TWELFTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

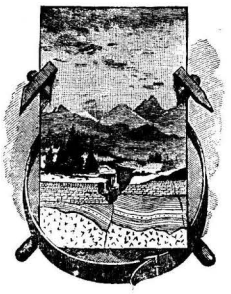
SECRETARY OF THE INTERIOR

1890-'91

BY

J. W. POWELL
DIRECTOR

PART II—IRRIGATION



WASHINGTON
GOVERNMENT PRINTING OFFICE
1891

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UNITED STATES GEOLOGICAL SURVEY.

Part II—IRRIGATION.

CONTENTS.

	Page.
REPORT UPON THE LOCATION AND SURVEY OF RESERVOIR SITES DURING THE FISCAL YEAR ENDED JUNE 30, 1891, BY A. H. THOMPSON	1
Introduction	9
California	10
Colorado	55
Montana	127
New Mexico	165
Nevada	209
HYDROGRAPHY OF THE ARID REGIONS, BY F. H. NEWELL	213
Hydrographic measurements and irrigation	219
The arid regions	219
Hydrographic data	221
Deficiency of water	221
Increase of water duty	223
Water storage	224
Relative amount of flood waters	227
Time of floods	228
Intensity of floods	230
Rainfall and river flow	230
Points of maximum utility	231
Classification of drainage basins	232
Humidity and irrigation	234
Evaporation observations	234
Results of stream measurements	235
Upper Missouri and Yellowstone basins	236
Platte Basin	238
Arkansas Basin	240
Rio Grande Basin	240
Topography and elevations	240
Annual and monthly rainfall	243
The Colorado district of the Rio Grande	245
San Luis Valley	247
Irrigation practice	248
The Taos district of the Rio Grande	251
Tres Piedras Mesa	256
Embudo gauging station	257
Espanola Valley	258
The Chama district	261
Santa Fe district	269
Albuquerque district	270
Tributaries below the Chama	273
Santa Fe and adjacent streams	273
Jemez River	274

Page.

Rio Grande Basin—Continued.
Tributaries below the Chama—Continued.
Puerco River 275
Résumé of water supply 277
Mesas along the Rio Grande 278
Mesilla Valley 279
Gypsum Plains district 281
Pecos River 282
General topography 282
Climate and water supply 283
Upper tributaries 284
Lower tributaries in New Mexico 286
Agriculture along the Pecos 287
Irrigation works on the Pecos 288
Colorado River drainage basin 290
The Gila Basin 292
Topography and altitudes 292
Agricultural lands 295
Duty of water 296
Water storage 298
Rainfall 299
Upper Gila district 302
San Pedro district 303
Middle Gila district 305
Verde district 309
Upper Salt district 310
Lower Salt district 311
Lower Gila district 314
Agua Fria and Hassayampa districts 315
Santa Cruz district 315
Sacramento and San Joaquin basins 316
Kern River 319
Tule River 319
Kaweah River 320
Kings River 320
San Joaquin River 321
Merced River 322
Tuolumne River 322
Mokelumne River 323
Lower San Joaquin River 323
The Great Basin 324
Truckee River 324
Carson River 325
Salt Lake Basin 325
Bear River 325
Bear Lake 327
Lower Bear River 329
Cache Valley 330
Ogden and Weber rivers 334
Utah Lake drainage 334
Sevier River 339
Snake River drainage 344
Discharge tables 345
IRRIGATION IN INDIA, BY HERBERT M. WILSON 363
Preface 369

Page.
Author's list 371
Introduction 375
CHAPTER I.—Finance and statistics 390
Value and necessity of irrigation 390
Land and crops 395
CHAPTER II.—Topography, meteorology, and forestry 399
Topography and geology 399
Meteorology 403
Forestry 404
CHAPTER III.—History and administration 406
History of irrigation works 406
Administration and legislation 407
CHAPTER IV.—Wells and inundation canals 415
Classes of works 415
Extent of irrigation 416
Financial and agricultural results 417
Objections to irrigation 419
Wells 423
Inundation canals 425
CHAPTER V.—Deltaic and perennial canals 428
Source of supply 428
Water duty and evaporation 428
Deltaic canals 435
Perennial canals 438
Ganges Canal 439
Lower Ganges Canal 443
Agra Canal 445
Sirhind Canal 447
Bari Doab and Western Jumna Canals 450
Sidhnai Canal 451
Soane Canals 452
Cross-section, slope, and alignment 455
Headworks 458
Weirs 460
Scouring sluices 467
Canal regulators 473
Well foundations 477
Escapes 479
Falls and rapids 481
Drainage works 484
Distributaries 490
Methods of applying water 495
CHAPTER VI.—Storage works 498
Classes of works 498
Reservoirs 503
Mutha project 504
Nira project 506
Betwa project 515
Periar project 520
Tansa Reservoir 525
Masonry dams 527
Materials, labor, and cost 530
Tanks 536
Ekruk Tank 544
Ashti Tank 545

Page.

CHAPTER VI.—Storage works—Continued.
Tank dams 550
Combined storage and canal systems 553
Palar anicut system 554
Zhara Karez irrigation scheme 556
River conservancy 557
Land reclamation 561
FINANCIAL STATEMENT 562
INDEX 569

ILLUSTRATIONS.

