 825 second-feet. This would be equivalent to an annual run-off of 597,300 acre-feet, or nearly double the proposed reservoir capacity. At the same time it was noted, by the appearance of the drift along the banks and the statements of the residents of Victor, that the highest floods of that season lacked several feet of reaching the high-water marks of previous years.

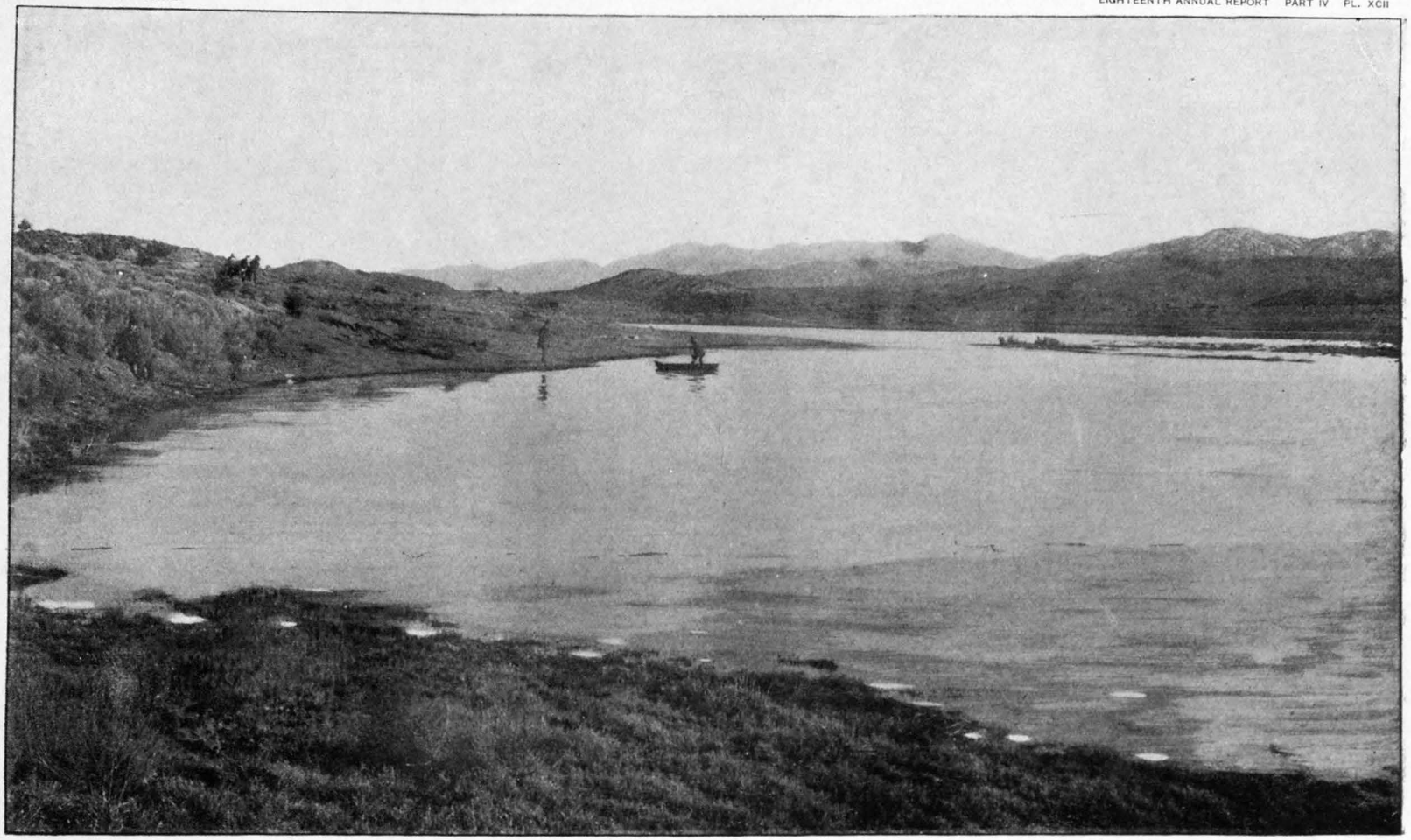
In connection with the laying of the foundations of the dam, it is interesting to consider the probable volume of underflow in the stream at this point. The area of cross section shown by the soundings below the surface is approximately 4,160 square feet. The rate of percolation determined by the Agua Fria dam construction (p. 697), if applied to this area, would give an underflow of 11 miner's inches, and even if this were multiplied by 10 the flow to be handled by pumps during construction would be but little more than 4 second-feet, which is not a formidable amount to contemplate taking care of.

The lands to be irrigated from the reservoir lie west of the river, between the Southern California Railway and the Atlantic and Pacific Railroad, and north of the latter. The area of good land in this region requiring water is greatly in excess of the probable water supply. The cost of the entire system of storage and distribution, including canals and laterals delivering water to 200,000 acres, is estimated at $1,742,000, or $8.46 per acre, although the company states that it has secured bids from reliable contractors which will greatly reduce these figures of cost. It appears to be an enterprise which would reclaim so large an area of the public domain that is now a desert as to entitle it to be classed among those which should be carried to successful completion.

[1] Bull. U. S. Geol. Survey No. 140, 1896, p. 318.




MAP OF VICTOR RESERVOIR.



VIEW OF A CORNER OF THE BASIN OF ALPINE RESERVOIR BEFORE WORK WAS BEGUN.

## ANTELOPE VALLEY WATER COMPANY, CALIFORNIA.

Piru Creek is a tributary of the Santa Clara River, in Ventura County, California, which drains a region of high mountain watershed in the Coast Range and whose waters flow to the ocean unused, save a small amount flowing in summer, and are unavailable for irrigation except by the construction of storage reservoirs. The Antelope Valley Water Company has projected two reservoirs in the immediate drainage lines of the creek in Lockwood Valley and at the mouth of Rays Creek, to serve as regulators of the flood flow. From these, water will be released into the channel and picked up again at a lower point in the canyon, where a canal of 240 second-feet capacity will convey it 12 miles to two other reservoirs, which will constitute the main storage. These are located in commanding positions on the summit of the divide separating the Piru Creek drainage from Antelope Valley on the east and from San Joaquin Valley on the northeast—one of them supplying the lands at the western end of Antelope Valley and the other the sloping foothill plains in the frostless thermal belt southeast of Buena Vista Lake, at the head of San Joaquin Valley.

The summit reservoirs are both natural basins which have a large capacity for storage that can be utilized by simply providing outlet tunnels at the proper levels, but which require dams of about 50 feet maximum height to enable them to store the full flow of the stream with the proper amount of reserve supply for years of drought. The material available for the building of these dams renders them more readily and cheaply constructed by the hydraulic process. The dams of the regulating reservoirs in the canyon of Piru Creek are planned as rock-fills, of the type heretofore described, viz, with a water-tight skin of asphaltum concrete.

The area of watershed available for this enterprise is about 200 square miles in Piru Creek and some 40 or 50 miles additional from adjoining drainage lines, from which it is computed a sufficient supply may be gathered to yield a mean flow of 125 second-feet during the irrigation season of six months, maintaining a reserve of 75 per cent in the reservoirs in addition as a provision for dry years.

## ALPINE RESERVOIR, CALIFORNIA.

In the same neighborhood as that last mentioned is to be found an interesting example of the type of reservoir formed by utilizing natural basins (which are less frequently to be seen in California than on the Great Plains of the eastern Rocky Mountain slope), the project of the South Antelope Valley Irrigation Company, completed in May, 1896, and put into service in the spring of 1897. This reservoir has special interest, not only as the first one of any magnitude completed on the Mojave Desert or Antelope Valley side of the Sierra Madre in southern California, but because it lies directly in the line of what is known

as "the great earthquake crack" of this region, which is marked by a series of similar basins behind a distinct ridge that appears to have been the result of the great seismic disturbance.

This remarkable line of fracture can be traced for nearly 200 miles through San Bernardino, Los Angeles, Kern, and San Luis Obispo counties, and deviates but slightly here and there from a direct course of about N. 60° to 65° W. There appears to have been a distinct "fault" along the line, the portion lying south of the line having sunken, and that to the north of it being raised in a well-defined ridge. In many places along the great crack ponds and springs make their

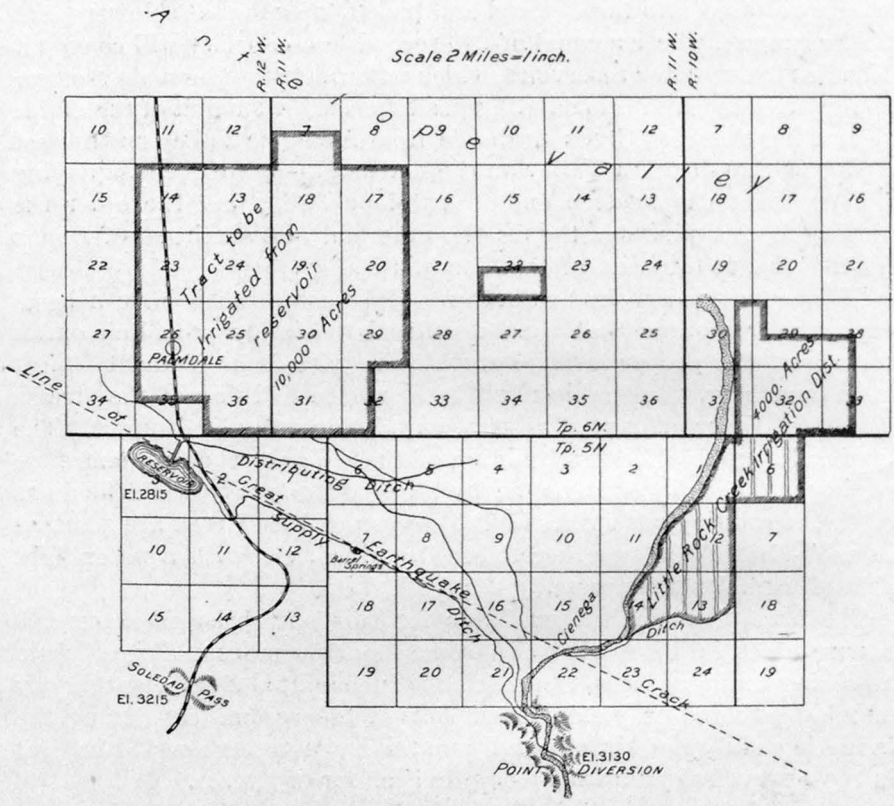
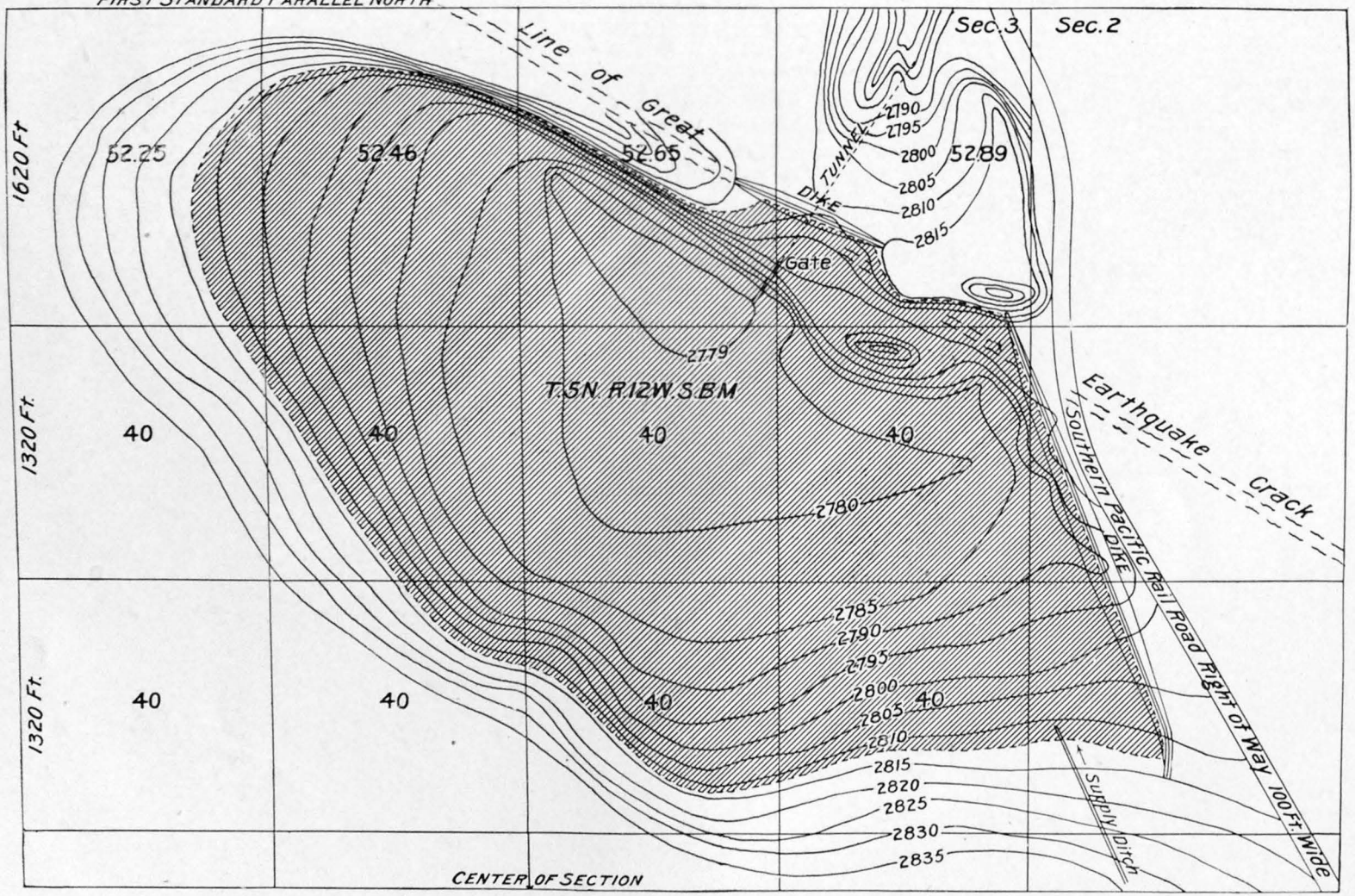



FIG. 120.—Map of Little Rock Creek Irrigation District.

appearance, and water can be had in wells at little depth anywhere on the south side of the ridge before mentioned. A tough, plastic, blue clay distinguishes the line of the break in this portion of its course, at least, and where the line crosses Little Rock Creek the blue clay has formed a submerged dam, which has forced the underflow near the surface and created a "cienaga" immediately above it. After crossing the line the water of the creek drops quickly away into the deep gravel and sand of the wash. The same effect is noticeable at other streams, and it has been suggested as the probable cause of the very distinct




RESERVOIR OF SOUTH ANTELOPE VALLEY IRRIGATION COMPANY.

CRAIN LAKE, LOOKING NORTHWEST.

One of the reservoir sites of the Antelope Valley Water Company.

rim marking the lower margin of the San Bernardino Valley artesian basin and confining its waters within well-defined limits, as this rim is nearly on a prolongation of the line that is traceable on the north side of the mountains—the break having crossed the mountains through the Cajon Pass on the line of Swartout Canyon.

One of the largest depressions on the earthquake line is the basin near Alpine or Harold station on the Southern Pacific Railroad, which has always held a small amount of water, supplied by the rainfall over the small catchment of 6 or 8 square miles above it, but which is now transformed into a reservoir, fed by a canal, 8.6 miles long, from Little Rock Creek. The railway passes through one side of the basin and crosses the outer rim near the outlet tunnel. A low levee or dike, about 4,000 feet long, will have to be built alongside the track to enable the reservoir to be filled to its maximum depth of 34 feet, for which it has been planned. At this level it will cover 263 acres of surface and impound 5,500 acre-feet of water. The basin will carry 15 feet of water without submerging the track, and for present purposes a dike lower than that which is planned for a full use of the basin has been built to permit the storage of 21 feet depth of water. A corner of the basin is shown in Pl. XCII as it appeared before beginning work. The view is taken looking east across the railroad tracks toward the mountain source of supply.

The feeder canal from Little Rock Creek consists of 2 miles of flume and chute and 6½ miles of earth canal, including two ponds or sand-settling basins, 1,600 and 1,400 feet long. The location of the conduit, after getting out of the canyon of the creek, is directly on the earthquake line for the greater part of the way, the straightness of the line being noticeable on the map, fig. 120. The canal heads at an elevation of 3,130 feet above sea level, and it has a total fall to the surface of the reservoir of 317 feet, of which the canal grade required but 70 feet. The superfluous fall was taken up by a series of inclines or chutes, down which the water flows with great velocity. They are 7 in number, and have a total length of 4,600 feet.

The canal has a maximum capacity of 250 to 300 second-feet. Under normal conditions it is expected that the reservoir can be filled twice or more each season, and by irrigating freely in winter and early spring the duty of the reservoir and canal system may be increased to accomplish the irrigation of as great an area as though the reservoir were of double the capacity. The tract which the company hopes to supply from this source covers about 10,000 acres, a part of which is being planted in olives.

The watershed of Little Rock Creek, as shown by the best maps to be had, does not exceed 61 square miles, but as it heads in one of the highest peaks of the Sierra Madre and drains the north slopes of the mountain, the run-off to be expected from it may ordinarily reach 400 acre-feet per square mile. The normal flow of the stream, which reaches

a minimum of 2 second-feet, is diverted at the before-mentioned earthquake cienega by a ditch supplying the Little Rock Irrigation District, the outlines of which are shown on the sketch map (fig. 120). Consequently the South Antelope Valley Company must depend entirely upon the surplus flood water after the district is supplied.

Incidentally it will be of interest in this connection to mention that a careful measurement of the underflow in the gravel bed of the stream overlying the blue clay of the earthquake crack, made by Mr. J. B. Lippincott in June, 1896, resulted in the conclusion that the rate of flow of the percolating water passing through the sand and gravel of the channel was 2.16 feet per hour, or 3.53 miles per annum, which is extremely slow, but much greater than that noted at the Agua Fria

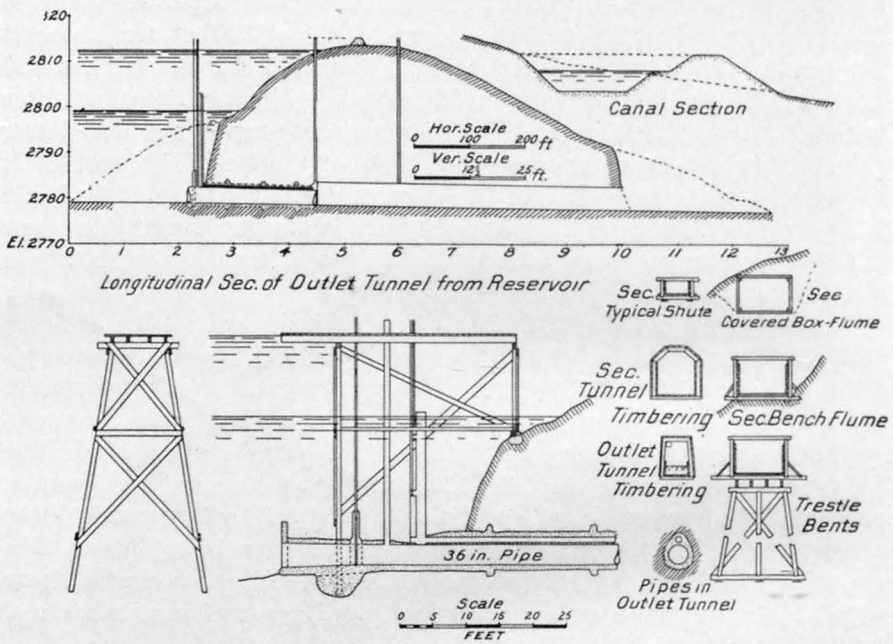
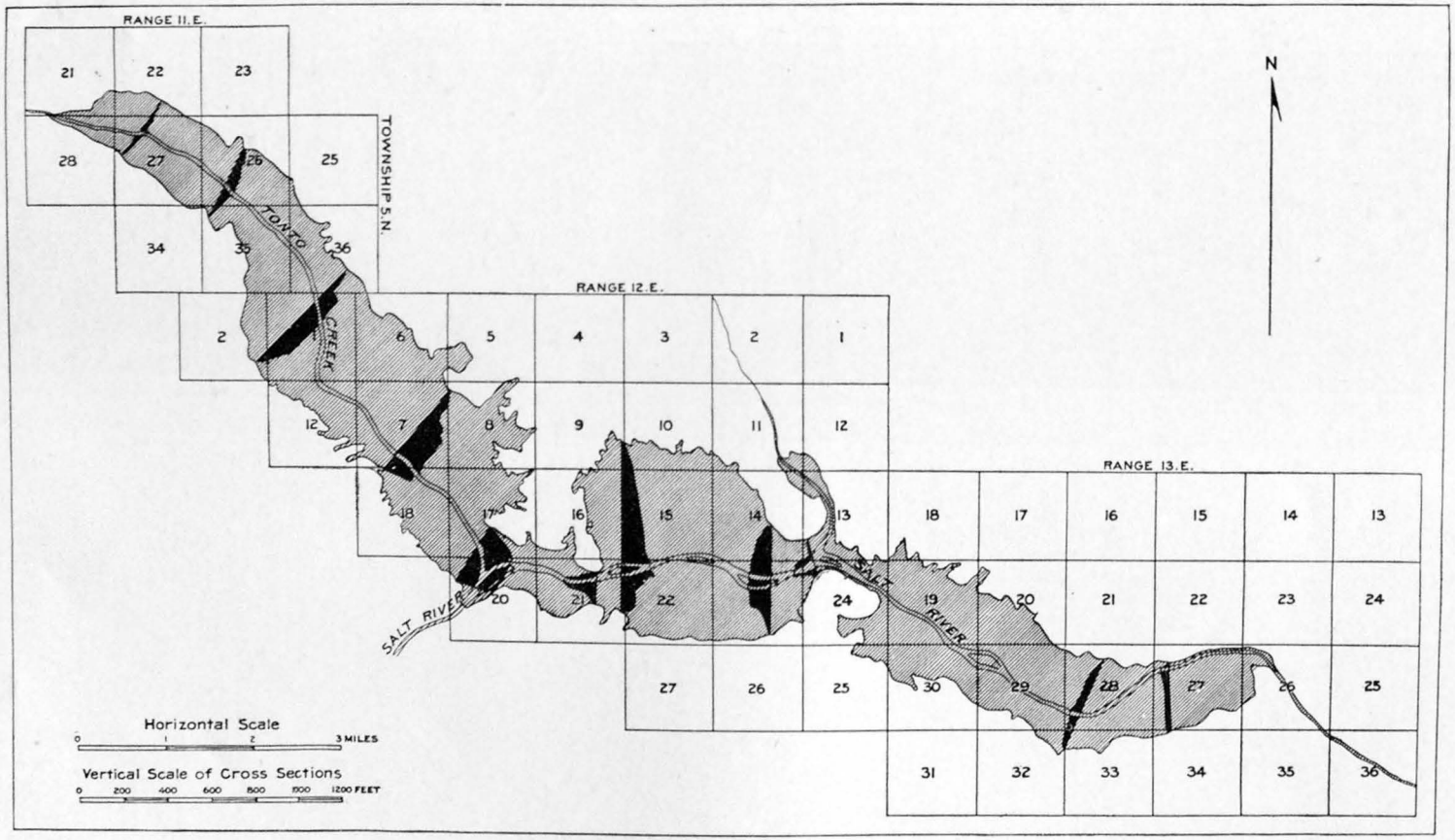



FIG. 121.—Details of tunnel outlet of the Alpine reservoir.

River, Arizona (p. 697), doubtless because of the greater coarseness of the gravel at Little Rock.

The outlet to the Alpine reservoir (Pl. XCII and fig. 121) is made by a tunnel 750 feet long, in which a 36-inch riveted steel pipe is laid for irrigation supply alone, and a 10-inch pipe of the same character is placed above the former for domestic purposes only, both being surrounded with concrete, filling the 8-inch space concentric with the pipes to the walls of the tunnel. The pipes extend only 200 feet from the interior to a gate shaft, and thence the main pipe discharges into a flume placed inside the tunnel timbers. This flume is 2 feet deep, 3 feet 8 inches wide, and delivers the water to the distributing ditches running east and west from the mouth of the tunnel on suitable grade lines. A




MAP OF TONTO BASIN RESERVOIR, SHOWING ELEVATIONS OF TEN CROSS SECTIONS OF THE RESERVOIR.

wooden platform on a trestle built over the inner end of the tunnel serves as the place from which to operate the 36-inch gate valve at the head of the pipe and three 10-inch valves on a standpipe at different levels controlling the domestic supply, which is taken under pressure to the town of West Palmdale.

The entire cost of the enterprise is not definitely stated, but it is thought to have somewhat exceeded $100,000, or over $10 per acre for the tract to be supplied with water. The cost per acre-foot of reservoir capacity was probably $18 to $20, the chief expense having been for the canal. The works were planned and built by Burt Cole, a civil engineer residing in the district.

## SANTA ANA CANYON STEEL DAM, CALIFORNIA.

One of the novelties among the newer projects of southern California for water storage is the proposed erection of a steel dam 250 feet high in the canyon of the Santa Ana River below its junction with Bear Creek, for the catchment of flood water and as a diverting dam for power purposes. The reservoir to be formed by a dam of this height in the canyon will be of limited area, as the grade of the river in both forks is very steep, but the volume of storage capacity has been computed as 1,500 six-months inches, or 10,860 acre-feet, which would be but a small part of the normal waste water of winter floods draining from the precipitous watershed of the Santa Ana.

The dam is to be located in a part of the canyon where the walls are of hard rock and so precipitous and near together as to admit of spanning the distance between them with a succession of arched steel girders, placed at frequent intervals one above another, and faced with steel plates riveted together like the segment of a great steel tank. The estimated cost of the dam is not given, but that it will be very large per unit of volume stored goes without saying, and in no other region than southern California could such costly works for irrigation storage prove profitable. Mr. F. E. Brown, the engineer who originated and built the Bear Valley dam, is the promoter of the new enterprise on the stream below his first work.

## TONTO BASIN RESERVOIR PROJECT, ARIZONA.

Nothing so vast or so pretentious in the way of dam construction or water storage has come to public notice in the arid region as the scheme of the Hudson Canal and Reservoir Company of New York for converting the great Tonto Valley on Upper Salt River, Arizona, into an enormous reservoir, covering 14,200 acres and impounding 1,020,000 acre-feet, with a dam that will be 200 feet high above the ordinary low-water level of the stream. (Pls. XCV and XCVI.) The extreme height of the dam above its foundation base will be 250 feet, and its length on top will be 647 feet, measured on the arc of its curvature upstream,

which will be on a radius of 818½ feet. The design of the dam (Pl. XCVII and fig. 122) is for a masonry structure, laid in Portland cement, with a gravity profile of modern type. It is to be provided with a spillway channel on the north side 250 feet wide, and with one 150 feet in width on the opposite side of the river.

The first construction is intended to be carried 130 feet above low-water level, and the dam finished off as an overflow weir, permitting floods to pass freely over its crest. Maximum floods are estimated to reach a depth of 16½ feet over the top of the weir, the length of which will be 500 feet. At the level of the crest the reservoir will impound 303,900 acre-feet, covering an area of 6,570 acres. The outline of the reservoir (Pl. XCV) is mapped only to the 180-foot contour, and the ultimate height of the water level will cover a much greater surface than is

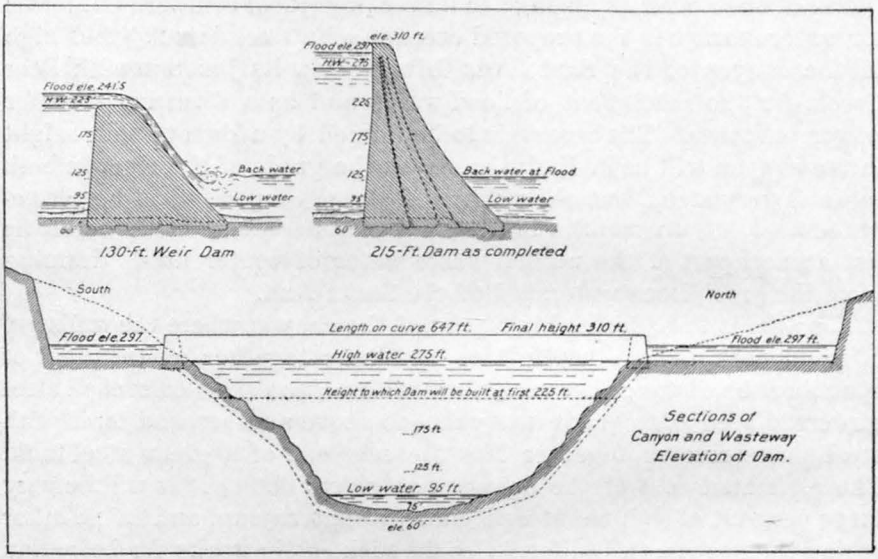


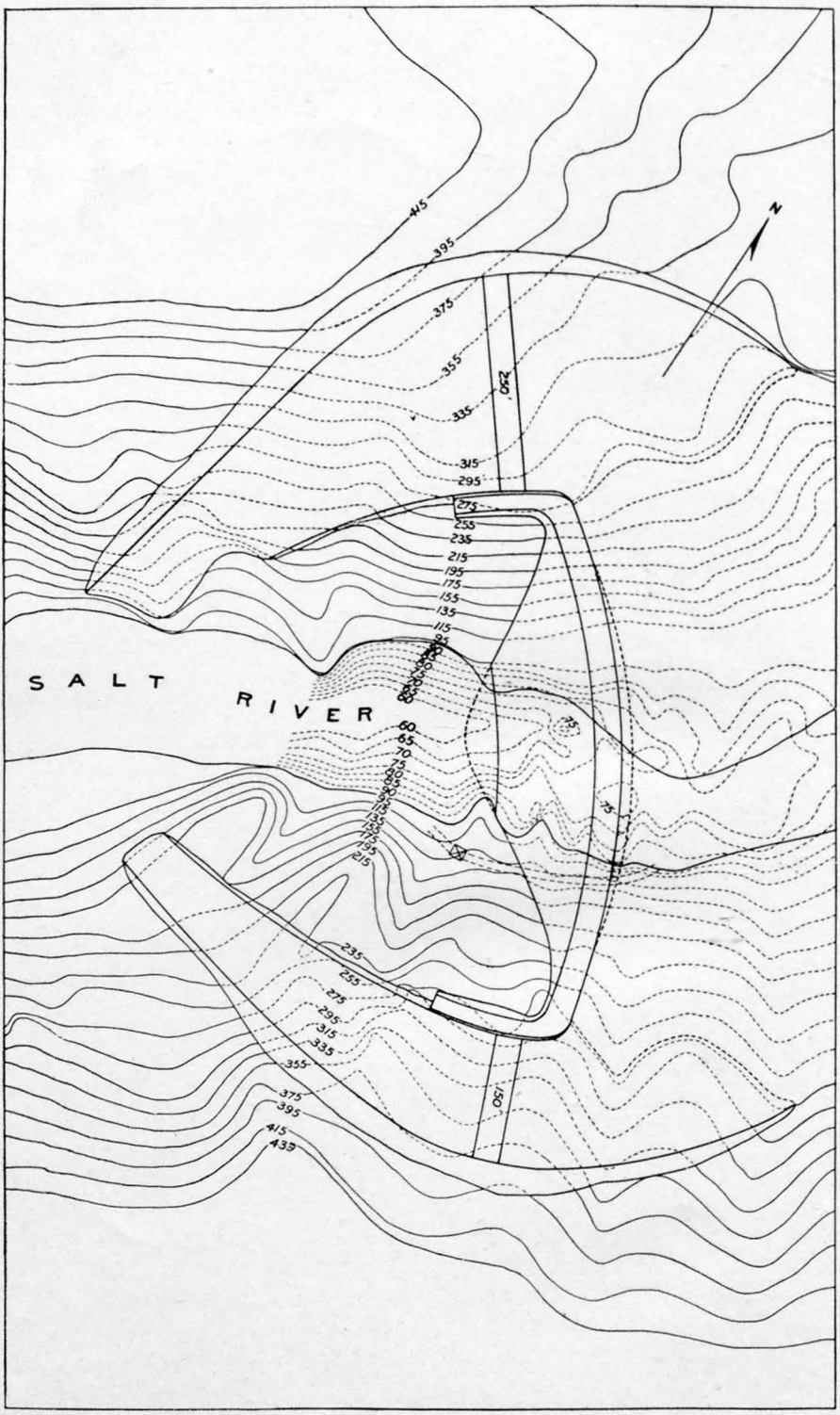

FIG. 122.—Sections of dam and canyon of Tonto reservoir.

shown by the map. Mr. A. P. Man, chief engineer of the company, by whose courtesy the plans and maps have been made available for this paper, furnishes information as to the hydrography of the basin, from which the following data are compiled:

The area of the watershed above the dam is 6,260 square miles; the elevation of the base of the dam at low-water level is 1,925 feet above tide water, the maximum altitude of the watershed being about 7,000 feet, upon which a mean precipitation of 23 inches per annum is estimated. The run-off for seven years has been computed as follows:

| | Acre-feet. | | Acre-feet. |
|---|---|---|---|
| 1889 | 1,111,790 | 1894 | 297,704 |
| 1890 | 1,659,726 | 1895 | 1,124,196 |
| 1891 | 1,999,092 | Mean | 1,125,466 |
| 1892 | 663,025 | | |
| 1893 | 999,728 | | |

DAM SITE ON SALT RIVER BELOW MOUTH OF TONTO CREEK.




PLAN OF TONTO DAM.

The mean of these seven years would represent about 15 per cent of a mean precipitation of 23 inches. The maximum flood yet recorded, that of February, 1891—180,000 second-feet for twenty-four hours—would fill the spillways planned to a depth of 22 feet, while the dam is intended to be 13 feet higher than this maximum flood height. After making allowances for evaporation and other losses, the promoters of this great enterprise reckon on being able to increase the irrigable area of the Salt and Gila river valleys sufficiently to bring the total up to 650,000 acres. As there are now irrigated some 270,000 acres—150,000 on the north and 120,000 on the south side of the Salt River—the reservoir would therefore be expected to add 380,000 acres to the present duty of the river. Maps of this region are given in Pls. XCVII and XCIX.

The canal survey made by the company commands about 525,000 acres above and beyond the reach of existing canals, including about 250,000 acres of the Sacaton Indian Reservation. The canal line began in the canyon of Salt River, 12 miles above its mouth, and is 115 miles in length to the crossing of the Southern Pacific Railroad, crossing the Gila River at the sixty-third mile.

## PROPOSED RESERVOIRS ON RIO VERDE, ARIZONA.

The Rio Verde, which has a watershed of 6,000 square miles above its junction with the Salt River of Arizona, supplies a large surplus flood flow, which the Rio Verde Canal Company is organized to utilize as far as possible. The principal reservoir site is located some 40 or more miles above the mouth of the stream, and is called the "Horseshoe reservoir," where a dam 170 feet in height will close a reservoir of 205,000 acre-feet capacity (Pl. C). The length of this dam will be 1,250 feet on top, the length at the stream bed being 360 feet. Soundings taken along the line of the dam indicate that the greatest depth to bed rock is 24 feet below low-water line, which will therefore make the extreme height of dam 194 feet. A spillway 1,000 feet long, over a solid rock ledge, located 2,200 feet away from the dam, is a commendable feature of the work.

The elevation of the top contour of the reservoir is 2,052 feet above tide level, and it covers an area of 3,402 acres. Water released at the dam will flow down the river channel for 25 miles to a diverting dam, 70 feet high and 480 feet long at the crest line, of which the elevation is 1,614 feet above sea level. Both dams are of the same type—rock-fills with a facing of asphaltum concrete. A canal with a capacity of 800 second-feet starts at the lower dam and skirts the northern edge of the Salt River Valley, practically parallel with the Arizona Canal, but extending far beyond the lower end of the latter. It is to be 69 miles in length, of which 25 miles, from the mountains to Cave Creek, are practically completed. The outlet tunnel to the Horseshoe reservoir, 715 feet long, through solid granite rock, is also finished. It is

12 feet wide and 13 feet high, and has a gate shaft near its upper end for controlling the supply to the canal. The estimated cost of the work is as follows:

| | |
|---|---|
| Horseshoe reservoir | $600,000 |
| Diverting dam | 200,000 |
| Main canal to New River | 560,000 |
| Extension of main canal, 19 miles | 180,000 |
| Miscellaneous | 60,000 |
| Total | 1,600,000 |

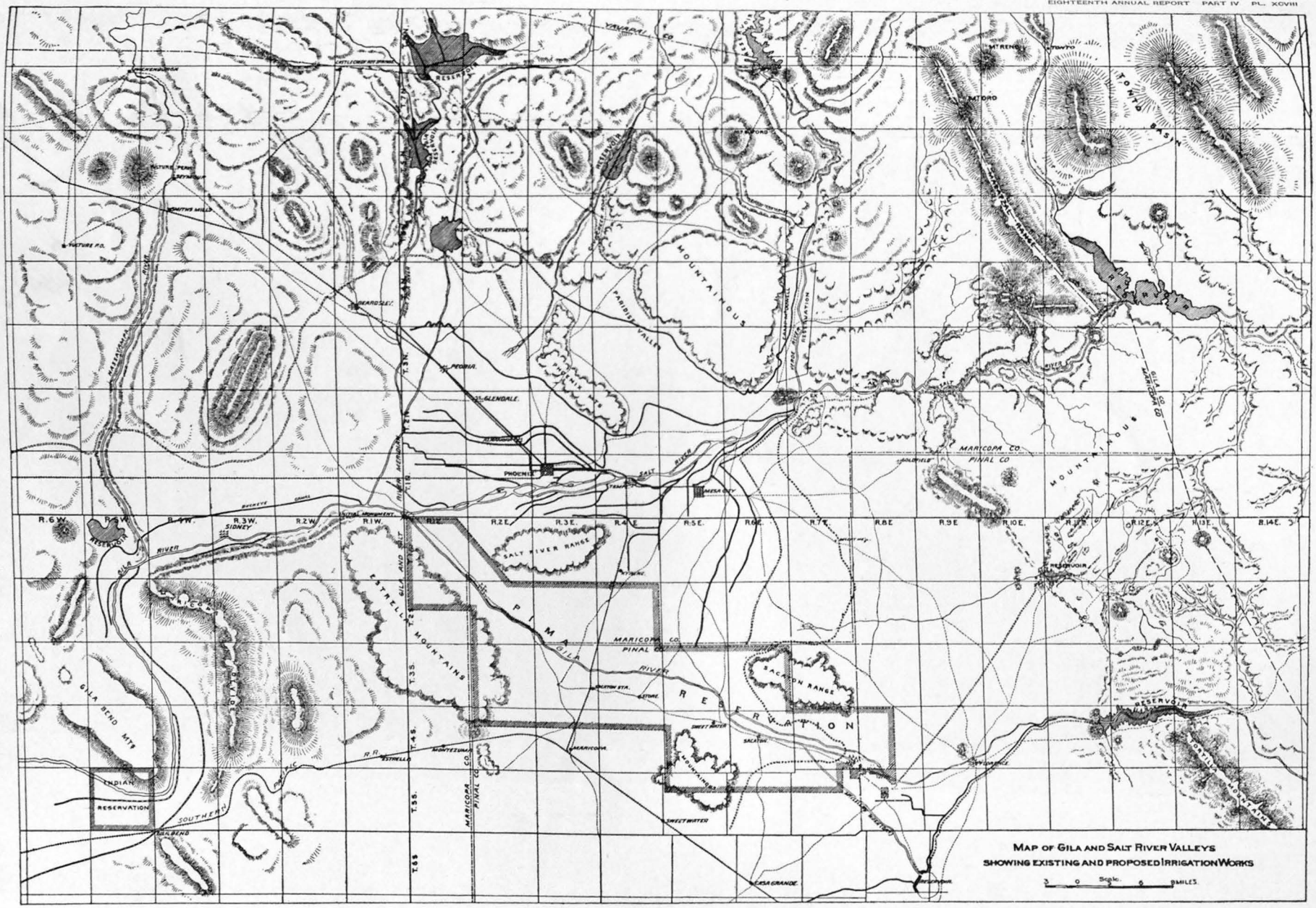
The area of tillable land above the highest canals that would be irrigated by the works herein mentioned (which are only those noted in the company's prospectus as the works to be built on "Initial Construction") is given as 220,000 acres, of which 15,000 acres are in the Verde Valley and may form a part of another reservoir to be built by the Arizona Improvement Company, 110,000 acres are between old Fort McDowell and the Agua Fria River, and 95,000 acres are west of the Agua Fria.

The plans of the company also contemplate the construction of the following: A reservoir on New River, to be fed by the canal and the rather limited drainage of the stream, and to have a capacity of 133,500 acre-feet, covering 3,416 acres; "Reservoir No. 3," covering 1,000 acres, with a capacity of 10,000 acre-feet; and "Reservoir No. 4," with an area of 2,493 acres and a capacity of 68,093 acre-feet. The cost of these is not included in the above estimate. The entire system will cost from $3,000,000 to $4,000,000. All of the dams proposed are to be of the rock-fill, asphaltum-covered type.

The company proposes to guarantee to the irrigators, in their water-right contracts, the delivery to them of 2 acre-feet per acre, if demanded, in any one irrigating season; if more water is required it will be paid for extra, and the company does not guarantee to furnish it if there is a shortage. The annual rates are to be on a sliding scale of increase up to the eleventh year, when the maximum will be $2.42 per acre-foot, the first two years being one-half that rate. Water rights are sold at $10 per acre, of which $1 is paid down and $1 per acre per annum thereafter until fully paid, with 8 per cent interest on deferred payments.

### McDOWELL RESERVOIR PROJECT, ARIZONA.

The Arizona Improvement Company, the owner of the Arizona Canal, which heads in Salt River half a mile below the mouth of the Verde, has in contemplation the erection of a storage-reservoir dam a short distance above the mouth of the Verde, on the Verde River, to afford a means of fortifying their canal during low-water periods. The reservoir will flood a large part of the abandoned military reservation of Fort McDowell, from which it takes its name. The capacity of the reservoir is computed by Mr. F. P. Trott, county surveyor, of Phœnix, as 15,000,000,000 cubic feet, or 344,350 acre-feet. The height of dam


MAP OF GILA AND SALT RIVER VALLEYS
SHOWING EXISTING AND PROPOSED IRRIGATION WORKS
Scale.
MILES.
PHOENIX
MESA CITY
GLENDALE
PEORIA
TEMPE
MARICOPA CO.
PINAL CO.
SALT RIVER RANGE
SACATON RANGE
SACATON
MARICOPA
ESTRELLA MOUNTAINS
GILA BEND MTS
GILA BEND
INDIAN RESERVATION
SOUTHERN PACIFIC
SALT RIVER
GILA RIVER
MOUNTAINOUS
PARADISE VALLEY
PHOENIX MTS
SUPERSTITION MTS
MT. ORD
MT. RENO
TONTO BASIN
RESERVOIR
SIDNEY
BUCKEYE
SACATON STA.
ESTRELLA
MONTEZUMA
SWEET WATER
CASA GRANDE
R.6W.
R.5W.
R.4W.
R.3W.
R.2W.
R.1W.
R.1E.
R.2E.
R.3E.
R.4E.
R.5E.
R.6E.
R.7E.
R.8E.
R.9E.
R.10E.
R.11E.
R.12E.
R.13E.
R.14E.
T.1N.
T.2N.
T.3N.
T.1S.
T.2S.
T.3S.
T.4S.
T.5S.
T.6S.

proposed is 140 feet; extreme length, 1,594 feet. A spillway, 800 feet long and 10 feet deep, will be excavated in the crest of a ridge of rock east of the dam. The computation of contents is made from a contour line run at 114 feet above the low-water level at the dam, or 1,430 feet above tide. Bed rock is exposed across the site with the exception of 200 feet, where soundings locate it at a depth of from 1 to 22 feet below the surface. Plans for the dam have not been definitely adopted, and no estimates of cost have been made.