		Page.
PLATE LIV.	Reservoir site, Colorado, No. 8	56
LV.	Reservoir site, Colorado, No. 55	126
LVI.	Reservoir site, New Mexico, No. 38	204
LVII.	Reservoir site, New Mexico, No. 39	208
LVIII.	Index map of river measurements	222
LIX.	Diagram of monthly river flow and rainfall	226
LX.	Diagram of daily discharge of the West Gallatin River and Red Creek, Montana	228
LXI.	Diagram of daily discharge of the Madison River, Montana	230
LXII.	Diagram of daily discharge of the Missouri River, Montana	232
LXIII.	Diagram of daily discharge of the Sun River, Montana	234
LXIV.	Diagram of daily discharge of the Yellowstone River, Montana	236
LXV.	Diagram of daily discharge of the Cache la Poudre, Colorado, 1884 to 1891	238
LXVI.	Diagram of daily discharge of the upper tributaries of the Arkansas River, Colorado, 1890	240
LXVII.	Diagram of daily discharge of the Arkansas River at Canyon City, Colorado, 1888 to 1891	242
LXVIII.	Map of the Rio Grande and Pecos basins	244
LXIX.	Earth columns near station at Embudo, New Mexico	246
LXX.	Diagram of monthly rainfall in the Rio Grande Basin	248
LXXI.	Diagram of daily discharge of the Rio Grande at Del Norte, Colorado	250
LXXII.	Diagram of daily discharge of the Rio Grande at Embudo, New Mexico	252
LXXIII.	Diagram of daily discharge of the Rio Grande at El Paso, Texas	280
LXXIV.	Diagram of gauge height of the Colorado River at Yuma, Arizona, 1880 to 1891	290
LXXV.	Map of the Gila Basin, Arizona	292
LXXVI.	Diagram of monthly rainfall in the Gila Basin, Arizona	300
LXXVII.	View of the Hassayampa Reservoir, Arizona	302
LXXVIII.	Diagram of daily discharge of the Gila River, Arizona	306
LXXIX.	Diagram of daily discharge of the Salt River, Arizona	308
LXXX.	Diagram of daily discharge of the Kern River, California, 1879 to 1882	310
LXXXI.	Diagram of daily discharge of the Kaweah River, California, 1879 to 1882	312
LXXXII.	Diagram of daily gauge height of the Kings River, California, 1880 to 1891	314
LXXXIII.	Diagram of daily discharge of the upper San Joaquin River, California, 1879 to 1882	316
LXXXIV.	Diagram of daily gauge height of the upper San Joaquin River, California, 1880 to 1891	318

Page.

PL. LXXXV. Diagram of daily discharge of the Merced River, California, 1879 to 1882 320
LXXXVI. Diagram of daily discharge of the Tuolumne River, California, 1879 to 1882 322
LXXXVII. Diagram of daily discharge of the Mokelumne River, California, 1879 to 1882 322
LXXXVIII. Diagram of daily gauge height of the lower San Joaquin River, California, 1880 to 1891 322
LXXXIX. Diagram of daily discharge of the Truckee and Little Truckee rivers at Boca, California, and of Prosser Creek 324
XC. Diagram of daily discharge of the Truckee River at Vista, Nevada 324
XCI. Diagram of daily discharge of the Carson River at Empire, Nevada, and of the East and West forks of the Carson 324
XCII. Map of the Bear River drainage basin 326
XCIII. View of the Bear River Canyon, Utah 328
XCIV. Diagram of daily discharge of the Bear River at Battle Creek, Idaho 330
XCV. Diagram of daily discharge of the Bear River at Collinston, Utah 332
XCVI. Diagram of daily discharge of the Ogden River, Utah 336
XCVII. Diagram of daily discharge of the Weber River, Utah 336
XCVIII. Diagram of daily discharge of the American Fork and Spanish Fork rivers, Utah 338
XCIX. Diagram of daily discharge of the Provo River, Utah 340
C. Diagram of daily discharge of the Sevier River, Utah 342
CI. Diagram of daily discharge of Henry Fork, Idaho 344
CII. Diagram of daily discharge of the Falls and Teton rivers, Idaho 344
CIII. Diagram of daily discharge of the Snake River, at Eagle Rock, Idaho 344
CIV. Diagram of daily discharge of the Owyhee River, Oregon 344
CV. Diagram of daily discharge of the Malheur River, Oregon 344
CVI. Diagram of daily discharge of the Weiser River, Idaho 344
CVII. Folding map of India ..... In pocket.
CVIII. Aden Tanks, Arabia 388
CIX. Persian wheel and paecottah 424
CX. Single mot 426
CXI. Gopalpur bifurcation, Ganges Canal 442
CXII. Sirhind Canal system 448
CXIII. Soane Canal system, Bengal 452
CXIV. Cross-sections of modern weirs 462
CXV. Plan of headworks, Soane Canals 464
CXVI. Sidhnai Canal, section of river in line of dam 466
CXVII. Headworks and river training works, Ganges Canal 468
CXVIII. Narora Weir, Lower Ganges Canal, plan of well foundations 470
CXIX. Narora Weir, Lower Ganges Canal, plan of superstructure 472
CXX. Narora Weir, Lower Ganges Canal, detail of canal sluices 474
CXXI. Soane Canal, automatic sluice gate 476
CXXII. Headworks, Lower Ganges Canal, Narora 478
CXXIII. Sinking foundation wells, Nadrai Aqueduct, Lower Ganges Canal 480
CXXIV. Asafnagar Falls, Ganges Canal 482
CXXV. Rapids, Bari Doab Canal 484
CXXVI. Agra Canal, cross-section of Kushuk Fall 486