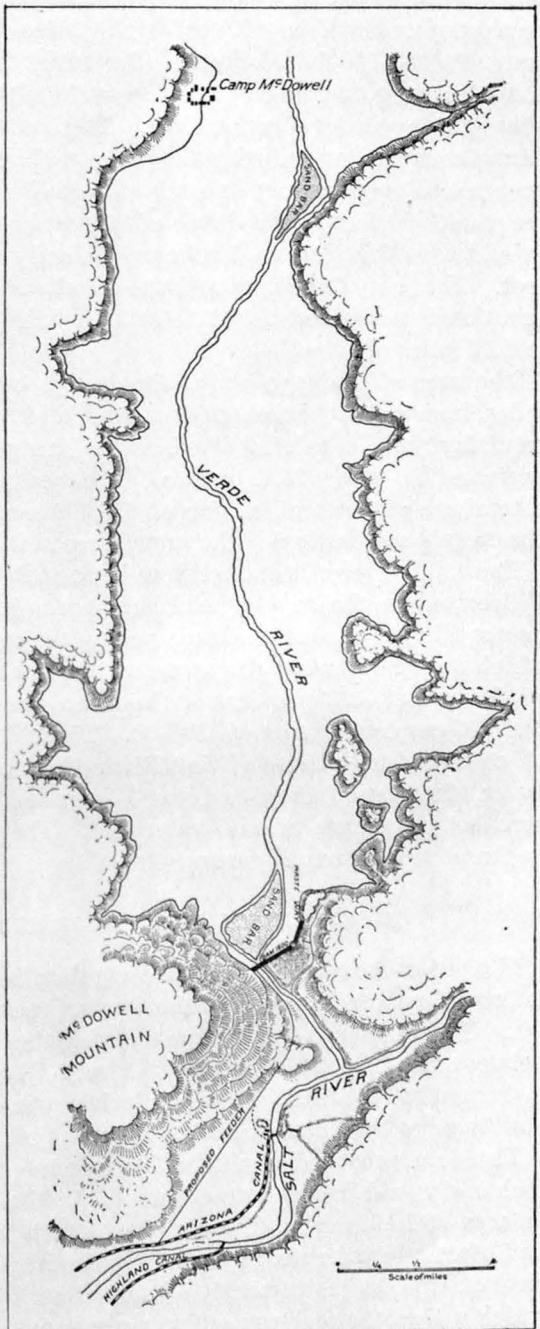



FIG. 123.—Map of lower portion of McDowell reservoir.

## BUTTES RESERVOIR SITE ON THE GILA RIVER, ARIZONA.

A complete description of this capacious site for water storage, the result of an exhaustive study of the problems involved, by Mr. Arthur P. Davis, C. E., has been recently published,[1] from which it appears that a masonry dam 235 feet high above its foundations, 167 feet thick at base and 12 feet at top, with a length of 800 feet at top and a base length of over 300 feet, is proposed for the impounding of 207,795

[1] Report on the Irrigation Investigation for the benefit of the Pima and other Indians on the Gila River Indian Reservation, Arizona, by Arthur P Davis, Hydrographer: Senate Doc. 27, 54th Congress, 2d session, 1897

acre-feet of water, covering a surface area of 3,602 acres. The maximum depth of excavation to bed rock is given as 65 feet; hence the dam proposed will be 170 feet high above the stream bed, carrying water to the 160-foot contour. The outlet is to be through a tunnel 1,200 feet long, starting 300 feet away from the dam inside and 30 feet above low-water level in the river. This is to be made large enough to carry the entire river during the process of building the dam. A spillway in two sections, one on each side of the dam, and having a total length of 800 feet and a depth of 10 feet below the top of the dam, is provided in the plan to discharge a flood volume of 102,566 second-feet. The cost of the dam and the canal system for irrigating the reservation is estimated as $2,244,000, including 23 miles of main canal and 50 miles of laterals.

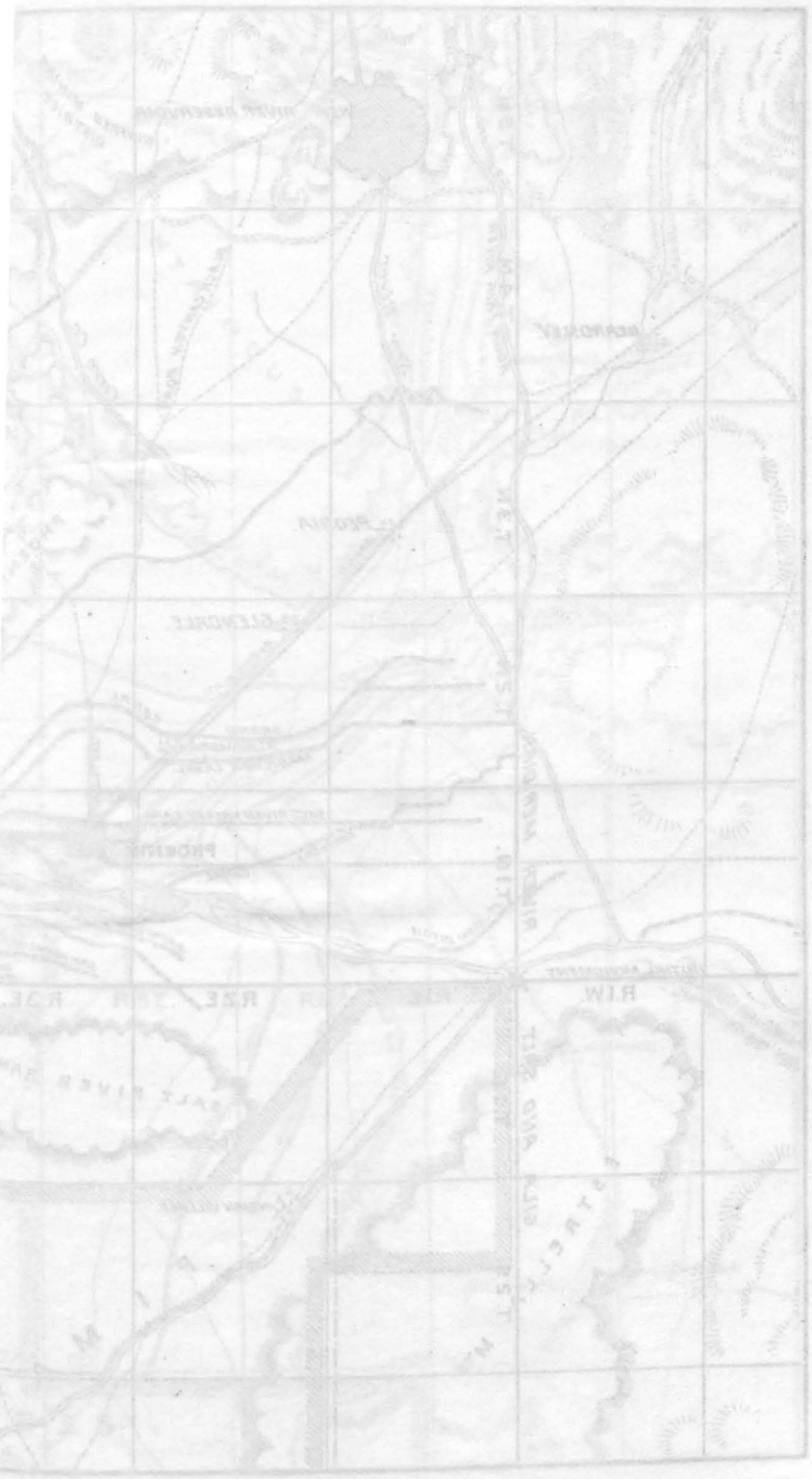
The area of drainage above the dam is computed as 13,750 square miles, from which the measured run-off in 1889–90 was 366,593 acre-feet, resulting from a rainfall of which the mean at three stations on the drainage basin was 15.52 inches. The measurements of 1895–96 gave a total run-off for that season of 623,069 acre-feet, during which time the mean precipitation of the same three stations was but 11.21 inches.

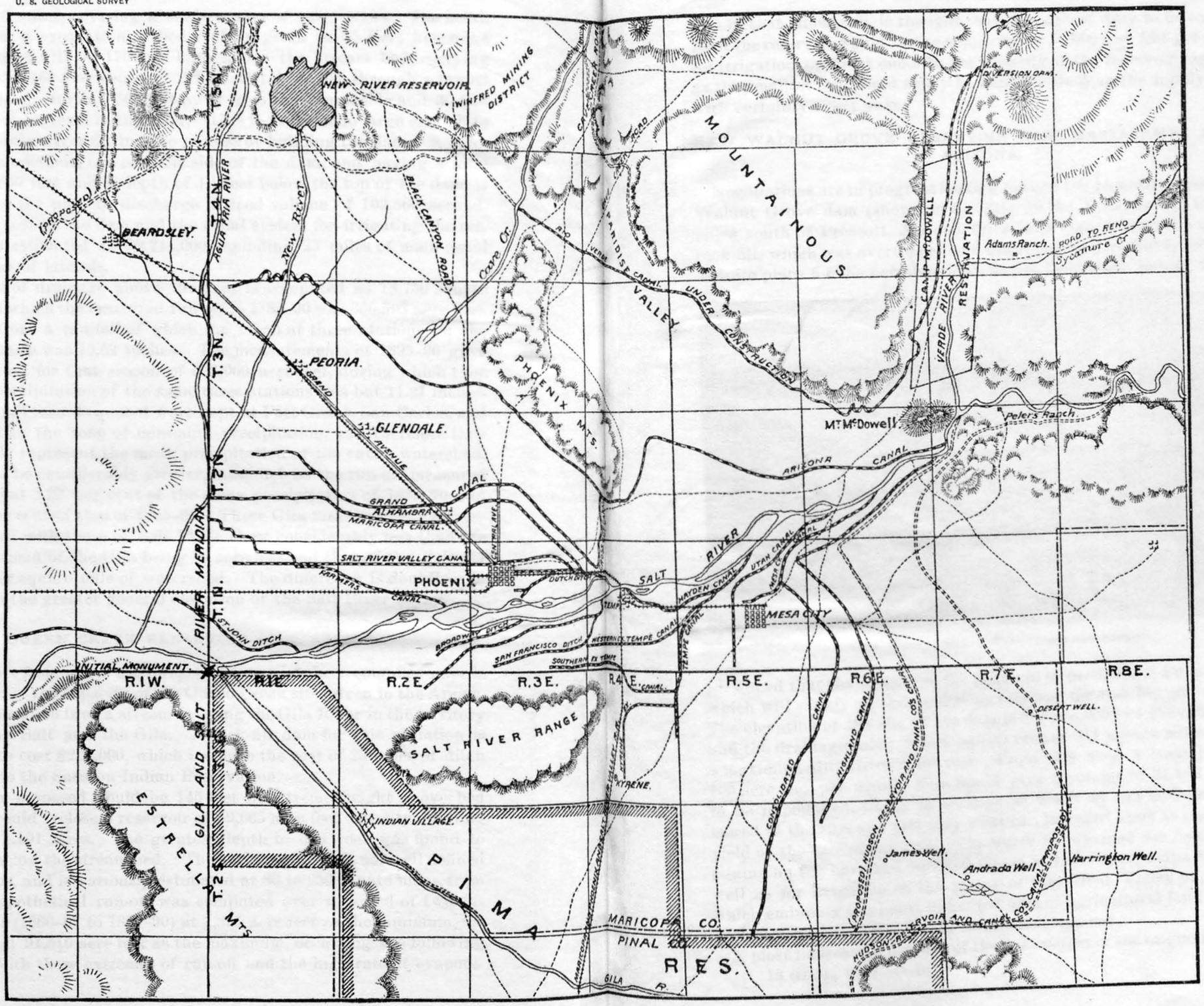
The rainfall records quoted were kept at Fort Grant, San Carlos, and Wilcox, all in the zone of minimum precipitation, and therefore they do not fairly represent the mean precipitation of the entire watershed, which must be considerably greater, inasmuch as the run-off measured would be but 3.22 per cent of the mean precipitation of 1889–90 and but 7.57 per cent of that of 1895–96. These Gila measurements of run-off compared with those of Salt River show considerably less than the latter, the mean of the Gila being 36 acre-feet and that of the Salt 177 acre-feet per square mile of watershed. The difference is doubtless to be found in the greater general elevation of the Salt River basin.

## QUEEN CREEK RESERVOIR SITE, ARIZONA.

The report from which the foregoing data have been compiled affords information of the capacity of the Queen Creek site, given in the Appendix. The location is on a stream entering the Gila River in the territory between the Salt and the Gila. A rock-fill dam for this situation is estimated to cost $221,000, which includes the cost of 23 miles of ditch and flume to the Sacaton Indian Reservation.

The dam proposed would be 145 feet in extreme height above bed rock and would inclose a reservoir of 59,665 acre-feet capacity, flooding an area of 1,191 acres. The greatest depth to bed rock was found to be 32 feet below the stream bed. The drainage basin is not well defined on the maps, and is variously estimated at 80 to 250 square miles, from which a hypothetical run-off was computed over a period of twenty-three years (1866–67 to 1889–90) at 1,391 acre-feet as the minimum, for 1870–71, and 91,510 acre-feet as the maximum, occurring the following season. With these extremes of run-off and the high rate of evapora-






MAP OF SALT RIVER VALLEY, SHOWING CANALS CONSTRUCTED AND PROPOSED.

tion in that climate, it is thought that the highest duty to be expected from the reservoir would be the supplying of 10,000 acre-feet per annum for irrigation, or about one-fifth the capacity of the reservoir suggested as the smallest that could safely be built for yielding the supply stated with certainty every year.

## NEW WALNUT GROVE RESERVOIR DAM, HASSAYAMPA RIVER, ARIZONA.

Negotiations are in progress looking toward the reconstruction of the Walnut Grove dam (shown in fig. 124), on the Hassayampa River 28 miles south of Prescott, Arizona, on a larger scale than the original rock-fill, which was overtopped and destroyed by a freshet in 1890. No definite plans for the new dam have as yet been made public, but it is

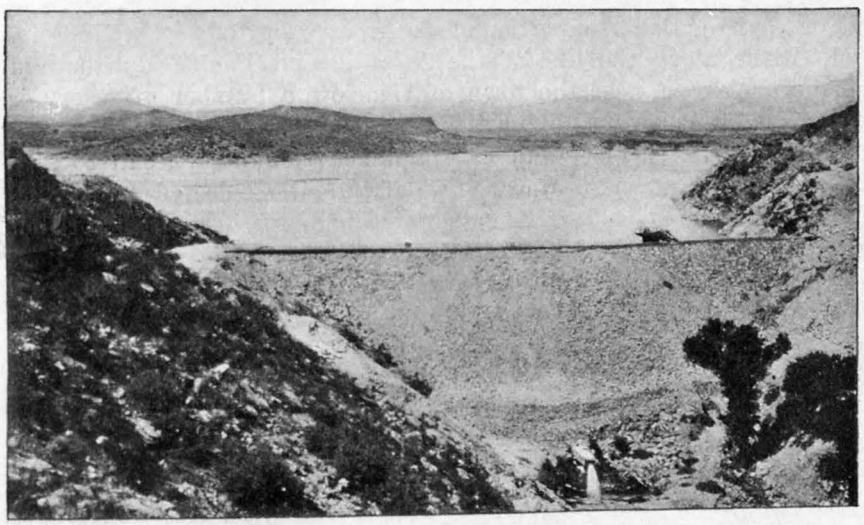


FIG. 124.—View of back of Walnut Grove rock-fill dam.

presumed that the lessons of the past will be heeded and a dam erected which will satisfy all the conditions required for stability and security. The elevation of the site of the dam is about 3,000 feet above sea level, and the drainage basin, which has an area of 311 square miles, reaches a maximum altitude of 8,000 feet. From this shed a mean run-off of 100 acre-feet per square mile would give a volume of 31,100 acre-feet to be impounded, which is perhaps as much as can be economically stored at the site, and probably what can be relied upon as the average yield of the catchment area. The water is intended for use in placer mining on the bars and elevated mesas of the Hassayampa Valley, as well as for irrigation on the plains of the Great Valley of the Gila, which embraces an almost unlimited area of agricultural land awaiting such storage enterprise for its future development.

A most interesting account of the destruction of the original dam has

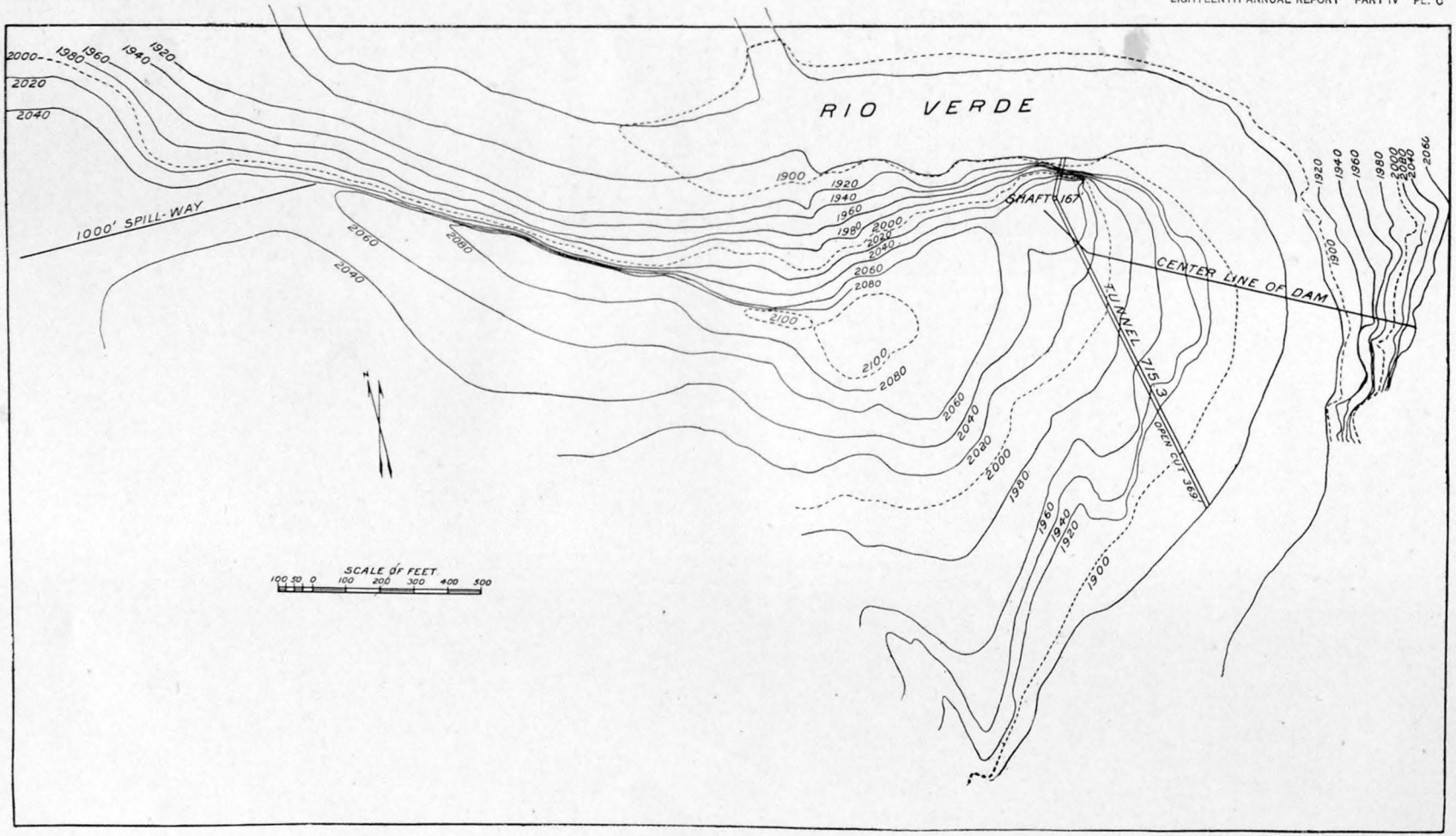
been given by Mr. Herbert Wilson,[1] together with a description of the plan and method of construction. As very justly concluded by Mr. Wilson, the failure of this dam, although a most awful public disaster, teaching emphatic lessons of caution and care in such works, is in no sense a reflection upon the general type of rock-fill dams, for "its destruction was largely due to the insufficiency of waste way and carelessness in the workmanship." The most important lesson to be drawn from it is that under no circumstances is it prudent or permissible to allow flood water to flow over the top of a rock-fill dam to any extent, and that it is absolutely imperative to provide ample spillway for the greatest possible discharge of the stream without reaching anywhere near the height of the crest of the dam.

### RESERVOIR SITES ON LITTLE COLORADO RIVER, ARIZONA.

For the irrigation of a portion of the great valley of the Little Colorado River, along the line of the Atlantic and Pacific Railroad in northern Arizona, near the town of Winslow, a number of reservoir sites have been surveyed by parties interested. The general elevation of the valley is 4,800 feet, and its watershed summits extend to altitudes of 7,000 feet and upward. Two of the sites selected are basins in the bottom lands adjacent to the river channel, a few miles north of Winslow, to be closed by earth dams 20 and 40 feet high, respectively. Reservoir No. 1 has a capacity of 68,800 acre-feet, and No. 2 a capacity of 114,800 acre-feet. They will be fed by the drainage from Sunset Canyon and Salt Creek, having a watershed area of about 300 square miles, and also by a canal from the river, starting at the mouth of the Rio Puerco near Holbrook and taking in on the way the water of Chevlons Fork and Clear Creek, the total length of the canal being 27 miles to Chevlons Fork, thence 8 miles to Clear Creek, thence 14 miles to Reservoir No. 1; total, 49 miles. This canal would not only be used as a feeder for the reservoirs, but for distribution of irrigation water along the valley from another reservoir, of 55,000 acre-feet capacity, located near the town of Woodruff. A rock-fill dam 60 feet high is projected at this latter site.

At Hay Lake, on the head of Sunset Canyon, a fourth site, having a capacity of 150,000 acre-feet, has been selected, where a dam of earth but 20 feet high and 600 feet long is required. The supply to this reservoir is to be supplemented by a short canal diverting the drainage of the upper part of Canyon Diablo. All the dams mentioned are to be 5 feet higher than the level to which they would be filled. Other dams are projected on Clear Creek and Chevlons Fork, to serve rather as diverting weirs than as storage-reservoir dams. They are to be constructed of the sandstone which abounds in this region. The minimum low-water flow of these streams is about 10 and 12 second-feet respectively, and that of the Little Colorado about 40 second-feet. The entire

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, p. 297.




MAP OF SITE OF HORSESHOE RESERVOIR, ON VERDE RIVER.

system contemplates four storage dams and four diverting or pick-up weirs, the total storage provided being about 353,500 acre-feet, at an estimated cost of $357,000. The canals for conveying and distributing the water are estimated at $373,000, making the total cost of the system $730,000, or a little more than $2 per acre-foot.

The watersheds available for the purposes of catchment, as nearly as can be determined from the best maps to be had, are approximately as follows:

| | Square miles. |
|---|---|
| Canyon Diablo, upper part | 100 |
| Sunset Canyon | 300 |
| Clear Creek | 452 |
| Chevlons Fork | 500 |
| Little Colorado, at mouth of Rio Puerco | 5,281 |

## PROPOSED ROCK CREEK RESERVOIR ON HUMBOLDT RIVER, NEVADA.

One of the tributaries of Humboldt River, which enters that stream above Battle Mountain, Nevada, is known as Rock Creek. It drains a territory of 750 square miles, whose altitude ranges from 5,000 to 13,000 feet above tide level. As it debouches into Humboldt Valley it passes through a narrow, rocky gorge, 5 miles in length, cut deeply through a volcanic range of hills, at the head of which is a favorable site for a dam forming a capacious storage reservoir. The capacity of this reservoir at the 75-foot contour is 80,000 acre-feet, covering 3,670 acres of surface (Pl. CI). The character of dam proposed is a rock-fill, for which the site is best adapted. The canyon is but 120 feet wide at bottom and 300 feet at the 75-foot level. On one side the canyon wall rises quite abruptly over 250 feet high (Pl. CII). The material is a hard porphyry at the dam site, capped at a few hundred feet height by a layer of lava or basalt of considerable depth.

The duty of the reservoir, supplemented by the normal summer flow of Humboldt River, is expected to be the irrigation of 100,000 acres of valley land between Battle Mountain and Winnemucca. Underlying a portion of this land is an artesian belt, which has been explored by a few flowing wells in the neighborhood of Battle Mountain, at the mouth of Reese River, and the general water plane of the valley below the surface is not at a great depth, so that the duty of water in irrigation is expected to be rather higher than on less favorably situated lands. Irrigation in the valley is confined to the neighborhood of Beowawe and Lovelocks, where extensive alfalfa fields are watered from the stream, and the district in question is between these two localities. The run-off from the watershed tributary to the reservoir is estimated at over 150,000 acre-feet per annum—an average of 200 acre-feet per square mile—the precipitation varying from 7 inches annually in the lower portion to over 40 inches in the higher mountain ranges. The cost of the dam is estimated at about $1 per acre-foot of storage capacity.

## LOST CANYON RESERVOIR SITE, AND NATURAL DAM, COLORADO.

The region of Lost Park and Lost Canyon, on Goose Creek, Colorado, a tributary of South Platte River, is one of rugged grandeur, characterized by scenery of the wildest imaginable description, abounding in high cliffs and rock masses of fantastic shapes and colors and of Titanic dimensions. Nature has here made an effort at rock-fill dam construction on a grand scale by filling in the canyon to a maximum depth of 250 feet with an aggregation of enormous bowlders thrown from the neighboring cliffs. This remarkable rock-fill is 2,100 feet in length, and is fairly well represented in a general way by the longitudinal and cross sections shown in figs. 125 and 126. The maximum height above the upper toe is, as stated, 250 feet, but as the bed of the canyon falls 150 feet in the length of the dam, the height of the crest is 400 feet above the lower toe, where the stream emerges from underneath

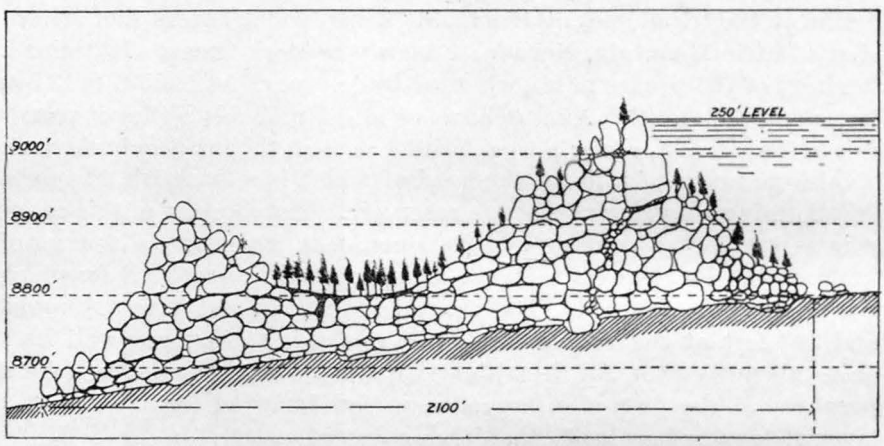
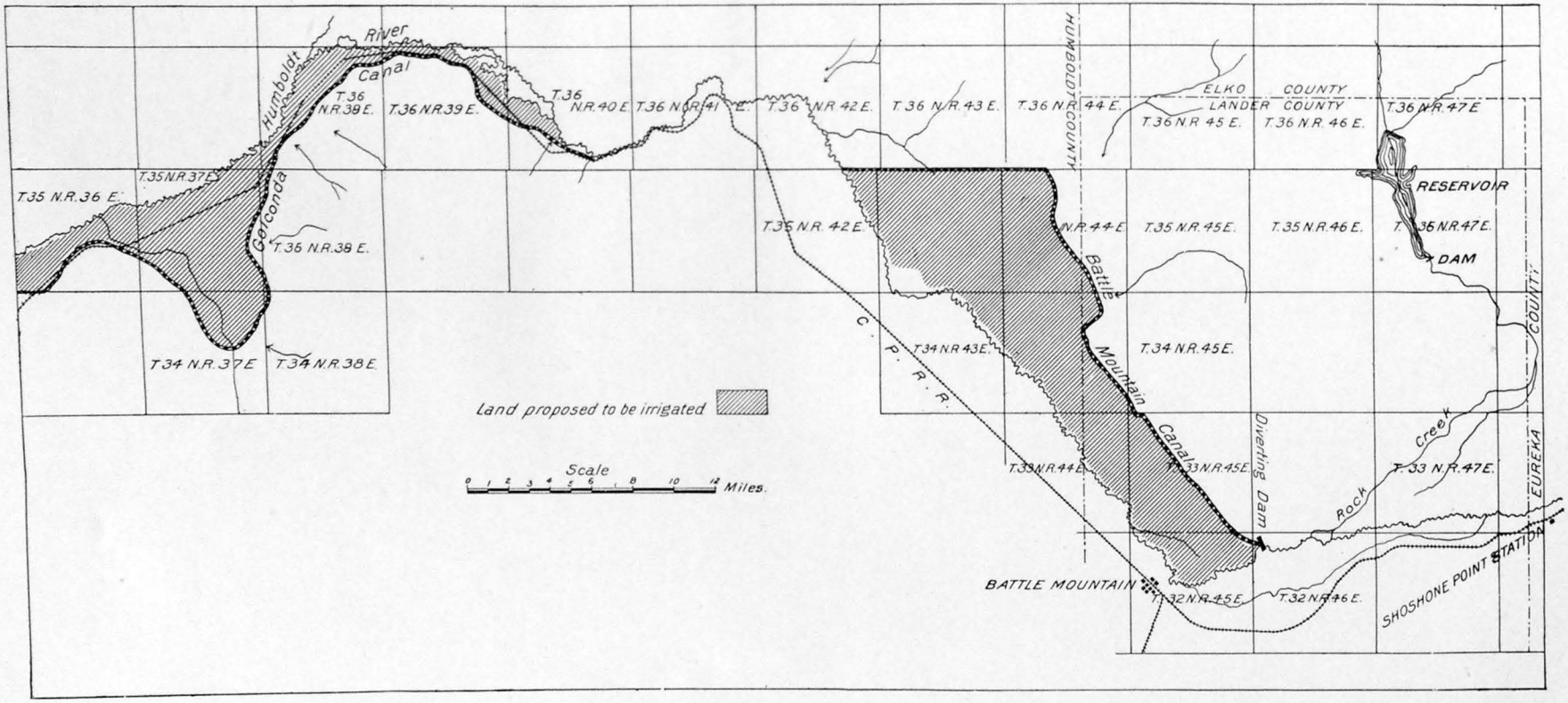



FIG. 125.—Sketch of longitudinal section of Lost Canyon natural dam.

the bowlders. The extreme width on top is 400 feet, although the bulk of the fill is less than 100 feet in width, and at the bottom the canyon width between well-polished walls is but 20 to 25 feet, at such places as it is possible to go underneath and inspect it.

Some of the bowlders that form the embankment are as large as an ordinary two-story dwelling house, and the stream finds its way through them with little apparent obstruction, although the presence of a pile of driftwood at the mouth of a cave on the upper face, 150 feet above the bottom, is an indication that occasionally the volume is too great to find exit in the lower passages and is forced to rise to this higher outlet. It is possible to descend in this cave, by means of ladders and ropes, into the interior of the dam almost to the water level. The crest of the solid mass of the dam proper is at the 200-foot level, although a chain of huge bowlders, 25 to 50 feet high, lying near together, extends across the canyon from side to side. The entire sur-




MAP OF ROCK CREEK RESERVOIR, CANAL LINES, AND LANDS TO BE IRRIGATED

face of the natural embankment is dotted over with large fir trees, growing in the soil that has lodged in the crevices. As the stream emerges from the foot of the dam it has the appearance of a spring flowing out from beneath an old glacial moraine.

Surveys of the site have developed the fact that a reservoir with a capacity of 24,000 acre-feet can be made available for storage and use by making nature's dam water-tight. This may readily be done by filling the crevices and cavities on the upper face with concrete and providing a proper outlet for the water by means of a tunnel. The

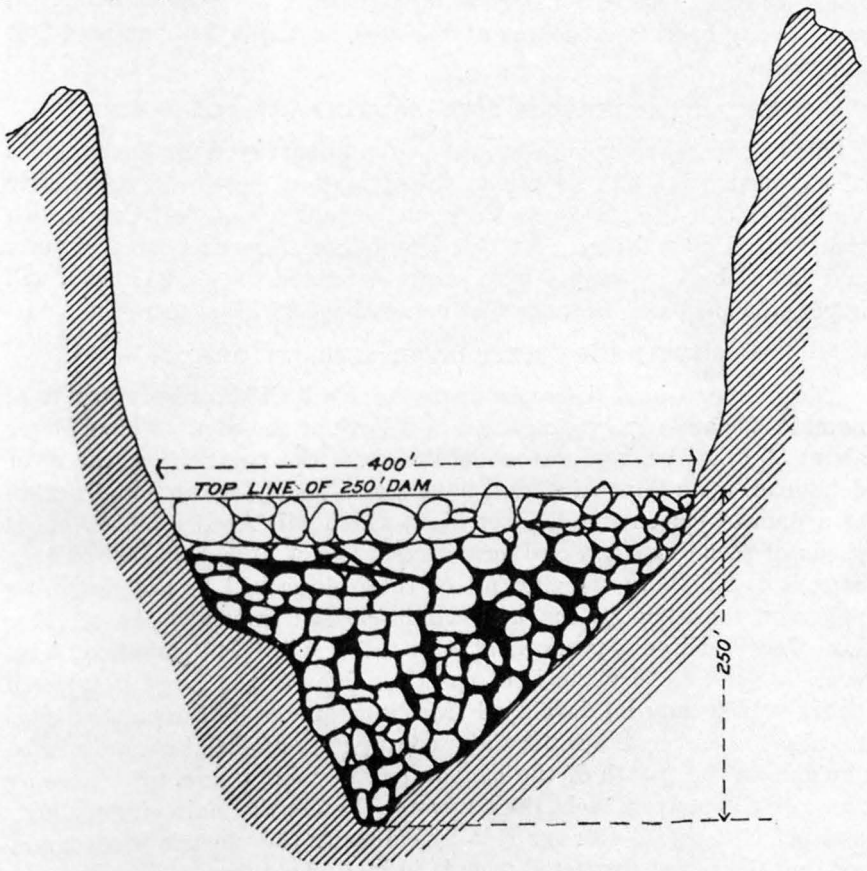



FIG. 126.—Sketch of cross section at upper end of Lost Canyon natural dam.

latter has been projected on the 75-foot level, and will require to be 1,200 feet long to reach a neighboring canyon. The cost of this work has been estimated at $104,000, or $4.35 per acre-foot of storage capacity in the reservoir. An addition of 20 feet to the top of the dam would increase this capacity to 27,700 acre-feet, and the cost to $144,000, the work to be done in Portland-cement masonry. The reservoir has been in contemplation for some years as a storage for irrigation and domestic supply in and around Denver, from which city it is some 60 miles distant.

### TARRYALL RESERVOIR SITE, COLORADO.

The Rocky Mountain park region abounds in reservoir sites of more or less magnitude and value. On Tarryall Creek, near its junction with the South Platte River, a dam and reservoir site exists, whose capacity at the 160-foot contour is 46,000 acre-feet. The width of the canyon at the dam-site is but 80 feet at the stream bed and 480 feet at the 160-foot line. The area flooded at that level would be 775 acres.

The foundations for the dam are of granite, and the general conditions are well adapted for a masonry structure, the cost of which on safe gravity lines is estimated at $550,000, or about $12 per acre-foot impounded.

### ANTERO RESERVOIR SITE, SOUTH PARK, COLORADO.

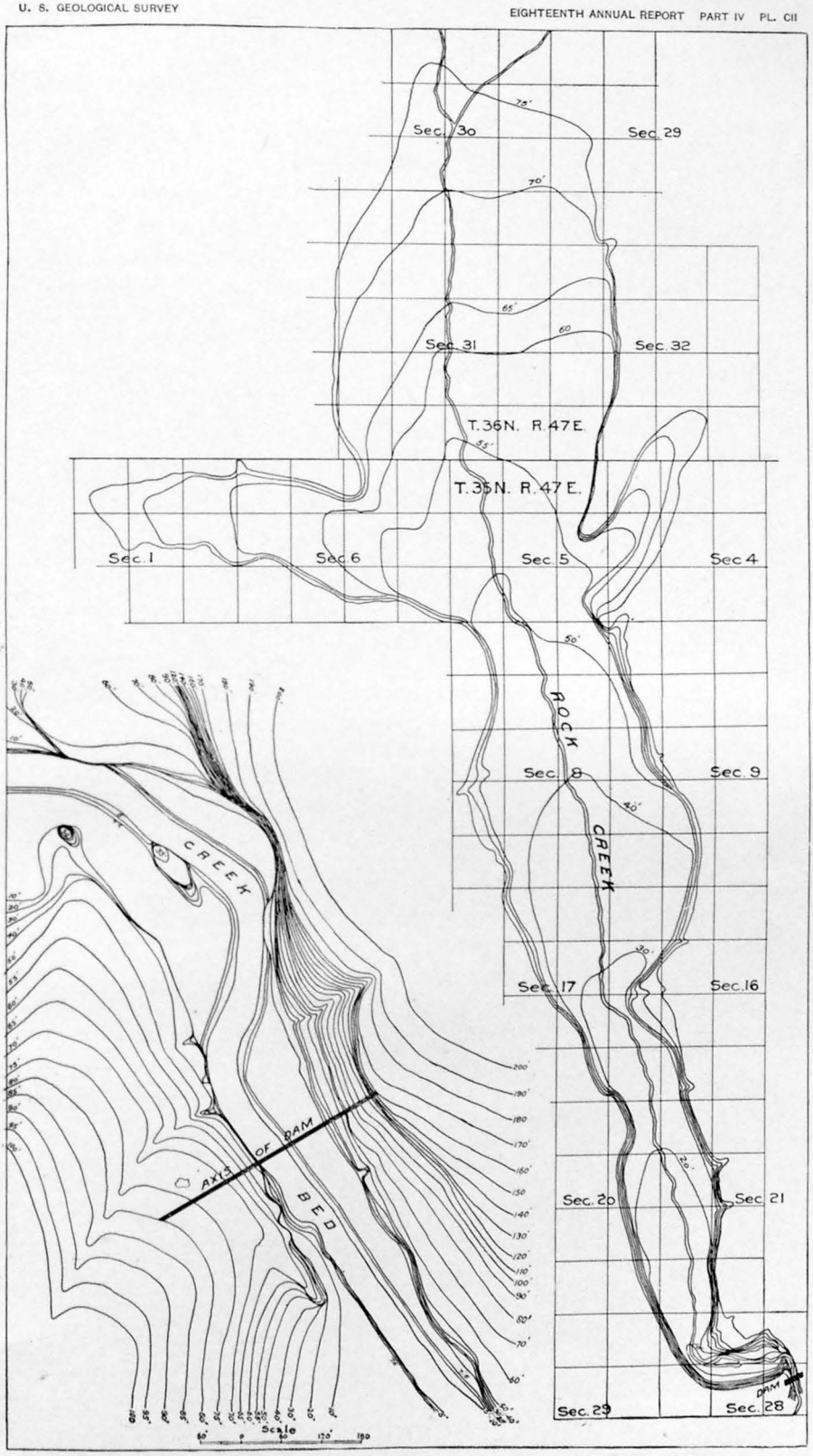
One of several reservoir sites selected and surveyed for the purpose of supplementing the supply to the irrigation canals of the Platte Valley is located in the South Park, at the junction of Salt Creek with the South Platte River. At this site a dam of earth 4,000 feet long and 36 feet high, riprapped with stone, estimated to cost $140,000, will impound 50,640 acre feet, the cost being about $2.76 per acre-foot.

### SOUTH FORK RESERVOIR SITE, COLORADO.

The Denver Union Water Company have acquired a reservoir site of notable size and capacity on the South Fork of the South Platte River about 30 miles back in the mountains from the point where the river debouches upon the plains, and have made plans for the construction of a dam of masonry 211.5 feet high, which will require 60,000 cubic yards of stone masonry and form a reservoir of 22,000,000,000 gallons capacity. This site is below all of those described in the foregoing pages on the same stream, and water released from any one of them into the river would necessarily pass through it. Its elevation, however, is such as to make it of special value for the large volume of power which may be developed from its water and transmitted electrically to Denver, the water to be conveyed in artificial conduits from the dam to the mouth of the canyon or the point where, after passing through the power wheels, the water would enter the main city conduits and be conveyed to Denver side by side with the electric wires transmitting the power extracted from it in its descent from the mountains. The dam proposed will be 473 feet long on top; 20 feet on the river bed. Its base will be 170 feet, and top width 20 feet. It will be straight in alignment, and the top of the parapet will be 7.5 feet above the high-water line, the spillway being located on a long ridge of hard granite, which happens to be of the desired height, at some little distance from the dam on the left bank.

## ACKNOWLEDGMENTS.

In closing this paper the author desires to make due acknowledgment to the following gentlemen for many courtesies received and valuable assistance rendered in the collection and compilation of the data




CONTOUR MAP OF ROCK CREEK RESERVOIR AND DAM SITE.

used in the foregoing pages: H. N. Savage, M. Am. Soc. C. E., chief engineer San Diego Land and Town Company, National City, California; J. M. Howells, C. E., president San Diego Flume Company, San Diego, California; F. S. Hyde, resident engineer San Diego Flume Company, San Diego, California; Burr Bassell, C. E., Los Angeles, California; E. L. Mayberry, manager Lake Hemet Water Company and constructing superintendent Hemet dam, Hemet, California; Walter James, C. E., Bakersfield, California; E. F. Tabor, C. E., Escondido, California; W. E. Sickler, superintendent Escondido Irrigation District, Escondido, California; A. P. Man, C. E., M. Am. Soc. C. E., chief engineer Hudson Canal and Reservoir Company, New York; J. B. Lippincott, C. E., hydrographer United States Geological Survey, Los Angeles, California; F. P. Trott, C. E., Phœnix, Arizona; J. K. Doolittle, secretary Rio Verde Canal Company, Phœnix, Arizona; Pillsbury & Skinner, civil engineers, Los Angeles, California; Burt Cole, engineer South Antelope Valley Irrigation Company, Palmdale, California; Capt. W. H. Hancock, Phœnix, Arizona; Hermann Schussler, C. E., chief engineer Spring Valley Waterworks, San Francisco, California; L. H. Taylor, C. E., hydrographer United States Geological Survey, Battle Mountain, Nevada; E. H. McHenry, chief engineer Northern Pacific Railway, St. Paul, Minnesota; Charles S. Bihler, resident engineer Northern Pacific Railway, Tacoma, Washington; H. J. Cambie, chief engineer Pacific Division Central Pacific Railway, Vancouver, British Columbia; Edmund Duchesnay, division engineer Central Pacific Railway, Vancouver, British Columbia; Burt Cole, C. E., Palmdale, California.