		Page.
Pl. CXXVII.	Solani Aqueduct, Ganges Canal	488
CXXVIII.	Nadrai Aqueduct, Lower Ganges Canal	490
CXXIX.	Ranipur superpassage, Ganges Canal	492
CXXX.	Sasoon superpassage, Sirhind Canal	494
CXXXI.	Rutmoo level crossing, Ganges Canal	496
CXXXII.	Drainage map, showing arrangement of distributaries	498
CXXXIII.	Standard masonry outlet for distributaries, Punjab	500
CXXXIV.	Plan of Mutha and Nira irrigation projects, Bombay	504
CXXXV.	Plan and cross-section of Bhatgur Dam, Nira system, Bombay	506
CXXXVI.	Bhatgur Dam, Nira system, Bombay	508
CXXXVII.	Main and subsidiary weirs, Nira system, Vir, in great flood	512
CXXXVIII.	Betwa project, plan of dam and headworks	516
CXXXIX.	Betwa project, plan of regulator and scouring sluices	518
CXL.	The Periar project, Madras	520
CXLI.	Periar headworks, plan of dam and escape	522
CXLII.	Natives building Tansa Dam, Bombay	526
CXLIII.	Ekruk Tank	544
CXLIV.	Palar anicut system, plan and cross-section	554
CXLV.	Zhara Karez irrigation project, Beluchistan	556
CXLVI.	Training works, Agra Canal, Okhla	560
Fig. 81.	Reservoir site, California, No. 5	11
82.	Reservoir site, California, No. 6	12
83.	Reservoir site, California, No. 14	14
84.	Reservoir site, California, No. 15	15
85.	Reservoir site, California, No. 16	16
86.	Reservoir site, California, No. 17	17
87.	Reservoir site, California, No. 18	18
88.	Reservoir site, California, No. 19	19
89.	Reservoir site, California, No. 20	21
90.	Reservoir site, California, No. 21	22
91.	Reservoir site, California, No. 22	23
92.	Reservoir site, California, No. 23	24
93.	Reservoir site, California, No. 24	26
94.	Reservoir site, California, No. 25	27
95.	Reservoir site, California, No. 26	28
96.	Reservoir site, California, No. 27	29
97.	Reservoir site, California, No. 28	30
98.	Reservoir site, California, No. 29	32
99.	Reservoir site, California, No. 30	33
100.	Reservoir site, California, No. 31	35
101.	Reservoir site, California, No. 32	36
102.	Reservoir site, California, No. 33	37
103.	Reservoir site, California, No. 34	38
104.	Reservoir site, California, No. 35	40
105.	Reservoir site, California, No. 36	41
106.	Reservoir site, California, No. 37	43
107.	Reservoir site, California, No. 38	44
108.	Reservoir site, California, No. 39	45
109.	Reservoir site, California, No. 40	47
110.	Reservoir site, California, No. 41	48
111.	Reservoir site, California, No. 42	51
112.	Reservoir site, California, No. 43	52
113.	Reservoir site, California, No. 44	54
114.	Reservoir site, Colorado, No. 6	55
115.	Reservoir site, Colorado, No. 9	58

Page.

FIG. 116. Reservoir site, Colorado, No. 10 60
117. Reservoir site, Colorado, No. 11 61
118. Reservoir site, Colorado, No. 12 63
119. Reservoir site, Colorado, No. 13 65
120. Reservoir site, Colorado, No. 14 67
121. Reservoir site, Colorado, No. 15 68
122. Reservoir site, Colorado, No. 16 69
123. Reservoir site, Colorado, No. 17 71
124. Reservoir site, Colorado, No. 18 72
125. Reservoir site, Colorado, No. 19 74
126. Reservoir site, Colorado, No. 20 75
127. Reservoir site, Colorado, No. 21 77
128. Reservoir site, Colorado, No. 22 78
129. Reservoir site, Colorado, No. 23 80
130. Reservoir site, Colorado, No. 24 83
131. Reservoir site, Colorado, No. 26 84
132. Reservoir site, Colorado, No. 27 86
133. Reservoir site, Colorado, No. 28 87
134. Reservoir site, Colorado, No. 29 89
135. Reservoir site, Colorado, No. 30 90
136. Reservoir site, Colorado, No. 31 91
137. Reservoir site, Colorado, No. 32 93
138. Reservoir site, Colorado, No. 33 95
139. Reservoir site, Colorado, No. 34 96
140. Reservoir site, Colorado, No. 35 98
141. Reservoir site, Colorado, No. 36 99
142. Reservoir site, Colorado, No. 37 100
143. Reservoir site, Colorado, No. 40 102
144. Reservoir site, Colorado, No. 41 104
145. Reservoir site, Colorado, No. 42 105
146. Reservoir site, Colorado, No. 43 107
147. Reservoir site, Colorado, No. 44 108
148. Reservoir site, Colorado, No. 45 110
149. Reservoir site, Colorado, No. 46 112
150. Reservoir site, Colorado, No. 47 114
151. Reservoir site, Colorado, No. 48 115
152. Reservoir site, Colorado, No. 49 117
153. Reservoir site, Colorado, No. 50 118
154. Reservoir site, Colorado, No. 51 120
155. Reservoir site, Colorado, No. 52 121
156. Reservoir site, Colorado, No. 53 123
157. Reservoir site, Colorado, No. 54 124
158. Reservoir site, Montana, No. 11 128
159. Reservoir site, Montana, No. 12 129
160. Reservoir site, Montana, No. 13 130
161. Reservoir site, Montana, No. 14 131
162. Reservoir site, Montana, No. 15 132
163. Reservoir site, Montana, Nos. 16 and 17 134
164. Reservoir site, Montana, No. 18 135
165. Reservoir site, Montana, No. 19 138
166. Reservoir site, Montana, No. 20 139
167. Reservoir site, Montana, No. 21 140
168. Reservoir site, Montana, Nos. 22 and 23 141
169. Reservoir site, Montana, No. 24 143
170. Reservoir site, Montana, No. 25 147