---

# APPENDIX.

## TABLES OF RESERVOIR CAPACITIES AND AREAS.

### ESCONDIDO IRRIGATION DISTRICT RESERVOIR, CALIFORNIA.

[Area of tributary watershed, 8 square miles; elevation of base of dam above sea level, 1,300 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 20 | ..... | 46 | Capacity of reservoir as completed in 1895, 3,500 acre-feet. Outlet of reservoir is 16 feet above base. |
| 35 | ..... | 288 | |
| 50 | ..... | 970 | |
| 65 | ..... | 2,400 | |
| 80 | 174 | 4,576 | |
| 90 | ..... | 6,455 | |
| 100 | ..... | 8,693 | |
| 110 | 285 | 11,355 | |

## LOWER OTAY RESERVOIR, CALIFORNIA.

[Area of tributary watershed, 100 square miles; elevation of base of dam above sea level, 345 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 30 | 40 | 321 | Outlet tunnel 48 feet above base of dam. For cross section of dam site see fig. 117, p. 707. |
| 40 | 96 | 1,002 | |
| 50 | 160 | 2,284 | |
| 60 | 239 | 4,281 | |
| 70 | 276 | 6,860 | |
| 80 | 303 | 9,756 | |
| 90 | 452 | 13,530 | |
| 100 | 567 | 18,623 | |
| 130 | 1,000 | 42,190 | |
| 150 | 1,414 | 66,455 | |

## MORENA RESERVOIR, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 135 square miles; elevation of base of dam above sea level, 3,100 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 50 | 46 | 460 | Outlet tunnel is at 30-foot contour. Rock-fill dam, with asphalt concrete facing. For cross section of dam site see fig. 117, p. 707. |
| 60 | 73 | 1,079 | |
| 70 | 111 | 2,029 | |
| 80 | 152 | 3,316 | |
| 90 | 225 | 5,188 | |
| 100 | 304 | 7,831 | |
| 110 | 438 | 11,466 | |
| 120 | 624 | 16,804 | |
| 130 | 850 | 24,107 | |
| 140 | 1,137 | 34,358 | |
| 150 | 1,370 | 46,733 | |

## LA MESA RESERVOIR, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 5 square miles; elevation of base of dam above sea level, 433.5 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 30 | 12 | 110 | |
| 35 | 18 | 190 | |
| 40 | 24 | 290 | |
| 45 | 30 | 430 | |
| 50 | 41 | 610 | |
| 55 | 53 | 850 | |
| 60 | 62 | 1,190 | |
| 65 | 70 | 1,460 | Hydraulic-fill dam, completed 1895, to 66-foot contour. Outlet at base of dam. |
| 70 | 83 | 1,850 | |
| 75 | 96 | 2,290 | |
| 80 | 113 | 2,820 | |
| 85 | 129 | 3,420 | |
| 90 | 152 | 4,120 | |
| 95 | 181 | 4,950 | |
| 100 | 205 | 5,920 | |
| 140 | 444 | 18,890 | |

## PINE VALLEY RESERVOIR, SAN DIEGO COUNTY, CALIFORNIA.

[Area of watershed, 45 square miles; elevation of base of dam, 3,700 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 40 | 90 | 550 | |
| 50 | 160 | 1,800 | |
| 60 | 240 | 3,800 | |
| 65 | 277 | 5,100 | |
| 70 | 300 | 6,530 | |
| 80 | 315 | 9,610 | |
| 90 | 330 | 12,835 | Dam proposed to be constructed by hydraulic process as a rock-fill earth dam. For cross section of dam site see fig. 117, p. 707. |
| 100 | 349 | 16,230 | |
| 110 | 397 | 19,960 | |
| 120 | 520 | 24,540 | |
| 125 | 586 | 27,080 | |
| 130 | 640 | 30,380 | |
| 140 | 720 | 37,180 | |
| 150 | 784 | 44,695 | |

## LAKE HEMET RESERVOIR, RIVERSIDE COUNTY, CALIFORNIA.

[Area of watershed, 65 to 100 square miles; elevation of base of dam, 4,200 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 40.0 | 2.0 | 33 | |
| 45.0 | 2.3 | 73 | Lowest outlet at 45 feet. |
| 50.0 | 3.0 | 113 | |
| 60.0 | 29.0 | 332 | |
| 70.0 | 62.0 | 773 | |
| 80.0 | 103.0 | 1,603 | |
| 90.0 | 133.0 | 2,787 | |
| 100.0 | 187.0 | 4,391 | |
| 110.0 | 252.0 | 6,598 | |
| 120.0 | 328.0 | 9,512 | |
| 122.5 | 365.0 | 10,500 | Top of dam as completed 1895. |
| 130.0 | 486.0 | 13,590 | |
| 140.0 | 601.0 | 19,077 | |
| 150.0 | 738.0 | 25,836 | |

## SWEETWATER DAM, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 186 square miles; elevation of lowest outlet above sea level, 140 feet.]

| Height above lowest outlet. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 0.0 | 3.5 | ..... | Lowest outlet is 24 feet above lowest foundations of dam. |
| 10.0 | 17.1 | 94 | |
| 20.0 | 75.2 | 540 | |
| 30.0 | 153.7 | 1,679 | |
| 40.0 | 272.2 | 3,748 | |
| 50.0 | 398.0 | 7,066 | |
| 60.0 | 539.0 | 11,737 | |
| 70.0 | 722.0 | 18,053 | |
| 75.5 | 895.0 | 22,500 | |

## LITTLE BEAR VALLEY RESERVOIR (ARROWHEAD RESERVOIR COMPANY), SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 6.6 square miles; elevation of base of dam, 4,946.3 feet.]

| Height above tunnel outlet. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 10 | 29.7 | 198 | Bottom of outlet tunnel is 15.5 feet above bed of creek at base of dam; lowest foundations about 15 feet lower. |
| 20 | 55.8 | 619 | |
| 30 | 77.0 | 1,280 | |
| 40 | 109.6 | 2,207 | |
| 50 | 191.8 | 3,680 | |
| 60 | 236.9 | 5,830 | |
| 70 | 286.0 | 8,414 | |
| 80 | 336.3 | 11,518 | |
| 90 | 395.8 | 15,170 | |
| 100 | 452.0 | 19,401 | |
| 110 | 535.0 | 24,326 | |
| 120 | 626.0 | 30,094 | |
| 135 | 716.0 | 40,144 | |
| 147 | 800.0 | 49,238 | |
| 160 | 884.0 | 60,179 | |
| 175 | 932.0 | 73,800 | |

## GRASS VALLEY RESERVOIR SITE (ARROWHEAD RESERVOIR COMPANY), SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 2.7 square miles; elevation of base of dam site, 5,108.3 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 22 | 5.4 | 37 |
| 32 | 29.5 | 196 |
| 42 | 52.8 | 502 |
| 52 | 72.8 | 1,225 |
| 62 | 100.7 | 2,090 |
| 72 | 115.7 | 3,180 |
| 82 | 138.0 | 4,460 |
| 92 | 159.7 | 5,946 |
| 102 | 180 4 | 7,632 |
| 112 | 200.2 | 9,550 |
| 122 | 210.0 | 11,635 |
| 125 | 234.0 | 12,329 |
| 150 | 301.8 | 19,010 |
| 175 | 381.7 | 27,547 |

## HUSTON FLAT RESERVOIR (ARROWHEAD RESERVOIR COMPANY), SAN BERNARDINO COUNTY, CALIFORNIA.

[Elevation of creek bed at dam site, 4,450 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 20 | 8.0 | 60 |
| 30 | 20.8 | 200 |
| 40 | 37.0 | 486 |
| 50 | 55.8 | 947 |
| 60 | 74.5 | 1,595 |
| 70 | 93.5 | 2,430 |
| 80 | 112.7 | 3,459 |
| 90 | 135.6 | 4,700 |
| 100 | 157.1 | 6,150 |
| 110 | 180.5 | 7,616 |
| 120 | 206.0 | 9,762 |
| 130 | 234.0 | 11,975 |
| 140 | 257.9 | 14,411 |
| 150 | 283.2 | 17,138 |
| 175 | 329.5 | 24,753 |

## PAUBA RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 372 square miles; elevation of base of dam, 1,350 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 10 | 10.7 | 54 | |
| 20 | 62.3 | 441 | |
| 30 | 110.5 | 1,262 | |
| 40 | 190.7 | 2,760 | |
| 50 | 282.8 | 5,150 | |
| 60 | 340.7 | 8,250 | Maximum depth to bed rock about 25 feet in center of channel. |
| 70 | 447.0 | 12,200 | |
| 80 | 584.2 | 17,355 | |
| 90 | 689.4 | 24,723 | |
| 100 | 805.9 | 32,200 | |
| 130 | 1,214.0 | 62,496 | |
| 140 | 1,441.0 | 75,770 | |

## WARNER'S RANCH RESERVOIR SITE, SAN LUIS REY RIVER, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 210 square miles; elevation of base of dam, 2,613 feet. For cross section of dam site see fig. 117, p. 707.]

| Height above stream bed. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 10 | 42 | 200 |
| 20 | 228 | 1,565 |
| 30 | 739 | 16,415 |
| 40 | 1,200 | 16,140 |
| 50 | 1,532 | 29,830 |
| 60 | 2,036 | 47,710 |
| 70 | 2,695 | 71,410 |
| 80 | 3,237 | 103,500 |
| 90 | 4,437 | 142,740 |
| 100 | 5,535 | 193,200 |

## SANTA MARIA VALLEY RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 60 square miles; elevation of base of dam, 1,300 feet. For cross section of dam site see fig. 117, p. 707.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 20 | 7.6 | 45 |
| 30 | 23.2 | 199 |
| 40 | 41.3 | 522 |
| 50 | 80.3 | 1,108 |
| 60 | 154.3 | 2,305 |
| 70 | 285.9 | 4,500 |
| 80 | 561.3 | 8,736 |

## PAMO VALLEY RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 125 square miles; elevation of base of dam, 803 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 40 | ..... | 204 | Outlet of reservoir to be at the 40-foot level. For cross section of dam site see fig. 117, p. 707. |
| 50 | ..... | 438 | |
| 60 | ..... | 766 | |
| 70 | ..... | 1,242 | |
| 80 | ..... | 2,049 | |
| 90 | ..... | 3,305 | |
| 100 | ..... | 5,083 | |
| 110 | ..... | 7,374 | |
| 120 | ..... | 10,425 | |
| 130 | 401.4 | 14,127 | |
| 140 | 476.5 | 18,527 | |
| 150 | 614.8 | 24,065 | |
| 160 | 708.8 | 31,700 | |
| 170 | ..... | 38,300 | |
| 185 | ..... | 49,100 | |

## DYE VALLEY RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 5 square miles; elevation of base of dam, 2,200 feet.]

| Height above base of dam. | Capacity of reservoir. | Remarks. |
|---|---|---|
| *Feet.* | *Acre-feet.* | |
| 80 | 4,800 | To be fed by diversion of Santa Ysabel Creek, draining 30 square miles of mountain territory. |

## CUYAMACA RESERVOIR, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 11.03 square miles; elevation of dam, about 4,850 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 10 | 6 | 12 | |
| 12 | 44 | 60 | |
| 14 | 106 | 200 | |
| 16 | 178 | 490 | |
| 18 | 255 | 900 | |
| 20 | 346 | 1,520 | |
| 22 | 428 | 2,290 | Top of dam, 41.5 feet above base. Floor of waste way at 35-foot contour above base. |
| 24 | 519 | 3,240 | |
| 26 | 605 | 4,360 | |
| 28 | 684 | 5,650 | |
| 30 | 768 | 7,100 | |
| 32 | 842 | 8,710 | |
| 34 | 919 | 10,470 | |
| 35 | 959 | 11,410 | |

## BARRETT RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 250 square miles; elevation of base of dam, 1,600 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 60 | 70 | 586 | |
| 70 | 97 | 1,412 | |
| 80 | 147 | 2,611 | |
| 90 | 183 | 4,312 | |
| 100 | 231 | 6,322 | |
| 110 | 285 | 8,975 | Used as a diverting dam, to the height of 60 feet, for diverting Morena reservoir water to the Lower Otay reservoir. For cross section of dam site see fig. 117, p. 707. |
| 120 | 363 | 12,123 | |
| 130 | 469 | 16,345 | |
| 140 | 576 | 21,530 | |
| 150 | 662 | 27,835 | |
| 160 | 784 | 35,160 | |
| 170 | 871 | 43,440 | |
| 175 | 936 | 47,970 | |

## UPPER OTAY RESERVOIR SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 8 square miles; elevation of base of dam, 480 feet. For cross section of dam site see fig. 117, p. 707.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 60 | 89 | 643 |
| 80 | 178 | 3,236 |
| 100 | 293 | 7,871 |
| 120 | 452 | 15,342 |

## BEAR VALLEY RESERVOIR, SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 56 square miles; elevation of base of dam, about 6,200 feet.]

| Height above base of dam. | Surface are. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres* | *Acre-feet.* |
| 15 | 10 | 52 |
| 20 | 35 | 159 |
| 25 | 141 | 411 |
| 30 | 295 | 1,558 |
| 35 | 428 | 3,347 |
| 40 | 1,060 | 7,166 |
| 45 | 1,425 | 13,357 |
| 50 | 1,691 | 21,139 |
| 53 | 1,859 | 26,463 |
| 55 | 1,960 | 30,010 |
| 57 | 2,069 | 34,040 |
| 60 | 2,251 | 40,476 |
| 65 | 2,532 | 52,428 |
| 70 | 2,812 | 65,065 |
| 80 | 3,300 | 95,500 |

## SOUTH ANTELOPE VALLEY IRRIGATION COMPANY'S ALPINE RESERVOIR, LOS ANGELES COUNTY, CALIFORNIA.

[Area of tributary watershed, 6 square miles; elevation bottom of reservoir, 2,779 feet.]

| Height above base of dam | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet* | *Acres.* | *Acre-feet.* | |
| 6 | 106 | 415 | Filled by 8 miles of conduit from Little Rock Creek, with drainage of 61 square miles. |
| 5 | 140 | 1,031 | |
| 16 | 170 | 1,807 | |
| 21 | 202 | 2,734 | |
| 26 | 228 | 3,808 | |
| 31 | 252 | 5,008 | |
| 36 | 277 | 6,332 | |

## VICTOR RESERVOIR SITE, SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 1,200 square miles; elevation of base of dam, 2,708 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 145 | 7,718 | 390,000 |

## SAN LEANDRO RESERVOIR, LAKE CHABOT, OAKLAND WATERWORKS, CALIFORNIA.

[Area of tributary reservoir, 50 square miles; elevation of base of dam above sea level, 115 feet.]

| Height above base of dam. | Surface area | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres* | *Acre-feet.* | |
| 30 | ..... | 0 | Outlet level. |
| 50 | 82 | 1,154 | High-water mark at present, 108.5 feet above base; capacity, 13,115 acre-feet, or 4,274,000,000 gallons. |
| 70 | 165 | 3,635 | |
| 90 | 259 | 7,886 | |
| 110 | 355 | 14,038 | |
| 130 | 468 | 22,290 | |
| 150 | 576 | 32,780 | |
| 170 | 715 | 45,740 | |

## MANACHE MEADOWS RESERVOIR SITE, SOUTH FORK KERN RIVER, CALIFORNIA.

[Area of watershed, 155 square miles; elevation of dam site, 8,200 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 10 | 22 | 110 |
| 20 | 146 | 954 |
| 30 | 812 | 4,563 |
| 40 | 1,865 | 18,827 |
| 50 | 2,599 | 40,732 |
| 60 | 3,254 | 69,885 |
| 70 | 3,814 | 105,236 |
| 80 | 4,420 | 146,419 |
| 100 | 5,830 | 248,852 |

## BIG MEADOWS RESERVOIR SITE, SALMON FORK KERN RIVER, CALIFORNIA.

[Area of watershed (estimated), 25 square miles.]

| Height above base of dam. | Surface area. | Capacity of reservoir. |
|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* |
| 20 | 81 | 409 |
| 30 | 468 | 3,174 |
| 40 | 603 | 8,530 |
| 50 | 723 | 15,169 |
| 60 | 802 | 22,784 |
| 70 | 870 | 31,148 |
| 80 | 930 | 40,036 |
| 100 | 1,020 | 59,311 |

## NORTH FORK LAKE RESERVOIR SITE, UPPER KERN RIVER, CALIFORNIA.

[Elevation, 6,500 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 20 | 46 | ..... | Out. |
| 70 | 104 | 3,763 | |
| 120 | 189 | 11,101 | |
| 170 | 318 | 23,770 | |
| 220 | 598 | 46,614 | |

## BUENA VISTA LAKE RESERVOIR, LOWER KERN RIVER, CALIFORNIA.

[Elevation above sea level, 260 feet.]

| Height above outlet. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 0 | 23,570 | 0 | A depth of 6 feet below the bottom of outlet canal is never drawn upon. |
| 10 | 25,000 | 170,000 | |

## TONTO BASIN RESERVOIR SITE, SALT RIVER, ARIZONA.

[Area of watershed, 6,260 square miles; elevation of base of dam, 1,925 feet.]

| Height above dam at low-water mark. | Area flooded. | Capacity of reservoir. | Height above dam at low-water mark. | Area flooded. | Capacity of reservoir. |
|---|---|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | *Feet.* | *Acres.* | *Acre-feet.* |
| 25 | 330 | 4,400 | 120 | 5,860 | 241,800 |
| 30 | 420 | 6,100 | 125 | 6,210 | 272,800 |
| 35 | 570 | 9,000 | 130 | 6,570 | 303,900 |
| 40 | 730 | 11,900 | 135 | 6,950 | 338,600 |
| 45 | 890 | 16,200 | 140 | 7,350 | 373,400 |
| 50 | 1,030 | 20,000 | 145 | 7,930 | 413,000 |
| 55 | 1,280 | 26,900 | 150 | 8,530 | 453,000 |
| 60 | 1,510 | 33,300 | 155 | 9,110 | 498,000 |
| 65 | 1,740 | 42,000 | 160 | 9,680 | 544,000 |
| 70 | 1,980 | 50,700 | 165 | 10,170 | 594,000 |
| 75 | 2,300 | 62,100 | 170 | 10,680 | 645,000 |
| 80 | 2,610 | 73,500 | 175 | 11,240 | 701,000 |
| 90 | 3,430 | 103,600 | 180 | 11,750 | 757,000 |
| 95 | 3,820 | 122,700 | 185 | 12,300 | 820,000 |
| 100 | 4,210 | 141,800 | 190 | 13,000 | 880,000 |
| 105 | 4,610 | 164,700 | 195 | 13,600 | 950,000 |
| 110 | 4,990 | 187,700 | 200 | 14,200 | 1,020,000 |
| 115 | 5,430 | 214,700 | | | |

## QUEEN CREEK RESERVOIR SITE, ARIZONA.

[Area of watershed, 80 to 250 square miles; elevation of base of dam, creek bed, 2,050 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 20 | 22 | 190 | |
| 30 | 52 | 560 | |
| 40 | 112 | 1,380 | |
| 50 | 209 | 2,985 | |
| 60 | 279 | 5,425 | |
| 70 | 356 | 8,600 | |
| 80 | 445 | 12,605 | Height of dam suggested, 115 feet, would flow to the height of 110 feet. |
| 90 | 538 | 17,520 | |
| 100 | 630 | 23,360 | |
| 110 | 757 | 30,795 | |
| 120 | 894 | 39,050 | |
| 130 | 1,019 | 48,615 | |
| 140 | 1,191 | 59,665 | |

## BUTTES RESERVOIR SITE, GILA RIVER, ARIZONA.

[Area of tributary watershed, 13,750 square miles; elevation of base of dam (low water), 1,600 feet.]

| Height above base of dam. | Surface area. | Capacity of reservoir. | Remarks. |
|---|---|---|---|
| *Feet.* | *Acres.* | *Acre-feet.* | |
| 10 | 20 | 100 | |
| 20 | 71 | 550 | |
| 30 | 229 | 2,050 | |
| 40 | 397 | 5,180 | |
| 50 | 533 | 9,830 | |
| 60 | 741 | 16,200 | |
| 70 | 928 | 24,545 | |
| 80 | 1,105 | 34,710 | |
| 90 | 1,329 | 46,880 | |
| 100 | 1,566 | 61,355 | Height of dam proposed, 170 feet, will carry 160 feet depth of water. |
| 110 | 1,769 | 78,030 | |
| 120 | 2,029 | 97,020 | |
| 130 | 2,367 | 119,000 | |
| 140 | 2,746 | 144,565 | |
| 150 | 3,149 | 174,040 | |
| 160 | 3,602 | 207,795 | |
| 170 | 4,118 | 246,395 | |
| 180 | 4,609 | 290,000 | |
| 190 | 5,133 | 338,740 | |
| 200 | 5,651 | 392,660 | |

# INDEX.


A.

Page.

Abiquiu, New Mexico, stream measurements at ..... 252
Adams, W. M., work of ..... 47
Agua Fria dam, Arizona, description of .. 695–698
Ailes, H. S., aid by ..... 553
Aitken, James, work of ..... 327
Akron, Ohio, water supply of ..... 544
Alabama, cooperation by State geologist of ..... 14
stream measurements in ..... 99–108
Albert, S. H., artesian irrigation by ..... 604
Alderson, West Virginia, stream measurements at ..... 111–113
Allen, S. E., cited ..... 546
Alpine reservoir, California, description of ..... 711–715
diagrams of ..... 714
capacity and area of ..... 737
Alston, South Carolina, stream measurements at ..... 67–68
Altamaha River Basin, hydrography of .. 77–84
Analyses, water ..... 495–501, 537, 538, 539, 540, 541, 542, 543, 546, 547, 548, 549, 550, 551, 554, 555, 611–615
Anderson, C. C., work of ..... 69, 71, 92
aid by ..... 84
Anderson, Latham, cited ..... 661
Anderson, Indiana, artesian well at ..... 487
water supply of ..... 537
Andrews, D. M., aid by ..... 101–102
Animas River, Colorado, measurements of ..... 283–285
diagram showing discharge of ..... 285
rating table for ..... 284
Antelope Valley Water Company, California, projected reservoirs of .... 711
Antero reservoir site, Colorado, location of ..... 726
Apalachicola Basin, work in ..... 84–93
Arboles, Colorado, stream measurements at ..... 279–283
Arickaree River, measurements of ..... 206
Arizona, stream measurements in ..... 286–299
Agua Fria dam in ..... 695–698
projected reservoirs in ..... 715–723
capacities and areas of reservoirs in . 739–740
Arizona Improvement Company, projected reservoirs of ..... 718
Arkalon, Kansas, stream measurements at ..... 243–244
Arkansas River, rating tables for ..... 225, 226, 229, 234
diagram showing discharge of ..... 231

Page.

Arkansas River and tributaries, measurements of ..... 223–240
Arkansas River Basin, stream measurements in ..... 223–245
Arkins, Colorado, stream measurements at ..... 174–175
Armour, South Dakota, artesian irrigation near ..... 602
Armstrong, T. W., aid by ..... 542
Arrowhead Reservoir Company, California, dam of ..... 690–692
capacity and area of reservoirs of .. 731, 732
Artesian, South Dakota, record of wells near ..... 574, 575
depths to bed rock at ..... 594
Artesian basin of South Dakota, extent of ..... 590–591
Artesian waters, South Dakota, irrigation by ..... 597–606
temperatures of ..... 606–611
volume of flow of ..... 613–615
Artesian wells, Ohio and Indiana ..... 485–493
South Dakota ..... 561–615
Asheville, North Carolina, stream measurements at ..... 116
Ashland, Ohio, water supply of ..... 544
Ashmore, H. K. and E. O., log of artesian well of ..... 575
Ashtabula, Ohio, water supply of ..... 542
Athens, Ohio, water supply of ..... 544–545
Atlanta, Georgia, monthly rainfall at .... 70
Attica, Indiana, artesian well at ..... 487
Attica, Ohio, water supply of ..... 545
Auglaize River, Ohio, description of ..... 469
Augusta, Georgia, stream measurements at ..... 75–77
Auld, O. R., artesian irrigation by ..... 597
Aurora County, South Dakota, artesian wells in ..... 572–573
artesian irrigation in ..... 597
Azusa, California, stream measurements near ..... 405–411

B.