Page.
FIG. 171. Reservoir site, Montana, No. 26 149
172. Reservoir site, Montana, No. 27 151
173. Reservoir site, Montana, No. 28 152
174. Reservoir site, Montana, No. 29 155
175. Reservoir site, Montana, No. 30 156
176. Reservoir site, Montana, No. 31 157
177. Reservoir site, Montana, No. 32 158
178. Reservoir site, Montana, No. 33 159
179. Reservoir site, Montana, No. 34 160
180. Reservoir site, Montana, No. 35 161
181. Reservoir site, Montana, No. 36 162
182. Reservoir site, Montana, No. 37 163
183. Reservoir site, Montana, No. 38 165
184. Reservoir site, New Mexico, No. 1 166
185. Reservoir site, New Mexico, No. 2 166
186. Reservoir site, New Mexico, No. 3 168
187. Reservoir site, New Mexico, No. 4 169
188. Reservoir site, New Mexico, No. 5 170
189. Reservoir site, New Mexico, No. 6 170
190. Reservoir site, New Mexico, No. 7 172
191. Reservoir site, New Mexico, No. 8 173
192. Reservoir site, New Mexico, No. 9 174
193. Reservoir site, New Mexico, No. 10 174
194. Reservoir site, New Mexico, No. 11 175
195. Reservoir site, New Mexico, No. 12 176
196. Reservoir site, New Mexico, No. 13 177
197. Reservoir site, New Mexico, No. 14 178
198. Reservoir site, New Mexico, No. 15 178
199. Resesvoir site, New Mexico, No. 16 179
200. Reservoir site, New Mexico, No. 17 180
201. Reservoir site, New Mexico, No. 18 181
202. Reservoir site, New Mexico, No. 19 182
203. Reservoir site, New Mexico, No. 20 182
204. Reservoir site, New Mexico, No. 21 183
205. Reservoir site, New Mexico, No. 22 184
206. Reservoir site, New Mexico, No. 23 185
207. Reservoir site, New Mexico, No. 24 186
208. Reservoir site, New Mexico, No. 25 187
209. Reservoir site, New Mexico, No. 26 188
210. Reservoir site, New Mexico, No. 27 189
211. Reservoir site, New Mexico, No. 28 190
212. Reservoir site, New Mexico, No. 29 191
213. Reservoir site, New Mexico, No. 30 192
214. Reservoir site, New Mexico, No. 31 193
215. Reservoir site, New Mexico, No. 32 194
216. Reservoir site, New Mexico, No. 33 196
217. Reservoir site, New Mexico, No. 34 198
218. Reservoir site, New Mexico, No. 35 200
219. Reservoir site, New Mexico, No. 36 201
220. Reservoir site, New Mexico, No. 37 202
221. Reservoir site, Nevada, No. 1 210
222. Reservoir site, Nevada, No. 2 211
223. Diagram of annual rainfall in the Rio Grande Basin 244
224. Diagram illustrating sediment measurements at Embudo, New Mexico 258

		Page.
FIG. 225.	An acequia at Roswell, New Mexico	289
226.	Diagram of annual rainfall in the Gila Basin	300
227.	Diagram of the daily gauge height of the Tule River, California, 1879 and 1880	319
228.	Diagram of daily gauge height of the Tuolumne River, California, 1890 and 1891	322
229.	Diagram of fluctuations of Utah Lake	336
230.	Paecottah	423
231.	Mot	424
232.	Persian wheel	425
233.	Percolation and evaporation	431
234.	Plan and profile, Ganges Canal, Hardwar to Roorkee	441
235.	Thora Nulla Aqueduct, Soane Canal	453
236.	Canal cross-sections	456
237.	Three ancient weirs	460
238.	Shutter on Soane Weir	465
239.	Sidhnai Weir	466
240.	Myapur Dam, Ganges Canal	468
241.	Dropping the Soane automatic sluices	471
242.	Details of Sidhnai Weir	472
243.	Regulating gates, Ganges and Jumna canals	474
243*a*.	Headworks, Ganges Canal	475
244.	Regulating gates, Soane Canal head	476
245.	Ogee and vertical falls, Ganges Canal	481
246.	Soane Canals, Bengal. Arrangement of branches and escape at Dunwar	483
247.	Cross-section of Solani Aqueduct, Ganges Canal	485
248.	Plan of Rutmoo Crossing, Ganges Canal	489
249.	Kao Nulla siphon aqueduct, Soane Canal	490
250.	Plan of distributing head, Mutha Canal, Bombay	494
251.	Reinolds automatic weir gate	509
252.	Vir headworks, Nira system, Bombay	510
253.	Plan of headworks, Nira Canal, Vir	511
254.	Plan of regulator head, Nira Canal	512
255.	Kurra Aqueduct, Nira Canal	513
256.	Nira Canal, siphon superpassage, Jewhar Nulla	514
257.	Cross section, Betwa Dam	518
258.	Periar Dam and escape weir	522
259.	Tansa Dam, Bombay	525
260.	Tansa project, longitudinal section of dam	526
261.	Foundation, Tansa Dam	526
262.	Mixing mortar with churus	528
263.	Carrying stones to build Tansa Dam	532
264.	Profile of masonry dam, Molesworth's formula	534
265.	Cross-sections, earth and combined dams	538
266.	Map showing Ashti Tank	546
267.	Ashti Tank dam	547
268.	Ashti Dam slips	553
269.	Palar Anicut system	554
270.	Training works, Lower Ganges Canal, Narora	559

UNITED STATES IRRIGATION SURVEY.

ABSTRACT OF THE THIRD ANNUAL REPORT, 1890-1891.

The operations of the United States Irrigation Survey were carried on during the third year under extensions of the appropriation made on March 2, 1889, the topographic work and surveys of reservoir sites being continued to the end of the fiscal year by the appropriation act dated August 30, 1890. The work accomplished during the year consists of surveys for topographic maps showing the relative location and elevation of certain parts of the arid region; also of surveys of reservoir sites, measurements of water available, and instrumental examinations of possible canal lines.

The two annual reports preceding this give in detail the organization of the Survey, together with the results accomplished up to June 30, 1890, in carrying forward this investigation of the extent to which the arid land can be redeemed by irrigation. As shown in those reports, this investigation naturally falls into two divisions of primary importance, and a third, of more immediately apparent utility, depending upon them. These are, first, the systematic mapping of the arid regions in order to show the location and altitude of the irrigable lands, their position with regard to the rivers from which the water is to be obtained, and the area, altitude, and character of the catchment basin from which the rivers receive their waters. By this means only can a comprehensive knowledge be obtained of the possibilities of the best development of these fertile lands, and without such knowledge of the drainage areas of the streams and of the altitudes of catchment areas and irrigable lands satisfactory progress can not be made.

The second division of this investigation is that relating to the water supply or hydrography of the arid region. This consists of measurements of the amount of water flowing in the most important streams and computations of the quantity available each day of the year, either for immediate irrigation or for storage purposes. Knowing the actual amount of water available and the characteristic fluctuations day by day and year by year of some typical stream in each part of the arid region, it then becomes possible, by means of the topographic maps of the catchment areas, to make computations of the character of the water supply in each basin and sub-basin, and to obtain data as to the feasibility of various irrigation schemes. It may be said that some of the most alluring projects to which popular attention has been drawn are at once shown by a careful examination of the topographic maps and hydrographic data to be impracticable, and each year the possession of this condensed information is saving to the people of the West large sums which otherwise would be spent in individual examinations and disconnected surveys of various localities.

The irrigation engineers and citizens of the arid States appreciate more and more, as time goes on, the necessity of good topographic maps, and numerous instances could be cited of material benefits derived from those already made. For example, in one locality long discussions were had concerning the advisability of increasing the discharge of one of the streams by bringing a portion of the headwaters of a

neighboring river around the divide by means of canal and tunnel, and steps were taken to raise money for the project, which involved the expenditure of several thousand dollars. An examination of the topographic map showed, however, that the increase of drainage area to be derived from such work was almost insignificant, and brought forcibly to the attention of the managers of the project the impracticability of the scheme. In short, no matter how familiar a person may be with a certain drainage basin, he can not have exact conceptions of relative areas and slopes until the whole is spread before him on a good map and every part is shown in its true relation. Case after case can be cited where, from lack of these, the wrong plan has been chosen or enterprises have been hastily entered upon, at the expense of endless changes and fruitless attempts to correct the fundamental error of location or design.

The third division of the Irrigation Survey consisted of engineering examinations of such localities as the knowledge of the topography and of the water supply seemed to indicate as favorable for great irrigation developments. At these places careful surveys were made to demonstrate the practicability of diverting the waters of some river and carrying them out by large canals to command extensive areas of arid, though fertile, land, or to hold the flood waters in great reservoirs so that the flow of the streams could be increased in time of drought. These surveys were in each case carried to the degree of demonstrating the feasibility of the schemes from a financial standpoint.

The results of the third year's work of the Irrigation Survey, excepting the topographic maps which are issued from time to time, are shown in this report, which gives a description of 147 reservoir sites surveyed and reported for segregation and also gives the hydrographic data, fully illustrated by diagrams. The report is accompanied by a paper upon irrigation engineering—Mr. Wilson's description of the irrigation works of India.

The topographic maps are similar to those previously made by the United States Geological Survey, and are published in sheets uniform in character and appearance with those made for other portions of the United States, so that when completed they are not only useful for irrigation purposes, but for the varied demands of the engineer, the geologist, and the public. By the system of contours now well known they show the elevation of all portions of the area, the contour interval varying from 25 to 100 feet, depending upon the steepness of the slopes. During the fiscal year ending June 30, 1891, areas in the States of California, Colorado, Idaho, Kansas, Montana, Nevada, New Mexico, and Texas were surveyed; in all 21,475 square miles being mapped.

Of the 147 reservoir sites surveyed and reported for segregation 33 are in California, 46 in Colorado, 27 in Montana, 39 in New Mexico, and 2 in Nevada. The total area segregated for these 147 reservoirs is 165,932 acres. As these segregations are made according to Land Office descriptions, all the bounding lines run either north and south or east and west. The area included within the reservation must, as a consequence, be larger than the area of the water surface of the reservoir itself. This will be seen at a glance by examining the map of any of the sites. The total area of the water surface of all these reservoirs, should they be filled to the height designated in the segregations, would be 108,350 acres. The difference, 57,582 acres, represents the area of the narrow strips surrounding each reservoir, extending out from the highest water level to the nearest section or quarter section line.

The aggregate contents of all these reservoirs are approximately 2,847,815 acre-feet. Assuming a water duty of 1·5 acre-feet to the acre, this amount of water would irrigate 1,898,544 acres, or, with a water duty of 2 acre-feet to the acre, these reservoirs would supply 1,423,907 acres of cultivated land, an amount nearly equaling the irrigated crop area of the census year in Arizona, New Mexico, Utah, Wyoming, Montana, Idaho, and Nevada. As a matter of course, it must not be supposed that all of these reservoirs will be constructed, or even that all of them are of sufficient value to warrant great expenditures. The utility of each depends so largely upon

surrounding circumstances other than favorable location and topography, that it is highly improbable that an engineer or corps of engineers can foresee all the requirements of a still undeveloped country.

These reservoir sites have been selected, however, with due regard to the physical requirements in each case. An examination having first been made as to the cubical contents of the reservoir, formed by building a dam of reasonable height, the water supply was then carefully considered, both as to its quantity and character, whether intermittent or perennial. The question of proper materials for a dam and their position, whether near or far from the site of the dam, was given due weight, as was also the practicability of discharging large quantities of water in times of flood. As far as possible the reservoir sites were selected at points where all the requirements of successful construction and utility were most nearly fulfilled. As a rule they are high in the mountains, at elevations of from 5,000 to 10,000 feet, a few being at lower altitudes. They are thus at heights where the loss from evaporation will be less than that which would take place down nearer the irrigated lands.

These reservoir sites have been segregated mainly from consideration of their fitness from an engineering standpoint. Unfortunately, however, many of them are situated upon lands claimed in part by individuals who have made entries under the homestead, timber claim, desert entry, and various other acts. This is the case with most of the best reservoir sites upon surveyed land in the arid States and Territories. The active search for localities where a man can obtain water, grass, and wood for fuel or fencing has brought adventurous settlers far up into the mountains, where, in spite of the rigorous climate, a home, at least for the summer season, can be made. As the population increases in the towns of the lower valleys and the water supply becomes scanty, the younger men and the late comers to the locality are forced to seek their fortunes elsewhere and naturally push upstream, taking out small ditches wherever a small patch of fertile land can be irrigated. Diversion of water at points above in turn reacts upon the lower settlements, tending to diminish the available water supply and causing more people to seek to move higher up, where the water supply is larger. Then the very headwaters are examined and every piece of level land is eagerly seized upon, and those areas which should be held for water storage are now occupied during summer, or held in whole or part for speculative purposes.

The hydrographic work at the beginning of the third year was carried on actively in the various drainage basins described in the preceding annual report. At the end of August, however, there being no longer an appropriation available for field-work, the hydrographers were discharged. Fortunately, a large amount of careful instrumental work had been accomplished during the summer, enabling computations of the daily discharge of some of the larger streams to be carried on throughout the year, thus affording exact data as to the amount of water available and its fluctuations from time to time. The variation in amount of water in these rivers from year to year is not only of general interest, but of primary practical importance, and testimony is constantly being received, not only as to the general need and demand for such information, but also as to the immediate benefits to irrigation development and in preventing loss through misconceptions as to quantities of water available.