Babb, Cyrus C., work of ..... 14, 77, 80, 110, 116, 276, 297, 330
Bachelder, W. N., work of ..... 166
Baker, M. N., aid by ..... 425
Ballinger, J. A., work of ..... 350
Barber, C. E., work of ..... 169
Barnett, S. M., work of ..... 98
Barnum, George E., work of ..... 188
Barrett dam site, California, description of ..... 642

Page.
Barrett dam site, California, cross section of ... 707
Barrett reservoir site, California, capacity and area of ... 735
Barrow, B. C., work of ... 92
Barton, J. D., artesian irrigation by ... 597
Battle Creek, Idaho, stream measurements at ... 313–315
Battle Mountain, Nevada, stream measurements at ... 302, 308–310
Beadle County, South Dakota, artesian irrigation in ... 598
Beamer, D., aid by ... 546
Bear Creek, California, measurements of ... 418
Bear Creek, Colorado, measurements of ... 167–169
rating table for ... 168
Bear River, Idaho, measurements of ... 311–316, 319–320
rating tables for ... 312, 314, 320
diagrams showing discharge of ... 316
Bear Valley dam, California, profile of ... 678
description of ... 682–685
cross section of ... 683
plan and elevation of ... 684
Bear Valley reservoir, California, annual rainfall at ... 685
watershed tributary to ... 685
capacity and area of ... 736
Beaver Creek, Nebraska, measurements of ... 193
Beaver River, Ohio, drainage system of ... 463–464
Beedle, A. T., aid by ... 553
Bellaire, Ohio, water supply of ... 545
Bellevue, Ohio, water supply of ... 545
Bellefontaine, Ohio, water supply of ... 545
Beloit, Kansas, stream measurements at ... 207–210
Berea, Ohio, water supply of ... 545
Beverly, Kansas, stream measurements at ... 210–212
Big Blue River, Kansas, measurements of ... 215–218
rating table for ... 217
Big Goose Creek, Wyoming, measurements of ... 137–138
Big Lake, California, projected irrigation from ... 706
Big Meadows reservoir site, capacity and area of ... 738
Big Thompson Creek, Colorado, measurements of ... 174–175
rating table for ... 175
Big Walker Creek, California, measurements of ... 417
Bihler, Charles S., quoted ... 660
Birdwood Creek, Nebraska, measurements of ... 206
Blake, Utah, stream measurements at ... 275–278
Blackfoot River, Idaho, measurements of ... 330–333
Blackfoot River reservoir site, area and capacity of ... 331
list of lands embraced in ... 331–333
Black River, Ohio, description of ... 467

Page.
Blacks Fork River, Wyoming, measurements of ... 268–272
rating table for ... 271
Blacksmiths Fork, Idaho, measurements of ... 315
Black Warrior River, Alabama, measurements of ... 103–108
rating table for ... 106–107
Blalocks Ferry, North Carolina, stream measurements at ... 60–61
Bloomington, Indiana, deep boring at ... 487
water supply of ... 537
Blue River, Kansas, measurements of ... 215–218
rating table for ... 217
diagram showing discharge of ... 219
Bluffton, Indiana, water supply of ... 537
Boise, Idaho, stream measurements at ... 340–344
Boise Canyon, Idaho, stream measurements in ... 342
Boise River, Idaho, measurements of ... 340–345
diagram showing discharge of ... 344
rating table for ... 345
Bond, Fred, work of ... 138
Bonhomme County, South Dakota, artesian wells in ... 586–587
depths to bed rock in ... 593
artesian irrigation in ... 598
Boulder, Colorado, stream measurements at ... 171–172
Boulder Creek, Colorado, measurements of ... 171–172
rating table for ... 171
Boyer, J. M., aid by ... 550
Boyd, David, cited ... 143, 159
Bowersock, J. D., work of ... 220
Bozeman, Montana, stream measurements near ... 127–128
Bradley, D., work of ... 264
Brady, H., boring on farm of ... 572–573
Brash, W. J., work of ... 286
Brawley, E. M., work of ... 64
Brayton, F. B., artesian irrigation by ... 598, 604
Bridge, W. F., aid by ... 540
Brittain, M. L., work of ... 118
Broad River, South Carolina, measurements of ... 65–68
rating table for ... 66
Brookville, Indiana, water supply of ... 537
analysis of water from ... 537
Brown, John, artesian well of ... 586
artesian irrigation by ... 598
Brownstown, Indiana, deep boring at ... 487
Brule County, South Dakota, artesian wells in ... 568–570
map showing location of artesian wells in ... 569
artesian irrigation in ... 598–600
Bruneau River, Idaho, diagram showing discharge of ... 341
measurements of ... 339–340
Bruner, Elias, work of ... 238
Bryson, North Carolina, stream measurements at ... 116–117
Buchanan, Virginia, stream measurements at ... 39–42
Bucyrus, Ohio, water supply of ... 545

Page.
Buena Vista Lake reservoir, California, description of ... 701-702
capacity and area of ... 739
Buffalo, Wyoming, stream measurements at ... 138-141
Buffalo County, South Dakota, artesian wells in ... 573
Buffalo Creek, Nebraska, measurements of ... 206
Burke, T. F., work of ... 280
Burkhart, John, aid by ... 537
Burnham, T. E., aid by ... 550
Burns, P. J., work of ... 151
Bush, J. D., work of ... 216
Buswell, L. A., artesian irrigation by ... 605
Butler, F. G., aid by ... 594
Buttes, Arizona, stream measurements at ... 286-291
Buttes reservoir, area and capacity of ... 291-292
description of ... 719-720
Buttes reservoir site, Arizona, capacity and area of ... 740

C.

Cache County, Utah, cooperation by commissioners of ... 15
Cady, E. E., work of ... 200
Calamus River, measurements of ... 193
Caldwell, H. W., work of ... 16
Caldwell, Idaho, stream measurements at ... 344-345
Calhoun Falls, South Carolina, stream measurements at ... 73-75
map showing gauging station near ... 73
California, stream measurements in ... 362-418
rainfall in ... 418
rock-fill dams in ... 627-644, 648-649
hydraulic dams in ... 649-660
masonry dams in ... 662-695
earthen dams in ... 698-702
projected reservoirs in ... 703-715
capacities and areas of reservoirs in ... 727-739
California (southern), measurement of creeks in ... 397-405
reservoir sites in ... 707
Call, R. E., cited ... 433
Calumet River, Indiana, description of ... 471
Cambie, H. J., acknowledgments to ... 659
Campbell, A. Q., work of ... 413
Campbell, Frank H., record of artesian well of ... 573-574
artesian irrigation by ... 604
Campbell, J. T., aid by ... 542
Camp Clark, Nebraska, stream measurements at ... 153-156
Canadian Pacific Railway, hydraulic fills on ... 657-659
Canadian River tributaries, New Mexico, measurements of ... 245
Canton Creek, Ohio, water supply of ... 545
Canton, Georgia, stream measurements at ... 94
Canyon, Colorado, stream measurements at ... 225-227
Cape Fear River, measurements of ... 54-57
rating table for ... 55-56

Page.
Cape Fear River, diagram showing discharge of ... 57
Carey, J. L., work of ... 78
Carey, Georgia, stream measurements at ... 78-79
Carley, J. A., work of ... 148
Carpenter, W. A., artesian irrigation by ... 599
Carter, S. M., work of ... 97
Carters, Georgia, stream measurements at ... 96-98
Cartersville, Georgia, stream measurements near ... 109
Cast, S. T., aid by ... 540
Catawba, North Carolina, stream measurements at ... 64-65
Catawba River, measurements of ... 61-65
rating tables for ... 62, 65
diagram showing discharge of ... 63
Cedar River, Nebraska, measurements of ... 193
Celina, Ohio, water supply of ... 545
Chagrin River, Ohio, description of ... 466
Chain Bridge, Virginia, stream measurements at ... 35
Chama River, New Mexico, measurements of ... 252
Chamberlain, South Dakota, record of artesian well at ... 568
head of water in deep well at ... 592
artesian irrigation near ... 599
temperature of artesian water at ... 606
Chamberlin, T. C., cited ... 434, 436, 463
Chandler, G. T., artesian irrigation by ... 602
Chapman Creek, Canada, hydraulic fill at ... 659
Charles Mix County, South Dakota, artesian wells in ... 570-571
Chatsworth Park dam, California, description of ... 643-644
Chattahoochee River, description of ... 84-85
measurements of ... 85-92
rating tables for ... 88, 91
diagram showing discharge of ... 89
Chattanooga, Tennessee, stream measurements at ... 119-122
Chemical analyses. (*See* Analyses.)
Chesapeake watershed, stream measurements in ... 16-18
Chestatee River, Georgia, measurements of ... 92
Chevlons Fork, Arizona, projected reservoirs on ... 722-723
Cheyenne Agency, South Dakota, artesian well at ... 587-588
pressure and head in artesian well at ... 592
Chittenden, H. M ... 426, 462
Cimarron River, Kansas, measurements of ... 243-244
rating table for ... 244
Cincinnati arch, Ohio, description of ... 428-429
Cincinnati, Ohio, water supply of ... 545-546
analysis of water from ... 546
Claypole, E. W., cited ... 467
Clark, J. A., artesian irrigation by ... 601
Clark, W. B., aid by ... 14
Clarksville, Virginia, stream measurements at ... 42-47
Clear Creek, Arizona, projected reservoirs on ... 722-723

Page.

Clear Creek, Wyoming, measurements of ... 138–141
rating table for ... 140
diagram showing discharge of ... 141
Cleveland, Ohio, water supply of ... 546
Clyde, Ohio, water supply of ... 546
Coffin, F. F. B., aid by ... vii
work of ... 567
Cole, Burt, work of ... 402
Collett, John, cited ... 431
Collinston, Utah, stream measurements at ... 319–320
Colorado, cooperation by State officers of ... 15
stream measurements in ... 159–175, 224–232, 246–249, 260–268, 279, 285
projected reservoirs in ... 724–726
Colorado River, measurements of ... 298–299
Colorado River Basin, stream measurements in ... 260–299
Columbia, Indiana, artesian wells at ... 487
water supply of ... 537–538
Columbia River Basin, stream measurements in ... 330–361
Columbus, Indiana, deep boring at ... 487
Columbus, Nebraska, stream measurements at ... 182–190
view of gaging station at ... 185
Columbus, Ohio, water supply of ... 546
Commons, William, aid by ... 544
Concrete dams of the Portland, Oregon, waterworks, description of ... 698
Conneaut, Ohio, water supply of ... 546
Conneaut Creek, Ohio, description of ... 465
Connell, Maurice, work of ... 362
Connor, J. H., aid by ... 554
Converse, Indiana, artesian wells at ... 488
Cook, T. R., aid by ... 553
Coolman, D. C., aid by ... 552
Coosa River, measurements of ... 99–103
rating tables for ... 101, 102–103
diagram showing current velocity and discharge of ... 104
Coosawattee River, measurements of ... 96–98, 110
rating table for ... 98
Corns, John M., aid by ... 549
Corydon, Indiana, deep borings at ... 488
Coshocton, Ohio, water supply of ... 546
Covington, Indiana, water supply of ... 538
Cox, E. T., cited ... 433
Crawford, H. W., artesian irrigation by ... 604
Crawfordsville, Indiana, deep boring at ... 488
Crocker-Hoffman Land Company, description of dam constructed by ... 700–701
Crooked Creek, Indiana, description of ... 471
Crow Creek Agency, log of artesian well in ... 573
pressure in artesian wells at ... 592
Crowe, H. S., work of ... 378
Crown Point, Indiana, deep boring at ... 488
Crystal Springs reservoir, watershed tributary to ... 690
Cub River, Utah, measurements of ... 318
Cumberland, Maryland, stream measurements at ... 22–24
Cunningham, C. S., aid by ... 541
Cunningham, R. N., work of ... 68

Page.

Cuyahoga River, Ohio, description of ... 466–467
Cuyamaca dam, California, description of ... 698–700
Cuyamaca reservoir, California, rainfall and run-off at ... 674
capacity and area of ... 735

D.

Dallin, John, work of ... 328
Dams, concrete ... 698
earthen ... 698–702
hydraulic ... 649–661
masonry ... 661–698
rock-fill ... 627–649
Dan River, Virginia, measurements of ... 42–45
rating table for ... 44
Danville, Indiana, water supply of ... 538
Darton, N. H., paper on well boring and irrigation in South Dakota by ... 561–615
Davenport, E. R., aid by ... 552
Davis, Arthur Powell, report of progress of stream measurements by ... 1–418
work of ... 128, 203, 207, 210, 212, 215, 232, 240, 242, 291, 295, 378, 696
cited ... 719
Davis, F. A. W., aid by ... 489, 540
Davis, John, work of ... 203
Davis, J. T., work of ... 355
Davis, W. J., acknowledgments to ... 442
Davison County, South Dakota, artesian wells in ... 575–579
artesian irrigation in ... 600–601
Dayton, Ohio, water supply of ... 546
Deansbury, Colorado, stream measurements at ... 159–162, 166
Defiance, Ohio, water supply of ... 546–547
De Kay, L. F., aid by ... 571
Delaware, Ohio, water supply of ... 547
Del Norte, Colorado, stream measurements at ... 246–248, 249
Delphi, Indiana, deep boring at ... 488
Dennis, D. W., analysis of water by ... 542
Dennison, Ohio, water supply of ... 547
Denver, Colorado, stream measurements at ... 162–166
Denver Union Water Company, reservoir site of ... 726
Derr, Elmer G., aid by ... 549
De Smet, South Dakota, depths to bed rock at ... 593, 594
log of artesian well at ... 595
Dewey County, South Dakota, artesian well in ... 588
Dickenson, I. M., aid by ... 551
Dilley, J. T., aid by ... 491
Dixon, W. A., aid by ... 552
Dodge, J. A., analyses of water by ... 612
Dolores, Colorado, stream measurements at ... 261–263
Dolores River, Colorado, measurements of ... 261–263
rating tables for ... 262–263
diagram showing discharge of ... 264
Dondelinger, N., artesian irrigation by ... 600
Donnenwirth, Charles, aid by ... 545
Douglas County, South Dakota, artesian irrigation in ... 602

Page.

Dove, W. C., aid by ..... 547
Drake, W. T., aid by ..... 489
Drayer, L. P., analysis of water by ..... 538
Dryer, C. R., cited ..... 474, 488
aid by ..... 538
Duchesnay, Edmond, acknowledgments to ..... 659
Dunan, O. E., aid by ..... 553
Durango, Colorado, stream measurements at ..... 283–285
Dutertre, L., work of ..... 303
Dye Valley reservoir site, California, capacity and area of ..... 734

E.

Earthen dams, description of ..... 698–702
"Earthquake crack" of southern California, description of ..... 712
East Canyon Creek, Idaho, measurements of ..... 315
East Gallatin River, measurements of ..... 131
East White River, Indiana, description of ..... 453–455
Eaton, Ohio, water supply of ..... 547
Eckfield, E., aid by ..... 547
Edgar and Mariner, analyses of water by ..... 612, 613
Eden, Utah, stream measurements at ..... 321–322
Edinburg, Indiana, artesian well at ..... 488
Eel River, Indiana, description of ..... 449–450
Eigenmann, C. H., cited ..... 474
Elkhart, Indiana, artesian well at ..... 488
water supply of ..... 538
Elkhart River, Indiana, description of ..... 470
Elkhorn River, Nebraska, measurements of ..... 193
Elkhorn River (South Fork), measurements of ..... 190–192
rating table for ..... 191
Elkin, D. R., work of ..... 67
Elko, Nevada, stream measurements at ..... 299–301
Ellsworth, Kansas, stream measurements at ..... 212–215
El Paso, Texas, stream measurements at ..... 257–259
cross section of Rio Grande at ..... 258
Elsom, J. F., aid by ..... 542
Elwood, Indiana, artesian well at ..... 488
Elyria, Ohio, water supply of ..... 547
Embudo, New Mexico, stream measurements at ..... 248–251
Engineering News, acknowledgments to ..... 425
Escondido irrigation district, California, dam in ..... 627–637
map of ..... 628
feeder conduit of ..... 629
capacity and area of reservoir in ..... 727
Etowah River, measurements of ..... 94–96, 109
rating table for ..... 95
Evansville, Indiana, artesian wells at ..... 488
water supply of ..... 538
Evaporation from Sweetwater reservoir, California ..... 680–681
Evens, Charles, aid by ..... 551
Ewers, Frank, work of ..... 167
Eyer, Philip, artesian irrigation by ..... 597

F.

Page.

Fall Creek, Colorado, stream measurements at ..... 264–265
Farmer, Ed., work of ..... 357
Farmer, South Dakota, depths to bed rock at ..... 594
artesian irrigation near ..... 602
Farren, George, cited ..... 678
Fawn River, Indiana, description of ..... 471
Fayette, West Virginia, stream measurements at ..... 113–115
Fayetteville, North Carolina, stream measurements at ..... 54–57
Findlay, Ohio, water supply of ..... 547
Fisher, James M., work of ..... 240
Fisher, W. W., work of ..... 196
Fiskin, J. B., aid by ..... 360
Flaherty, Morgan, work of ..... 323
Fleming, M., work of ..... 337
Flynn, P. J., cited ..... 185
Follows, R. M., work of ..... 406, 407
Follows Camp, California, rainfall at ..... 407
Folsom dam, California, description of ..... 687
Forchheimer, P., cited ..... 679
Fort Crawford, Colorado, stream measurements at ..... 265–268
Fortier, Samuel, work of ..... 311, 316
cited ..... 312, 661
Fort Randall, South Dakota, pressure in artesian well at ..... 592
temperature of artesian water at ..... 606
Fort Tejon, California, rainfall at ..... 399
Fort Tejon Creek, measurements of ..... 416
Fort Wayne, Indiana, artesian well at ..... 488
water supply of ..... 538
analysis of water from ..... 538
Foshay, P. Max, cited ..... 463
Foster, J. W., work of ..... 100
Fowler, S. W., aid by ..... 547
Frankfort, Indiana, water supply of ..... 538
Franklin, Ohio, water supply of ..... 547
analysis of water from ..... 547
Frazier, Ira, artesian irrigation by ..... 600
Frederick, Maryland, stream measurements at ..... 34–35
Frehse, A. W., aid by ..... 541
French Broad River, measurements of ..... 116
Frenchman River, Nebraska, measurements of ..... 196–199, 206
rating table for ..... 198
Fremont, Ohio, water supply of ..... 548

G.

Gaffney, South Carolina, stream measurements at ..... 65–67
Gage height tables, reference to ..... 15
Gallatin River, measurements of ..... 124–131, 128–130
rating table for ..... 129
diagram showing discharge of ..... 130
Gallipolis, Ohio, water supply of ..... 548
Gannett, Henry, acknowledgments to ..... 426
cited ..... 427
Garns, J. H., work of ..... 319
Garrett, Indiana, water supply of ..... 539
analysis of water from ..... 539
Georgia, cooperation by State geologist of 14

Page.

Georgia, stream measurements in ..... 68–72, 75–99, 108–110, 123
general discussion of streams of ..... 68–71
water-power streams in ..... 69–71
Gibbon, Oregon, stream measurements at ..... 361
Giesen, Jacob, aid by ..... 594
Gila River, rating table for ..... 289
diagram showing discharge of ..... 291
irrigation from ..... 719–720
Gila River and tributaries, measurements of ..... 286–297
Gila Valley, Arizona, projected irrigation in ..... 695
Gilbert, G. K., cited ..... 438
Glacial ridges in Ohio and Indiana, description of ..... 434–438
Glasgow, Virginia, stream measurements at ..... 36–38
Gleason, M., artesian irrigation by ..... 601
Glidden, A. J., artesian irrigation by ..... 605
Glover, Frank, work of ..... 54
Goose Creek, Colorado, projected reservoirs on ..... 724–725
Gorby, S. S., cited ..... 426
Goshen, Indiana, artesian wells at ..... 488
Gosport, Indiana, artesian well at ..... 488
Golconda, Nevada, stream measurements at ..... 303–306
Gould, D. T., cited ..... 467
aid by ..... 545
Grand Junction, Colorado, stream measurements at ..... 260–261
Grand River and tributaries, Colorado, measurements of ..... 260–267
Grand River, Ohio, description of ..... 465–466
Granger, Wyoming, stream measurements at ..... 268–271
Grass Valley reservoir site, California, capacity and area of ..... 731
Grass Valley, Little Bear Valley, and Houston Flat reservoirs, diagrams showing comparative contents of ..... 692
Great Cacapon station, West Virginia, stream measurements at ..... 25
Great Miami River, drainage system of ..... 457
Greene, J. M., artesian irrigation by ..... 599
Greenfield, Indiana, artesian wells at ..... 488–489
Greensburg, Indiana, water supply of ..... 539
Greenbrier River, measurements of ..... 111–113
rating table for ..... 112
Green River, Wyoming-Utah, rating table for ..... 274, 277
diagrams showing discharge of ..... 275, 279
Green River and tributaries, Wyoming-Utah, measurements of ..... 268–278
Greenriver City, Wyoming, stream measurements at ..... 272–275
Greenville, Ohio, water supply of ..... 548
analysis of water from ..... 548
Greenwood, Indiana, artesian wells at ..... 489
Gulf of Mexico watershed, hydrographic work in ..... 84–110
Gundert, Jacob, artesian well of ..... 584, 585
Guthrie, Page, cited ..... 569–570


H.


Page.

Hackedon, H. B., aid by ..... 549
Hadley, C. C., aid by ..... 538
Hagmen, F. W., artesian irrigation by ..... 605
Haigler, Nebraska, stream measurements at ..... 194–195
Hall, B. M., work of ..... 69, 75, 80, 86, 92, 93, 94, 100, 123
Hall, Max, work of ..... 69, 80, 97, 98, 109, 110
Hamilton, W. S., aid by ..... 555
Hamilton, Ohio, water supply of ..... 548
Hammond, Indiana, artesian wells at ..... 489
water supply of ..... 539–540
Hanson County, South Dakota, artesian wells in ..... 579–580
depths to bed rock in ..... 593
artesian irrigation in ..... 602
Harding, Horace, aid by ..... 104
Harris, D. H., cited ..... 571
Harrison, J. M., aid by ..... 538
Harvey, Robert, cited ..... 179
Hassayampa River, Arizona, projected irrigation from ..... 721–722
Hatfield, F. B., work of ..... 248
Haviland, W. T., aid by ..... 545
Hayes, C. W., cited ..... 433
Hay, O. P., cited ..... 473
Hay Lake, Arizona, reservoir sites near ..... 722
Heidinger, H., artesian irrigation by ..... 600
Hemet dam, California, description of ..... 662–669
Herschel, Clemens, cited ..... 661
Higgins, James F., aid by ..... 554
Hillsboro, Ohio, water supply of ..... 548
Hitchcock, South Dakota, artesian irrigation near ..... 605
Hiwassee River, measurements of ..... 118
Hocking River, drainage system of ..... 460
Hood, O. P., aid by ..... 215
Hood, William, aid by ..... 15
Holbrook, C. L., record of artesian well of ..... 579, 580
Holden, R. L., work of ..... 228
Hope, L. R., work of ..... 159
Howells, J. M., acknowledgments to ..... 655
Huber, H., aid by ..... 15
Hudson, Ohio, water supply of ..... 548–549
Hudson Canal and Reservoir Company, reservoir project of ..... 715–717
Hudspeth, William, work of ..... 216
Huggins, H. M., aid by ..... 548
Hughes, E. J., analysis of water by ..... 539
Humboldt River, Nevada, measurements of ..... 299–309
rating tables for ..... 301, 302, 305, 307
diagram showing discharge of ..... 309
proposed irrigation from ..... 723
Humboldt River (South Fork), measurements of ..... 311
Humphrey, F., work of ..... 266
Humphreys, D. C., work of ..... 42
Huncheon, R., aid by ..... 489
Huntington, Indiana, deep boring at ..... 489
water supply of ..... 540
Huron River, Ohio, description of ..... 468
Huston, C. E., artesian irrigation by ..... 602
Huston, H. A., aid by ..... 490
analyses of water by ..... 537, 540

Page.

Huston, H. A., cited ..... 540, 555
Huston Flat reservoir, California, capacity and area of ..... 732
Huston Flat, Little Bear Valley, and Grass Valley reservoirs, diagrams showing comparative contents of ..... 692
Hutchinson, Kansas, stream measurements at ..... 232–234
Hutchinson County, South Dakota, artesian wells in ..... 580–585
depths to bed rock in ..... 594
artesian irrigation in ..... 603
Hutterische Colony, Milltown, South Dakota, artesian wells at ..... 585, 586, 587
artesian irrigation at ..... 598
Hyde, F. S., aid by ..... 673
cited ..... 699
Hydraulic dams, descriptions of ..... 649–661
Hydraulic fills, Canadian Pacific Railway ..... 657–659
Northern Pacific Railway ..... 659–660
Hydrographers (resident), list of ..... 13–14

I.

Idaho, stream measurements in ..... 311–316, 330–345, 350–354
Illinois River, drainage system of ..... 471–472
Indiana, geologic sections in ..... 429–430
table of flowing wells in ..... 482
water supply of cities and towns of ..... 537–544
table showing precipitation in ..... 556
Indiana and Ohio, paper by Frank Leverett on water resources of ..... 419–559
glacial ridges in ..... 434–438
drainage systems of ..... 438–472
lakes of ..... 472–474
underground water of ..... 474–493
subterranean drainage lines in ..... 483–484
mineral springs in ..... 493–495
analyses of waters from ..... 495–501
water supply for cities and villages of ..... 502–555
Indianapolis, Indiana, artesian wells at ..... 489
water supply of ..... 540
Inman, A. W., aid by ..... 550
Intze, Professor, quoted ..... 679
Iola, Kansas, stream measurements at ..... 238–240
Ironton, Ohio, water supply of ..... 549
Iroquois River, Indiana, description of ..... 472
Irrigation, paper by James D. Schuyler on reservoirs for ..... 617–740
Irrigation and well boring in South Dakota, paper by N. H. Darton on ..... 561–615
Irrigation survey, summary of work of ..... ix–x

J.

Jackson, Ohio, water supply of ..... 549
Jacobs, Frank, work of ..... 276
James River, Virginia, measurements of ..... 39–42
rating table for ..... 40
diagram showing discharge of ..... 41
James River Basin, stream measurements in ..... 36–42
James River (North Fork), measurements of ..... 36–38
rating table for ..... 37
diagram showing discharge of ..... 38

Page.

James, Walter, aid by ..... 15
Jefferson River, measurements of ..... 134–136
Jellys Ferry, California, stream measurements at ..... 365–369
rating curve for station at ..... 368
Jerauld County, South Dakota, artesian wells in ..... 573–574
artesian irrigation in ..... 604
Johnson, J. K., artesian irrigation by ..... 600
Jordan, David Starr, cited ..... 473
Jordon, W. F., work of ..... 207
Judson, Charles, aid by ..... 553
Judson, North Carolina, stream measurements at ..... 117–118
Junction City, Kansas, stream measurements at ..... 203–205

K.

Kanawha Basin, stream measurements in ..... 111–116
Kankakee River, Indiana, description of ..... 471–472
Kansas, stream measurements in ..... 203–222, 232–244
Kansas River, measurements of ..... 218–222
rating table for ..... 221
diagram showing discharge of ..... 223
Kansas River and tributaries, measurements of ..... 215–222
Kansas River Basin, stream measurements in ..... 194–222
Kansas State board of irrigation, cooperation by ..... 15
Kaufman, D. N., record of artesian well of ..... 568
aid by ..... 608
Kaweah River, California, utilization of lakes on headwaters of ..... 706
Kearns, P. F., cited ..... 587
aid by ..... 593
Kelso, W. A., work of ..... 358
Kendall, L. B., work of ..... 330, 336
Kenney, James, jr., aid by ..... 545
Kentland, Indiana, artesian wells at ..... 489
Kenton, Ohio, water supply of ..... 549
Kern County, California, rainfall in ..... 396
Kern River, California, measurements of ..... 395–397
diagram showing discharge of ..... 398
reservoir sites on ..... 703–706
Kerr, Casper, artesian irrigation by ..... 600
Kewanna, Indiana, artesian well at ..... 489
Keyt, J. W., aid by ..... 552
Kimball, South Dakota, record of artesian well near ..... 568–569
King, F. H., cited ..... 476
Kingsbury, California, stream measurements at ..... 393–395
Kings River, California, measurements of ..... 390–395
rating table for ..... 392
diagram showing discharge of ..... 393
Kiona, Washington, stream measurements at ..... 358–359
Kiowa, Kansas, stream measurements at ..... 240–242
Knapp, George, artesian irrigation by ..... 602

Page.
Knowland, James T., aid by ..... 537
Knox, Indiana, water supply of ..... 540
Kokomo, Indiana, artesian well at ..... 489
water supply of ..... 540
Koontz, A. J., work of ..... 197

L.

Lacrosse, Indiana, artesian well at ..... 489
Lagrange, California, stream measurements at ..... 378–383
Lagrange dam, California, description of ..... 686–687
views of ..... 378, 687
Laird, A., work of ..... 411
Lake Andes, South Dakota, artesian wells at ..... 571
Lake Erie, drainage systems of streams entering ..... 464–469
Lafayette, Indiana, artesian well at ..... 490
water supply of ..... 540
Lake Helena dam site, California, description of ..... 654
Lake Hemet reservoir, California, capacity and area of ..... 729
Lake Michigan, drainage systems of streams entering ..... 470–471
La Mesa dam, California, description of ..... 649–653
La Mesa reservoir, California, capacity and area of ..... 729
Lancaster, Ohio, water supply of ..... 549
analysis of water from ..... 549
Laramie River, description of ..... 142–144
lands irrigated from ..... 142–144
measurements of ..... 145–150
rating tables for ..... 147, 149
Larwill, Indiana, artesian well at ..... 490
Laurel, Maryland, stream measurements at ..... 18
Lawrence, Kansas, stream measurements at ..... 219–222
Leach, Andrew, aid by ..... 549
Leavenworth, Indiana, artesian well at ..... 490
Lee, S. E., cited ..... 473–474
Lecompton, Kansas, stream measurements at ..... 218–219
Lemstrom, F., work of ..... 365
Lepper, A. F., aid by ..... 545
Levagood, M. H., aid by ..... 547
Leverett, Frank, paper on water resources of Indiana and Ohio by ..... 419–559
Levette, G. M., cited ..... 473
Liberty, Kansas, stream measurements at ..... 235–238
Lima, Ohio, water supply of ..... 549
Linda Vista Irrigation District, dam sites owned by ..... 707
Lingelbach, Henry, work of ..... 269
Linn, W. H., aid by ..... 553
Lippincott, J. B., work of ..... 365, 400, 402, 411, 416–417
Little Bear Valley dam and reservoir, California, description of ..... 690–692
Little Bear Valley reservoir, California, capacity and area of ..... 731
Little Bear Valley, Huston Flat, and Grass Valley reservoirs, diagrams showing comparative contents of ..... 692

Page.
Little Camas Creek, Idaho, measurements of ..... 336
Little Colorado River, Arizona, reservoir sites on ..... 722–723
Little Fountain Creek, Colorado, measurements of ..... 231
Little Goose Creek, Wyoming, rating table for ..... 136
Little Miami River, drainage system of ..... 458
Little Rock Creek, California, measurements of ..... 402–405
rating table for ..... 404
irrigation from ..... 713
Little Rock Creek Irrigation District, map of ..... 712
Little Tennessee River, measurements of ..... 117–118
Little Walker Creek, California, measurements of ..... 417
Little Wood River, Idaho, measurement of ..... 336–339
rating table for ..... 339
Livengood, A. T., aid by ..... 538
Lockwood Valley, California, projected reservoirs in ..... 711
Lodi, Indiana, artesian well at ..... 490
Logan, Montana, stream measurements at ..... 128–130
Logan, Utah, stream measurements at ..... 316–318
Logan River, Utah, measurements of ..... 316–318
rating table for ..... 318
Logansport, Indiana, deep borings at ..... 490
water supply of ..... 541
Lohman, H. S., work of ..... 254
London, Ohio, water supply of ..... 550
Long, Peter, work of ..... 219
Looking Glass Creek, Nebraska, measurements of ..... 193
Lord, Professor, analysis of water by ..... 550
Los Angeles, California, rainfall at ..... 407
stream measurements at ..... 413–415
Los Angeles River, California, measurements of ..... 413–415, 417
Lost Canyon, Colorado, projected reservoir site in ..... 724–725
Lost River, Indiana, description of ..... 455
Loup River, Nebraska, measurements of ..... 176–187
rating table for ..... 183
Low, James A., work of ..... 94
Lower Otay dam, California, description of ..... 637–640
cross section of ..... 707
Lower Otay reservoir, California, capacity and area of ..... 728
Lowrie, L., artesian well of ..... 593
Lucas, John P., aid by ..... 548
Lynchburg, Ohio, water supply of ..... 550
Lyons, Colorado, stream measurements at ..... 172–174
Lytle Creek, California, measurements of 417
Lytle Creek dam, California, description of ..... 648–649

M.

Maclay Rancho Water Company, view of measuring box used by ..... 694

Page.
Macon, Georgia, stream measurements at ... 79–84
Mad River, Ohio, description of ... 457
Madison River, measurements of ... 130–134
rating tables for ... 132, 133
diagram showing discharge of ... 134
Malad River, Idaho, measurements of ... 337–338
rating table for ... 338
Malheur River, Oregon, measurements of ... 348–350
rating table for ... 349
Manache Meadows, California, reservoir site at ... 703–705
maps of reservoir at ... 703, 704
capacity and area of reservoir site at ... 738
Man, A. P., acknowledgments to ... 716
Manhattan, Kansas, stream measurements at ... 215–218
Mansfield, Ohio, water supply of ... 550
Marietta, Ohio, water supply of ... 550
Marion, Indiana, artesian wells at ... 490
water supply of ... 541
Marion, Ohio, water supply of ... 550
Marnell, E., work of ... 341
Marshall, Colorado, stream measurements at ... 169–170
Martin, Robert, work of ... 212
Martinsville, Indiana, artesian wells at ... 490–491
water supply of ... 541
Marty, M., record of well of ... 568
Maryland, stream measurements in ... 16–18, 22–24, 29–33, 34–35
cooperation by State weather service of ... 14
Mason, Martin, work of ... 311
Mason's Ranch, Nevada, stream measurements at ... 311
Masonry dams, descriptions of ... 661–698
Massillon, Ohio, water supply of ... 550
Maumee River, Ohio, description of ... 468–469
Maxwell, C. A., aid by ... 75
McCallo, R. C., aid by ... 104
McCammon, Idaho, stream measurements at ... 333–334
McCook County, South Dakota, depths to bed rock in ... 594
McCrary, R. B., aid by ... 550
McDowell reservoir, Arizona, map of ... 719
McElroy, H. S., work of ... 127
McGowan, David, aid by ... 553
McHenry, C. H., quoted ... 660
McHenry, J. E., aid by ... 544
McLain, J. C., aid by ... 571
McTaggart, M. C., work of ... 235
Mead, Elwood, aid by ... 141
cited ... 268
Mechanicsburg, Ohio, water supply of ... 550
Medicine River, Kansas, measurements of ... 240–242
rating table for ... 242
Melton, C. E., work of ... 91
Metz, Charles L., cited ... 546
Merced Creek, California, measurements of ... 416
Merced reservoir, California, description of ... 700–701
Page.
Mercer, J. P., work of ... 80
Mew, W. W., analyses of water by ... 613
Michigan, Indiana, artesian well at ... 491
Michigan City, Indiana, water supply of ... 541
Middle Creek, Montana, measurements of ... 127–128
rating table for ... 128
Middle Loup River, measurements of ... 179–181, 186, 187, 193
Mill Creek, California, measurements of ... 418
Miller, J. J., aid by ... 594
Mills, F. J., aid by ... 312, 330, 333, 336
Milltown, South Dakota, artesian wells at ... 585
Millville, West Virginia, stream measurements at ... 26–28
Milstead, Alabama, stream measurements at ... 110
Milton, California, stream measurements near ... 375–377
Mineral springs, Ohio–Indiana ... 493–495
Minichaduza Creek, Nebraska, measurements of ... 193
Mississinewa River, description of ... 449
Mississippi River, diagram showing fluctuations of ... 443
Missouri River, measurements of ... 123–124
Mitchell, Indiana, artesian well at ... 491
water supply of ... 541
Mitchell, South Dakota, artesian wells at ... 578–579
Mobile Basin, work in ... 93–110
Modesto, California, stream measurements at ... 384–385
Mojave Desert, irrigation in ... 711
Mojave River, California, projected reservoir on ... 708–710
Monocacy River, Maryland, measurements of ... 34–35
rating table for ... 35
Monon, Indiana, artesian well at ... 491
Montana, stream measurements in ... 123–136
Monticello, Indiana, artesian well at ... 491
Montezuma, Indiana, artesian well at ... 491
Montgomery, George, work of ... 335
Montgomery Ferry, Idaho, stream measurements at ... 334–336
Moose Lake, California, projected irrigation from ... 706
Moraines in Indiana and Ohio, description of ... 435–438
Mora River, New Mexico, measurements of ... 245
Morena dam, California, description of ... 640–642
cross section of ... 707
Morena reservoir, California, capacity and area of ... 728
Morgan, Thomas, artesian well of ... 586
Morris, W. A., work of ... 61
Morrison, Colorado, stream measurements at ... 167–169
Moses, Thomas F., aid by ... 554
Mount Vernon, Ohio, analysis of water from ... 550
water supply of ... 550
Mullen Brothers, artesian irrigation by ... 597
Muncie, Indiana, artesian wells at ... 491

Page.
Murdock, John, work of ..... 313
Murphy, Daniel, aid by ..... 550
Murphy, E. C., work of ..... 220, 235, 238
Murphy, North Carolina, stream measurements at ..... 118
Murray, E. R., work of ..... 348
Muscatatuck River, Indiana, description of ..... 454
Muskingum River, drainage system of. 460–463
rainfall and run off in drainage basin of ..... 462
Myers, E. W., work of ..... 68, 123
Myers, J. J., artesian irrigation by ..... 605

N.

Naches River, Washington, measurements of ..... 355–356
rating table for ..... 356
Napoleon, Ohio, water supply of ..... 551
Neal, North Carolina, stream measurements at ..... 47–50
Nebraska, stream measurements in .... 154–158, 176–202, 206
Nelson, G. G., work of ..... 386
Nelson, W. H., work of ..... 378
Nelsonville, Ohio, water supply of ..... 551
Neosho River, Kansas, measurements of ..... 238–240
rating table for ..... 239
Neuse River, measurements of ..... 52–53
rating table for ..... 53
Nevada, stream measurements in ..... 299–311
projected reservoirs in ..... 723–725
New Albany, Indiana, water supply of .. 542
analysis of water from ..... 542
Newark, Ohio, water supply of ..... 551
Newcastle, Indiana, water supply of .... 542
Newell, F. H., letter of transmittal by. vii–viii
summary of work of irrigation survey by ..... ix–x
New Haven, Indiana, artesian well at .... 491
New Lisbon, Ohio, water supply of ..... 551
Newman, G. O., aid by ..... 672
New Mexico, stream measurements in .. 245, 250–257
rock-fill dams in ..... 645–648
New Philadelphia, Ohio, water supply of. 551
New River, Arizona, projected reservoir on ..... 718
New River, West Virginia, measurements of ..... 113–115
rating table for ..... 114
diagram showing discharge of ..... 115
New Straitsville, Ohio, water supply of.. 551
Nichols, W. B., work of ..... 60
Niles, Ohio, water supply of ..... 551
Niobrara River, Nebraska, measurements of ..... 193
Norbeck, Peter, aid by ..... 578
Norfolk, Nebraska, stream measurements at ..... 190–192
North Carolina, cooperation by ..... 14
stream measurements in ..... 47–61, 64–65, 116–118
Northern Pacific Railway, hydraulic fills on ..... 659–660

Page.
North Fork Lake reservoir site, California, capacity and area of ..... 738
North Loup River, measurements of 176–179, 193
rating table for ..... 177
North Manchester, Indiana, artesian wells at ..... 491
North Platte, Nebraska, stream measurements at ..... 156–158
North Platte River, description of ..... 141–142
measurements of ..... 150–158, 193
diagram showing discharge of ..... 153
rating tables for ..... 153, 154, 157–158
North River, Virginia, rating table for... 37
North Vernon, Indiana, artesian wells at. 491
North Yakima, Washington, stream measurements near ..... 355–356
Norwood, North Carolina, stream measurements near ..... 60–61
Noyes, W. A., analysis of water by ..... 532
quoted ..... 543–544
Nyssa, Oregon, stream measurements at ..... 346–347

O.

Oakdale, California, stream measurements at ..... 371–375
Oakdale, Georgia, stream measurements at ..... 85–89
Oberlin, Ohio, water supply of ..... 551–552
analysis of water from ..... 552
Ochsner & Bro., record of well of ..... 568–569
Ocmulgee River, measurements of ..... 79–84
rating table for ..... 81–82
diagram showing discharge of ..... 84
Oconee River, measurements of ..... 78–79
rating table for ..... 79
O'Connor, Felix, work of ..... 136, 137
Octoraro Creek, Maryland, measurements of ..... 16
Oestrich, J. C., acknowledgments to ..... 442
Ogden River, Utah, measurements of .. 321–322
rating table for ..... 322
Ogeechee Basin, water powers in ..... 77
Ohio, geologic sections in ..... 431–432
water supply of cities and towns of. 544–555
table showing precipitation in ..... 557–558
Ohio River, measurements of tributaries of ..... 111–123
drainage system of ..... 441–446
diagram showing fluctuations of ..... 443
Ohio and Indiana, paper by Frank Leverett on water resources of .... 419–559
glacial ridges in ..... 434–438
drainage systems of ..... 438–472
lakes of ..... 472–474
underground waters of ..... 474–493
subterranean drainage lines in ..... 483–484
mineral springs in ..... 493–495
analyses of waters from ..... 495–501
water supply for cities and villages of ..... 502–555
Okefenokee swamp, Georgia, description of ..... 71–72
Oostanaula River, measurements of .. 98–99, 109
rating table for ..... 99
Orton, Edward, projected paper on Ohio waters by ..... 425

Page.

Orton, Edward, cited ..... 426
quoted ..... 428-429
aid by ..... 546
Orchard, Colorado, stream measurements at ..... 166-167
Oreana, Nevada, stream measurements at ..... 306-308
Oregon, stream measurements in .. 346-350, 361
concrete dams in ..... 698
Orin, Wyoming, stream measurements at ..... 150-153
Osgood, C., work of ..... 171
Ottawa, Ohio, water supply of ..... 552
Owyhee River, Oregon, measurements of ..... 346-347

P.

Pacoima dam, California, description of 693-695
plan and profile of ..... 693
Palisade, Nebraska, stream measurements at ..... 197-198
Palmdale, California, stream measurements at ..... 402-405
Pamo Valley reservoir site, California, cross section of ..... 707
capacity and area of ..... 734
Parkinson, H. F., aid by ..... 15
work of ..... 406
Parkston, South Dakota, artesian wells near ..... 580-585
Parliman, R. W., aid by ..... 591
Patapsco River, drainage area of ..... 16
stream measurements on ..... 16-17
rating table for ..... 17
Patoka River, Indiana, description of .... 456
Patuxent River, drainage area of ..... 18
measurements of ..... 18
Pauba reservoir, California, capacity and area of ..... 732
Paul, E. G., work of ..... 14, 16, 34
Payette, Idaho, stream measurements at ..... 350-352
Payette River, measurements of ..... 350-352
rating table for ..... 351
Peale, A. C., cited ..... 493, 494, 495
Peas, S. W., aid by ..... 573
Pecos Valley dams, New Mexico, description of ..... 645-648
Pedee River, measurements of ..... 60-61
rating table for ..... 60
Pehrson, J. S., work of ..... 316
Pelham, C. T., work of ..... 257
Peru, Indiana, artesian well at ..... 491
Pfafflin, August, aid by ..... 538
Pfeiffer, Peter, work of ..... 74
Phillips, J. B., work of ..... 87
Phinney, A. J., cited .... 487, 488, 489, 490, 491, 492
Piedras River, Colorado, measurements of ..... 281-283
rating table for ..... 282
diagram showing discharge of ..... 283
Pierre, South Dakota, head of water in artesian well at ..... 592
temperature of artesian waters at .... 606
Pigeon River, Indiana, description of .. 470-471
Pilarcitos and San Andreas reservoir, California, measurements at ..... 370

Page.

Pindell, L. M., work of ..... 119
Pine River, Nebraska, measurements of .. 193
Pine Valley dam, California, description of ..... 653-654
cross section of ..... 707
Pine Valley reservoir, California, capacity and area of ..... 729
Piqua, Ohio, water supply of ..... 552
Piru Creek, California, projected irrigation from ..... 711
Plankinton, South Dakota, artesian irrigation near ..... 597
Plain City, Ohio, water supply of ..... 552
Platte Basin, stream measurements in. 141-193
Platte River, measurements of ..... 188-190, 193
rating table for ..... 189
Plymouth, Indiana, water supply of ..... 542
Point of Rocks, Maryland, stream measurements at ..... 29-33
Pogson, R. M., aid by ..... 400
Polk, John A., aid by ..... 489
Pomeroy, Ohio, water supply of ..... 552
Porter, Dwight, cited ..... 215, 425, 445, 457, 458, 459, 460, 464
Porter, James A., work of ..... 194
Porter, John B., cited ..... 545
Portland (Oregon) waterworks, concrete dams of ..... 698
Portneuf River, Idaho, measurements of ..... 333-334
Port Republic, Virginia, stream measurements at ..... 25-26
Portsmouth, Ohio, water supply of ..... 552
Potomac Basin, stream measurements in. 18-36
Potomac River, measurements of ..... 19-24, 25, 29-33, 35
drainage area of tributaries of ..... 19
rating tables for ..... 23, 31-32
diagrams showing discharge of ..... 24-33
Potomac River (South Branch), discharge of ..... 21
rating tables for ..... 21
Prentiss, J. L., work of ..... 225
Prescott, Albert, analysis of water by ... 543
Pressure in artesian wells, South Dakota ..... 591-592
Pritchard, A. H., work of ..... 378
Provo, Utah, stream measurements at. 325-327
Provo River, Utah, measurements of ... 325-327
rating table for ..... 326
diagram showing discharge of ..... 328
Pueblo, Colorado, stream measurements at ..... 227-231
Pukwana, South Dakota, artesian well near ..... 568
Pumpkinseed Creek, Nebraska, measurements of ..... 193, 206
Purgatoire River, Colorado, measurements of ..... 232

Q.