The oscillations of water supply from year to year are so great that measurements made in any one year must be looked upon with distrust if large interests are at stake. Along nearly every stream of importance canals have been projected whose united capacity far exceeds the ordinary discharge of the stream. Measurements of the quantity of water have, perhaps, been made, and the inference drawn that every year the same amount of water would be available, when in fact only a half or a third as much flowed during succeeding years. When public attention is forcibly drawn to these fluctuations in any one locality, the first thought is that it is something extraordinary, and that the shrinkage or increase of floods is perhaps due to some local cause. The popular explanation offered in most cases is that by cutting off the forests the regimen of the river has been altered.

As a matter of fact, exact measurements tend to show that fluctuations of water supply are not local or of recent origin, and comparison with streams in other parts of the country demonstrates that these comparatively great changes in the volume of a river from one year to another are to be expected, and must be foreseen in planning irrigation works. The history of the past also, though fragmentary at best, gives evidences of droughts or floods far exceeding those of the present decade, and modern geologic history furnishes warnings against relying too implicitly upon the permanence of climatic conditions. In order to plan wisely for the future it is necessary to measure accurately the fluctuations of the present, and to study all of the modifying influences tending to increase or diminish the water supply.

Too great reliance has been placed in the past upon theories or deductions as to what the water supply of the western rivers ought to be rather than what it is. For instance, an engineer preparing to discuss the feasibility of certain irrigation works made estimates of the water supply based upon the rainfall and drainage area. When his attention was called to the results of exact measurements of the river flow he could at first scarcely credit the testimony, because his carefully prepared figures showed that ten times as much water ought to be at the given place, and until the complete data were laid before him he was inclined to argue the absurdity of the results obtained by measurement because they did not coincide with any rule or previous deduction. The tables of discharge, therefore, given in the accompanying report have proved of unusual interest for the reason that they modify many assumptions upon the strength of which large amounts have been invested in past times.

The third paper in this report is of conspicuous value at the present time, when irrigation engineering has been recognized as a distinct branch and is already enlisting the life efforts of some of the most able engineers of the country. The earliest stages of development have about passed, when the planning of the larger works was intrusted to surveyors or contractors and construction was begun with little knowledge of prevailing conditions of topography and water supply. At this time, therefore, when the best methods of planning and constructing permanent works are in active demand, a description of the great engineering works for irrigation in British India is of more than usual interest and value. Innumerable details relating to economy and permanence have there been developed through long practice, and American engineers may receive the benefits of much of this costly experience, saving to our country both money and time in the successful operation of new projects.

Mr. Wilson has purposely confined his descriptions largely to those points which will be of greatest practical importance to Americans, and has sought to picture features of value under the conditions prevailing in the arid States rather than to describe works of merely novel or astonishing character. He shows the great benefits, financially and politically, derived from the canals of India, and points out how in many localities the topography, climate, and water supply resemble those of our arid West. Of course with our lower mountain ranges and smaller rivers, Americans can not construct such great canals, nor are we called upon to build such gigantic structures for the control of water supply, but, on the other hand, the smaller irrigation systems of India serve as a means of comparison and enable us to draw conclusions as to the excellencies or defects of our own methods.

REPORT UPON THE

LOCATION AND SURVEY OF RESERVOIR SITES DURING THE FISCAL YEAR ENDED JUNE 30, 1891.

BY

A. H. THOMPSON,
CHIEF OF WESTERN DIVISION OF TOPOGRAPHY.

CONTENTS.

	Page.
Introduction	9
California	10
Colorado	55
Montana	127
New Mexico	165
Nevada	209

ILLUSTRATIONS.

		Page.
PLATE LIV.	Reservoir site, Colorado, No. 8	56
LV.	Reservoir site, Colorado, No. 55	126
LVI.	Reservoir site, New Mexico, No. 38	204
LVII.	Reservoir site, New Mexico, No. 39	208
FIG. 81.	Reservoir site, California, No. 5	11
82.	Reservoir site, California, No. 6	12
83.	Reservoir site, California, No. 14	14
84.	Reservoir site, California, No. 15	15
85.	Reservoir site, California, No. 16	16
86.	Reservoir site, California, No. 17	17
87.	Reservoir site, California, No. 18	18
88.	Reservoir site, California, No. 19	19
89.	Reservoir site, California, No. 20	21
90.	Reservoir site, California, No. 21	22
91.	Reservoir site, California, No. 22	23
92.	Reservoir site, California, No. 23	24
93.	Reservoir site, California, No. 24	26
94.	Reservoir site, California, No. 25	27
95.	Reservoir site, California, No. 26	28
96.	Reservoir site, California, No. 27	29
97.	Reservoir site, California, No. 28	30
98.	Reservoir site, California, No. 29	32
99.	Reservoir site, California, No. 30	33
100.	Reservoir site, California, No. 31	35
101.	Reservoir site, California, No. 32	36
102.	Reservoir site, California, No. 33	37
103.	Reservoir site, California, No. 34	38
104.	Reservoir site, California, No. 35	40
105.	Reservoir site, California, No. 36	41
106.	Reservoir site, California, No. 37	43
107.	Reservoir site, California, No. 38	44
108.	Reservoir site, California, No. 39	45
109.	Reservoir site, California, No. 40	47
110.	Reservoir site, California, No. 41	48
111.	Reservoir site, California, No. 42	51
112.	Reservoir site, California, No. 43	52
113.	Reservoir site, California, No. 44	54
114.	Reservoir site, Colorado, No. 6	55
115.	Reservoir site, Colorado, No. 9	58
116.	Reservoir site, Colorado, No. 10	60
117.	Reservoir site, Colorado, No. 11	61
118.	Reservoir site, Colorado, No. 12	63
119.	Reservoir site, Colorado, No. 13	65

Page.

FIG. 120. Reservoir site, Colorado, No. 14 67
121. Reservoir site, Colorado, No. 15 68
122. Reservoir site, Colorado, No. 16 69
123. Reservoir site, Colorado, No. 17 71
124. Reservoir site, Colorado, No. 18 72
125. Reservoir site, Colorado, No. 19 74
126. Reservoir site, Colorado, No. 20 75
127. Reservoir site, Colorado, No. 21 77
128. Reservoir site, Colorado, No. 22 78
129. Reservoir site, Colorado, No. 23 80
130. Reservoir site, Colorado, No. 24 83
131. Reservoir site, Colorado, No. 26 84
132. Reservoir site, Colorado, No. 27 86
133. Reservoir site, Colorado, No. 28 87
134. Reservoir site, Colorado, No. 29 89
135. Reservoir site, Colorado, No. 30 90
136. Reservoir site, Colorado, No. 31 91
137. Reservoir site, Colorado, No. 32 93
138. Reservoir site, Colorado, No. 33 95
139. Reservoir site, Colorado, No. 34 96
140. Reservoir site, Colorado, No. 35 98
141. Reservoir site, Colorado, No. 36 99
142. Reservoir site, Colorado, No. 37 100
143. Reservoir site, Colorado, No. 40 102
144. Reservoir site, Colorado, No. 41 104
145. Reservoir site, Colorado, No. 42 105
146. Reservoir site, Colorado, No. 43 107
147. Reservoir site, Colorado, No. 44 108
148. Reservoir site, Colorado, No. 45 110
149. Reservoir site, Colorado, No. 46 112
150. Reservoir site, Colorado, No. 47 114
151. Reservoir site, Colorado, No. 48 115
152. Reservoir site, Colorado, No. 49 117
153. Reservoir site, Colorado, No. 50 118
154. Reservoir site, Colorado, No. 51 120
155. Reservoir site, Colorado, No. 52 121
156. Reservoir site, Colorado, No. 53 123
157. Reservoir site, Colorado, No. 54 124
158. Reservoir site, Montana, No. 11 128
159. Reservoir site, Montana, No. 12 129
160. Reservoir site, Montana, No. 13 130
161. Reservoir site, Montana, No. 14 131
162. Reservoir site, Montana, No. 15 132
163. Reservoir site, Montana, Nos. 16 and 17 134
164. Reservoir site, Montana, No. 18 135
165. Reservoir site, Montana, No. 19 138
166. Reservoir site, Montana, No. 20 139
167. Reservoir site, Montana, No. 21 140
168. Reservoir site, Montana, Nos. 22 and 23 141
169. Reservoir site, Montana, No. 24 143
170. Reservoir site, Montana, No. 25 147
171. Reservoir site, Montana, No. 26 149
172. Reservoir site, Montana, No. 27 151
173. Reservoir site, Montana, No. 28 152
174. Reservoir site, Montana, No. 29 155

Page.

FIG. 175. Reservoir site, Montana, No. 30 156
176. Reservoir site, Montana, No. 31 157
177. Reservoir site, Montana, No. 32 158
178. Reservoir site, Montana, No. 33 159
179. Reservoir site, Montana, No. 34 160
180. Reservoir site, Montana, No. 35 161
181. Reservoir site, Montana, No. 36 162
182. Reservoir site, Montana, No. 37 163
183. Reservoir site, Montana, No. 38 165
184. Reservoir site, New Mexico, No. 1 166
185. Reservoir site, New Mexico, No. 2 167
186. Reservoir site, New Mexico, No. 3 168
187. Reservoir site, New Mexico, No. 4 169
188. Reservoir site, New Mexico, No. 5 170
189. Reservoir site, New Mexico, No. 6 170
190. Reservoir site, New Mexico, No. 7 172
191. Reservoir site, New Mexico, No. 8 173
192. Reservoir site, New Mexico, No. 9 174
193. Reservoir site, New Mexico, No. 10 174
194. Reservoir site, New Mexico, No. 11 175
195. Reservoir site, New Mexico, No. 12 176
196. Reservoir site, New Mexico, No. 13 177
197. Reservoir site, New Mexico, No. 14 178
198. Reservoir site, New Mexico, No. 15 178
199. Resesvoir site, New Mexico, No. 16 179
200. Reservoir site, New Mexico, No. 17 180
201. Reservoir site, New Mexico, No. 18 181
202. Reservoir site, New Mexico, No. 19 182
203. Reservoir site, New Mexico, No. 20 182
204. Reservoir site, New Mexico, No. 21 183
205. Reservoir site, New Mexico, No. 22 184
206. Reservoir site, New Mexico, No. 23 185
207. Reservoir site, New Mexico, No. 24 186
208. Reservoir site, New Mexico, No. 25 187
209. Reservoir site, New Mexico, No. 26 188
210. Reservoir site, New Mexico, No. 27 189
211. Reservoir site, New Mexico, No. 28 190
212. Reservoir site, New Mexico, No. 29 191
213. Reservoir site, New Mexico, No. 30 192
214. Reservoir site, New Mexico, No. 31 193
215. Reservoir site, New Mexico, No. 32 194
216. Reservoir site, New Mexico, No. 33 196
217. Reservoir site, New Mexico, No. 34 198
218. Reservoir site, New Mexico, No. 35 200
219. Reservoir site, New Mexico, No. 36 201
220. Reservoir site, New Mexico, No. 37 202
221. Reservoir site, Nevada, No. 1 210
222. Reservoir site, Nevada, No. 2 211

THE LOCATION AND SURVEY OF RESERVOIR SITES.

By A. H. Thompson.

INTRODUCTION.

One hundred and forty-seven sites for reservoirs were located and surveyed by the Division of Topography west of the one hundredth meridian during the fiscal year ending June 30, 1890.

Plats of these surveys, showing in what range, township, section and subdivision of sections of the U. S. Land Survey these sites were situated, were submitted to the Secretary of the Interior, and their reservation from entry or settlement according to law asked for under date of February 27, 1891.

Thirty-three of these sites are situated in California; forty-six in Colorado; twenty-seven in Montana; two in Nevada; and thirty-nine in New Mexico.