Queen Creek, Arizona, measurements of ..... 292-297
diagram showing discharge of ..... 295
projected reservoir on ..... 720-721

R.


Page.

Railroads, cooperation by ..... 14
Rainfall, Atlanta, Georgia ..... 70
Bear Valley reservoir, California .... 685
California ... 363, 381, 396, 399, 400, 407, 418, 673, 674, 685
Follows Camp, California ..... 407
Fort Tejon, California ..... 399
Kern County, California ..... 396
Los Angeles, California ..... 407
Ohio-Indiana, tables showing ..... 555–559
Red Bluff, California ..... 363
Tejon ranch house, California ..... 400
Tuolumne County, California ..... 381
Ravenna, Ohio, water supply of ..... 552
Rawn, A. B., work of ..... 42
Ray, L. D., aid by ..... 488
Ray, W. B., aid by ..... 541
Raymond, C. F., artesian irrigation by ... 600
Rays Creek, California, projected irrigation from ..... 711
Read, M. C., cited ..... 477, 548–549
Red Bluff, California, stream measurements at ..... 362–365
rainfall at ..... 363
Redding, R. J., cited ..... 70
Redfield, South Dakota, artesian irrigation near ..... 605
Red Mountain, California, stream measurements at ..... 390–393
Reed, J. M., work of ..... 197
Reed, J. T., work of ..... 384
Reelsville, Indiana, artesian well at .... 491–492
Regan, J. S., work of ..... 246
Reiff, Charles F., aid by ..... 548
Rensselaer, Indiana, artesian well at ..... 492
Republican River, measurements of ... 194–207
rating tables for ..... 201, 205
North Fork, measurements of ..... 194–195
Resaca, Georgia, stream measurements at 98–99
Reservoirs for irrigation, paper by James D. Schuyler on ..... 617–740
capacities and areas of ..... 727–740
projected, descriptions of ..... 703–726
Richardson, C., work of ..... 52
Richins, W., work of ..... 286
Richmond, Indiana, water supply of ..... 542
analysis of water from ..... 542
Rio Grande, measurements of ..... 245–259
rating tables for ..... 247, 250, 253, 256
diagram showing discharge of .. 249, 251, 255
cross sections of ..... 257, 258
Rio Grande, New Mexico, stream measurements at ..... 252–254
Rio Verde, Arizona, proposed reservoirs on ..... 717–718
Ripley, Ohio, water supply of ..... 552
Ririe, James, work of ..... 321
River heights, reference to tables showing ..... 15
Riverside, Alabama, stream measurements at ..... 99–101
Riverside, California, water used in irrigation at ..... 672
Riverside County, California, masonry dam in ..... 707
Roanoke, Virginia, stream measurements at ..... 42
Roanoke River, measurements of ..... 42–50
rating table for ..... 48–49
Rochester, Indiana, water supply of ..... 542
Rock Creek, Nebraska, measurements of 206
Rock Creek, Nevada, measurements of . 308–310
rating table for ..... 310
projected reservoir on ..... 723
Rock-fill dams, description of ..... 627–649
Rock Hill, South Carolina, stream measurements at ..... 61–64
Rocky River, Ohio, description of ..... 467
Rodgers, J., work of ..... 306
Rome, Georgia, stream measurements at 109
Rosebud Reservation, South Dakota, artesian well at ..... 587, 588–589
Ross, Charles P., work of ..... 156
Ross, William F., aid by ..... 539
Rockville, Indiana, water supply of ..... 542
Rowlandsville, Maryland, stream measurements at ..... 16
Russell, G. M., aid by ..... 552
Russell, J. C., aid by ..... 493
Russell, W. G., work of ..... 241
Run-off, southern California ..... 673, 674
Ryan, James, log of artesian well of ..... 572
Ryan, J. W., log of artesian well of ..... 572
Ryan, John, acknowledgments to ..... 442
Ryan, W. E., artesian irrigation by ..... 604
Ryon, A. M., cited ..... 180


S.


Sacramento River, measurements of ... 361–36
rating tables for ..... 364, 368
diagrams showing discharge of ..... 366, 369
cross sections of ..... 367
rating curve for ..... 368
St. Joseph River, Indiana, description of ..... 470–471
St. Joseph-of-the-Maumee River, Ohio, description of ..... 469
St. Mary River, Ohio, description of ..... 469
St. Marys, Ohio, water supply of ..... 552–553
St. Paul, Nebraska, stream measurements near ..... 176–181, 186–187
St. Vrain Creek, Colorado, measurements of ..... 172–174
rating table for ..... 173
Salamonie River, description of ..... 449
Salem, South Dakota, depths to bed rock at ..... 594
Salesville, Montana, stream measurements at ..... 124–126
Salida, Colorado, stream measurements at ..... 224–225
Saline River, Kansas, measurements of . 210–212
rating table for ..... 211
Salisbury, R. D., cited ..... 433
Salisbury, North Carolina, stream measurements at ..... 57–59
Salmon Creek, California, dam site on ... 706
Salt River, Arizona, measurements of . 297–298
Salt Springs Valley reservoir, California, measurements of ..... 375–377
Saluda River, South Carolina, measurements of ..... 68

Page.
Santa Ana River, California, measurements of ..... 411–412
San Antonio Creek, California, measurements of ..... 417
San Bernardino Valley, California, projected irrigation in ..... 691
Sanborn County, South Dakota, artesian wells in ..... 574–575
artesian irrigation in ..... 604
Sanborn, J. S., aid by ..... 568
artesian irrigation by ..... 599
San Diego, California, Sweetwater dam near ..... 669–671
irrigation near ..... 671–682
San Diego County, California, cross sections of dam sites in ..... 707
Sandusky, Ohio, water supply of ..... 553
Sandusky River, Ohio, description of ..... 468
San Emidio Creek, California, measurements of ..... 397–399
Sanford, J. C., aid by ..... 123
San Francisco Bay, measurements of streams entering ..... 361–397
San Gabriel Canal, California, measurements of ..... 416, 417
San Gabriel River, California, measurements of ..... 405–411
rating tables for ..... 408
San Joaquin River, measurements of ..... 385–389
sections of ..... 387
rating curve for ..... 388
rating table for ..... 388
view of gaging station on ..... 389
diagram showing discharge of ..... 390
San Joaquin River and tributaries, measurements of ..... 371–379
San Juan River, Colorado, rating table for ..... 280
diagram showing discharge of ..... 281
San Juan River and tributaries, Colorado, measurements of ..... 278–285
San Leandro dam, California, description of ..... 655–657
San Leandro reservoir, California, capacity and area of ..... 737
San Luis Rey reservoir site, California, cross section of ..... 707
San Marcial, New Mexico, stream measurements at ..... 254–257
cross section of Rio Grande at ..... 257
San Mateo Creek, California, measurements of ..... 370
San Mateo dam, California, description of ..... 688
San Miguel River, Colorado, measurements of ..... 264–265
diagram showing discharge of ..... 266
Santa Ana River, California, irrigation from ..... 715
Santa Ana Canyon dam, California, description of ..... 715
Santa Maria Valley reservoir site, California, capacity and area of ..... 733
cross section of ..... 707
Sappington, Montana, stream measurements at ..... 136
Savage, H. N., aid by ..... 15, 415
Savage, M., work of ..... 182, 184, 185
Savannah River, measurements of ..... 73–77
rating table for ..... 75
Savannah River Basin, hydrography of ..... 72–77
Sawyer, R. C., work of ..... 117
Scannell, M., aid by ..... 553
Schlund, George, artesian irrigation by ..... 600
Schlund, Henry, artesian irrigation by ..... 601
Schuyler, James D., aid by ..... 15
paper on reservoirs for irrigation by ..... 617–740
Scioto River, drainage system of ..... 458–459
Scotland, South Dakota, log of artesian well near ..... 587
depths to bed rock in ..... 593
Seaton, A. B., artesian irrigation by ..... 600
Sedimentation in Sweetwater reservoir, California ..... 681–682
Selma, North Carolina, stream measurements at ..... 52
Seymour, Indiana, artesian wells at ..... 492
Shallow Ford, Georgia, stream measurements at ..... 92
Shannon, W. P., aid by ..... 539
Shaw, H., work of ..... 131
Shell Creek, Nebraska, measurements of ..... 193
Shenandoah River, measurements of ..... 25–29
rating table for ..... 28
diagram showing discharge of ..... 29
Shepard, J. H., cited ..... 607, 608, 611
Shereda, F., record of artesian well of ..... 568
artesian irrigation by ..... 600
Sheridan, Wyoming, stream measurements at ..... 136–138
Shereman, Henry, jr., aid by ..... 541
Shields, W. J., aid by ..... 542
Shoals, Indiana, artesian well at ..... 492
Siebenthal, C. E., acknowledgments to ..... 426
aid by ..... 537
Siever, G. W., work of ..... 243
Sidney, Ohio, water supply of ..... 553
Sinclair, O. C., aid by ..... 554
Sites, B., work of ..... 172
Skinner, F. W., cited ..... 710
Slater, William, work of ..... 272
Smith, A. J., artesian irrigation by ..... 601
Smith, E. G., analysis of water by ..... 539
Smith, E., work of ..... 378
Smith, Everett, artesian irrigation by ..... 600
Smith, Eugene A., aid by ..... 14
Smith, H. V., work of ..... 326
Smith, Martin, record of well of ..... 568
artesian irrigation by ..... 599
Smith, M. D., work of ..... 261
Smith, W. M., artesian irrigation by ..... 601
Smoky Hill River, measurements of ..... 207–215, 212–215
rating table for ..... 214
diagram showing discharge of ..... 215
Snake River, Idaho, measurements of ..... 334–336
rating table for ..... 335
Snake River and tributaries, measurements of ..... 330–354
Snyder, A. C., work of ..... 179, 181
Soda Springs, Idaho, stream measurements at ..... 312–313

Page.
Solomon River, Kansas, measurements of ... 207-210
rating table for ... 209
South Antelope Valley Irrigation Company, reservoir of ... 711-715
capacity and area of reservoir of ... 737
South Bend, Indiana, artesian wells at ... 492
water supply of ... 542-543
analysis of water from ... 543
South Boulder Creek, Colorado, measurements of ... 169-170
rating table for ... 170
South Carolina, stream measurements in ... 61-63, 65-68, 73-75, 123
South Dakota, paper by N. H. Darton on well boring and irrigation in ... 561-615
extent of artesian basin in ... 590-591
pressure and head in artesian wells of ... 591-592
depth to bed rock in ... 592-597
irrigation by artesian waters in ... 597-606
temperatures of artesian waters of ... 606-611
South Fork reservoir site, Colorado, description of ... 726
South Loup River, measurements of ... 181, 193
South Park, Colorado, Antero reservoir site in ... 726
South Platte River, measurements of ... 159-167, 193
rating tables for ... 161-162, 164-165
diagram showing discharge of ... 166
Spears, M., record of artesian well of ... 579
Spencer, Indiana, artesian wells at ... 492
Spicer, G. B., aid by ... 488
Spink County, South Dakota, artesian irrigation in ... 605
Spokane, Washington, stream measurements at ... 359-360
Spokane River, measurements of ... 359-360
Springfield, Ohio, water supply of ... 553
Springfield, West Virginia, stream measurements at ... 19-21
Spring Valley watersheds, California, run-off in ... 690
Spring Valley waterworks, California, description of dam for ... 688-690
Stalder, C. W., work of ... 390
Stanislaus River, measurements of ... 371-375
measurements of tributaries of ... 372, 375
rating table for ... 374
diagram showing discharge of ... 376
Stanislaus River (Main Fork), measurement of ... 417
Stanislaus River (South Fork), measurement of ... 417
Stanislaus and San Joaquin Canal, measurement of ... 417
Staunton River, Virginia, measurements of ... 42-43, 45-47
Steubenville, Ohio, water supply of ... 553
Stout, James, work of ... 176
Stout, O. V. P., work of ... 181, 184, 185
Stillwell, H. C., aid by ... 550
Stinking Water Creek, measurements of ... 206, 207
Stuntz, C. R., analysis of water by ... 547, 548
Page.
Sugar Creek, Indiana, description of ... 451
Sullivan, M. E., work of ... 231
Sullivan, Indiana, artesian wells at ... 492
water supply of ... 543
Suman, J. C. B., aid by ... 544
Summitville, Indiana, artesian well at ... 492
Sunset Canyon, Arizona, reservoir site at 722
Surface water, Ohio-Indiana, use of ... 503-510
Superior, Nebraska, stream measurements at ... 199-202
Sutton, A. J., work of ... 117
Swain, George F., cited ... 36, 42, 84
Swan, A. E., aid by ... 571, 586, 588, 593
Swart, W., work of ... 361
Sweeney, T. J., aid by ... 552
Sweetwater Creek, measurements of ... 92
Sweetwater dam, California, description of ... 669-682
profile of ... 678
Sweetwater drainage basin, run-off in ... 672-674
Sweetwater reservoir, California, evaporation from ... 680-681
capacity and area of ... 730
sedimentation in ... 681-682
Sweetwater River, California, measurements of ... 415-416

T.

Taft, Burr, work of ... 191
Talking Rock Creek, Alabama, measurements of ... 110
Tallapoosa River, description of ... 94
measurements of ... 110
Tarboro, North Carolina, stream measurements at ... 50-52
Tar River, North Carolina, measurements of ... 50-52
rating table for ... 51
Tarryall reservoir site, Colorado, description of ... 726
Taylor, J. M., work of ... 116
Taylor, John S., work of ... 308
Taylor, L. H., work of ... 299, 302, 303, 305, 306, 308, 311
Taylor, Z., work of ... 360
Tejon Creek, California, measurements of 417
Tejon House Creek, California, measurements of ... 400-402
rating table for ... 401
Tejon ranch house, California, rainfall at 400
stream measurements at ... 400-402
Temescal dam, California, description of ... 655-656
Temperatures of artesian waters ... 606-611
Templin, Frank, work of ... 371
Tennessee, stream measurements in ... 119-122
Tennessee Basin, stream measurements in ... 116-123
Tennessee River, measurements of ... 119-123
rating table for ... 120
Terre Haute, Indiana, artesian wells at ... 492-493
water supply of ... 543
analysis of water from ... 543
Texas, stream measurements in ... 110, 257-259
Thompson, A., work of ... 394

Page.

Thompson, W. H., cited ..... 473–474
Thorn, C. E., aid by ..... 555
Three Forks, Montana, stream measurements at ..... 131–133
Tiffin, Ohio, water supply of ..... 553
Tight, W. G., cited ..... 460–461
Tippecanoe River, description of ..... 450–451
Todd, J. E., cited ..... 587, 593
Toledo, Ohio, water supply of ..... 553
Tonto Basin, Arizona, reservoir project in ..... 715–717
Tonto Basin reservoir site, Arizona, capacity and area of ..... 739
Toponis, Idaho, stream measurements at ..... 336–339
Townsend, Montana, stream measurements at ..... 123–124
Tragier, A., artesian irrigation by ..... 601
Trinidad, Colorado, stream measurements at ..... 231–232
Tripp, W. H., record of artesian well of ..... 579–580
Troy, Ohio, water supply of ..... 553
True, A. M., aid by ..... 545
Tuckaseegee River, measurements of ..... 116–117
Tunis Creek, California, measurements of ..... 416
Tuolumne County, California, rainfall in ..... 381
Tuolumne River, measurements of ..... 378–385
cross section of ..... 380
rating curve for ..... 382
rating table for ..... 382, 385
diagrams showing discharge of ..... 383, 386
Turlock dam, California, description of ..... 686–687
Turner, J. N., work of ..... 232
Tuscaloosa, Alabama, stream measurements at ..... 103–108
Tyler, F. D., artesian irrigation by ..... 601
Tyler, Texas, description of dam at ..... 654–655

U.

Uinta, Utah, stream measurements at ..... 323–325
Umatilla River, measurements of ..... 361
Union City, Indiana, water supply of ..... 544
Union Creek, Nebraska, measurements of ..... 193
Uncompahgre River, Colorado, measurements of ..... 265–268
rating table for ..... 267
diagram showing discharge of ..... 268
Upham, Warren, cited ..... 461
aid by ..... 546
Upper Crystal Springs reservoir, California, measurements at ..... 370
Upper Otay reservoir, California, description of ..... 642
Upper Otay reservoir site, California, capacity and area of ..... 736
cross section of ..... 707
Urbana, Ohio, water supply of ..... 553–554
Utah, stream measurements in ..... 275–279, 316–330
Utah Lake, measurements of ..... 327–330
Uva, Wyoming, stream measurements at ..... 148–150

V.

Vale, Oregon, stream measurements at ..... 348–350
Valparaiso, Indiana, water supply of ..... 544

Page.

Van Nuys, T. C., analyses of water by ..... 538–539
Van Wert, Ohio, water supply of ..... 554
Veach, William A., aid by ..... 551
Vedder, V. W., work of ..... 261
Verde River, measurements of ..... 297
Verdigris River, measurements of ..... 235–238
rating table for ..... 236–237
Vermilion River, Ohio, description of ..... 468
Victor, California, description of projected dam near ..... 708–710
cross section of dam site near ..... 709
Victor reservoir, California, map of watershed and lands to be irrigated from ..... 708
Victor reservoir site, California, capacity and area of ..... 737
Virginia, stream measurements in ..... 25–28, 35–47
Visalia, California, projected irrigation at ..... 706
Von Behren, Louis, aid by ..... 541

W.

Wabash, Indiana, artesian wells at ..... 493
water supply of ..... 544
Wabash River, drainage system of ..... 446–450
table of altitudes and distances along ..... 448
Walnut Grove reservoir, Arizona, description of ..... 721–722
Wapakoneta, Ohio, water supply of ..... 554
analysis of water from ..... 554
Warm Springs Canyon, California, stream measurements at ..... 411–412
Warner's Ranch reservoir site, California, capacity and area of ..... 733
Warren, A. K., aid by ..... 395
Warsaw Indiana, water supply of ..... 544
Washington stream measurements in ..... 355–360
Water, analyses of ..... 495–501, 537, 538, 539, 540, 541, 542, 543, 546, 547, 548, 549, 550, 551, 554, 555, 611–615
Water (surface), Indiana and Ohio cities using ..... 503–510
Waterloo, South Carolina, stream measurements at ..... 68
Water supply, Ohio and Indiana cities ..... 502–555
Watkins, E. D., artesian irrigation by ..... 600
Watrous, New Mexico, stream measurements at ..... 245
Wauneta, Nebraska, stream measurements at ..... 196–197
Weber River, Utah, measurements of ..... 323–325
rating table for ..... 324
diagram showing discharge of ..... 325
Webster, South Dakota, artesian well at ..... 591
Weiser Idaho, stream measurements at ..... 352–354
Weiser River, Idaho, measurements of ..... 352–354
rating table for ..... 353
Well boring and irrigation in South Dakota, paper by N. H. Darton on ..... 561–615
Welsh, Professor, analysis of water by ..... 549
Wellington, Ohio, water supply of ..... 554
Wells, L. W., acknowledgments to ..... 655
Wells, Ohio-Indiana, descriptions of ..... 475–493, 511–555
Wells (artesian), Ohio-Indiana ..... 485–493
South Dakota ..... 613–615

Page.
Wellsville, Ohio, water supply of ..... 554
Welty, Joseph, aid by ..... 551
West, J. B., aid by ..... 550
West Fork, Indiana, artesian well at ..... 493
West Gallatin River, measurements of .. 124–126
rating table for ..... 125
West Point, Georgia, stream measurements at ..... 90–92
West Union, Ohio, water supply of ..... 554
West Virginia, stream measurements in ..... 19–21, 25, 111–115
West White River, Indiana, description of ..... 451–453
White, I. C., cited ..... 463
White River, Nebraska, measurements of ..... 193
Whitewater River, drainage system of .. 456–457
Whiting, George H., artesian irrigation by ..... 606
Whiting, Indiana, water supply of ..... 544
Whitlow's ranch, Arizona, stream measurements at ..... 292–295
Whitten, William M., aid by ..... 542
Wildcat Creek, Indiana, description of .. 451
Wiles, C. W., aid by ..... 547
Williams, I. T., work of ..... 124
Williams, R. H., work of ..... 50
Wiley, A. J., aid by ..... 339–340
Williamsport, Indiana, artesian well at .. 493
Willis, Robert H., work of ..... 153
Willrodt, H. L., artesian irrigation by .. 599, 600
Wilmington, Ohio, water supply of ..... 554
Wilson, A. F., aid by ..... 493
Wilson, J., aid by ..... 554
Wilson, J. A., artesian irrigation by ..... 602
Wilson, J. E. C., aid by ..... 571
Wilson, Jerome, work of ..... 210
Wilson, H. M., cited ..... 626, 644, 698, 722
Wilson, W. S., aid by ..... 545
Winamac, Indiana, artesian well at ..... 493
Winslow, Arizona, reservoir sites near .. 722
Woodruff, Arizona, projected reservoir near ..... 722
Woods, Wyoming, stream measurements at ..... 145–148
Page.
Woodstock, Maryland, stream measurements at ..... 16–17
Wooster, Ohio, water supply of ..... 554–555
analysis of water from ..... 555
Worthen, A. H., cited ..... 433
Worthington, Indiana, artesian well at .. 493
Wright, A. A., cited ..... 467, 468
aid by ..... 552
Wright, G. F., cited ..... 434
Wright, S. B., cited ..... 70
Wyman, W. S., work of ..... 103
Wyoming, stream measurements in ... 136–153, 268–275

X.

Xenia, Ohio, water supply of ..... 555

Y.

Yadkin River, measurements of ..... 57–61
rating tables for ..... 58, 60
diagram showing discharge of ..... 59
Yakima, Washington, stream measurements at ..... 356–358
Yakima River, Washington, measurements of ..... 355–359
rating tables for ..... 357, 359
Yankton Agency, Greenwood, South Dakota, record of artesian well at .. 570–571
pressure in artesian well at ..... 592
Yankton County, South Dakota, artesian wells in ..... 587
artesian irrigation in ..... 606
Yeates, William S., aid by ..... 14
Yellowstone River, measurements of tributaries of ..... 136–140
Yosemite reservoir, California, description of ..... 700–701
Youngfelt, E. T., aid by ..... 201, 202
Youngstown, Ohio, water supply of ..... 555
Yankton, South Dakota, depths to bed rock at ..... 593
Yuma, Arizona, stream measurements at ..... 298–299

Z.

Zanesville, Ohio, water supply of ..... 555
Zola dam, France, profile of ..... 678