In the selection of reservoir sites the topographers were instructed to consider the probable supply of water as indicated by the altitude and area of the drainage basin; the declivity of its slopes, and whether forest-covered, grass-clad or bare; the rapidity with which water would be delivered into the reservoir; the best location for the dam—taking into account its length, height, availability of proper materials for its construction, and the opportunity for a sufficient spillway; the nearness of cultivable lands and the grade of canal line required to convey the waters to these lands; and, if any choice could be made, they were directed to locate reservoirs where these requirements were best fulfilled.

In the final reports upon the surveys of these reservoir sites are given the name and situation of each; the area and general altitude of its drainage basin; the general character of the topography; the township, range, sections, and subdivisions of section of each site; the height and location of dam; the bench mark of the survey; the area in acres and approximate content of the reservoir in acre-feet; where material for construction of dam can be found; and the situation of available irrigable lands.

The plats of the survey of each reservoir site show its situation in reference to the divisions of the U. S. Land Survey, and the approximate location on the same of the water line at the given height of dam, and is accompanied by a schedule describing in terms of the General Land Survey to the nearest forty-acre subdivision the areas included; and also by another schedule showing as nearly as can be ascertained from the records of the General Land Office whether the lands affected belong to the public domain or individuals.

The reports, plats, and schedules are designated by corresponding numbers, a distinct series being used for each State and Territory.

In addition, the figure number of the volume for each plat is given in the report for that site.

The reservoir and schedule numbers are not always consecutive, as certain reservoir sites bearing numbers of the series have been previously surveyed and reported upon.

CALIFORNIA.

RESERVOIR SITES NUMBERED 5, 6, AND 14 TO 44, INCLUSIVE.

RESERVOIR SITE NO. 5.

Summit Valley, situated on the Yuba River, in Nevada and Placer Counties, California.

The drainage basin comprises only about 6 square miles. Altitude ranges from 6,700 to 8,300 feet. Rocks and timber in abundance. Surrounding hills rough and rocky. Ample snow in winter to furnish water. Summer supply limited.

Reservoir site is in T. 17 N., R. 14 E., Secs. 22, 23, 25, and 26.

The dam is in the SW. ¼ Sec. 23 and SE. ¼ Sec. 22, T. 17 N., R. 14 E.

Dam is 20 feet high.

Bench mark is on a flat granite rock east of dam, and has an approximate altitude of 6,750 feet.

Top contour has the same altitude as the bench mark.

Area inclosed by top contour is 320 acres.

Approximate content of reservoir is 2,400 acre-feet.

Stone and timber for construction of dam are to be found in the immediate vicinity of the site.

Land Office records show reservoir site to be almost entirely settled.

Irrigable lands are in the western foothills bordering the east side of Sacramento Valley.

Recommended for segregation in letter to Secretary of the Interior, dated February 27, 1891.

Schedule of lands segregated for reservoir.

				Acres.
SE. ¼ SE. ¼ Sec.	22,	T. 17 N.,	R. 14 E.	40
SW. ¼	23	17	14	160
S. ½ SE. ¼	23	17	14	80
NW. ¼	26	17	14	160
NE. ¼	26	17	14	160
W. ½ NW. ¼	25	17	14	80
Area segregated				680

Action affecting the titles to lands segregated for reservoir site No. 5 has been taken as follows:

					Acres.
SW. ¼	Sec. 23,	T. 17 N.,	R. 14 E.	(patented C. P. R. R. Co.)	160
S. ½ SE. ¼	23	17	14	(patented C. P. R. R. Co.)	80
SE. ¼ SE. ¼	22	17	14	(patented October, 1869)	40
W. ½ NW. ¼	25	17	14	(patented C. P. R. R. Co., 1875)	80
NE. ¼	26	17	14	(patented May, 1874)	160
NW. ¼	26	17	14	(selected by State November, 1875)	160
					640

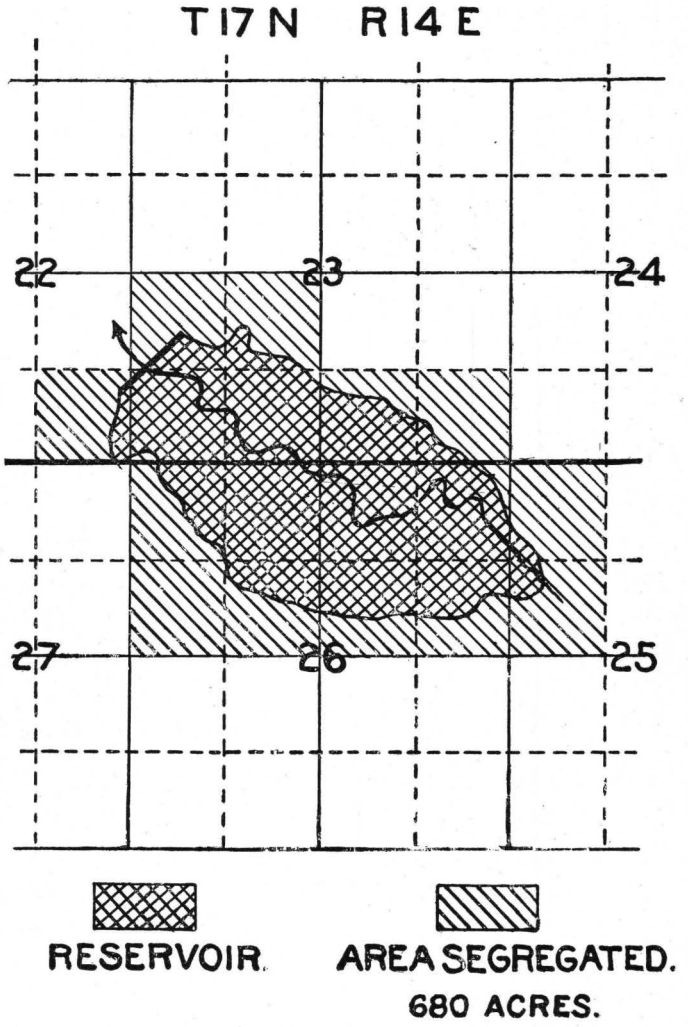


FIG. 81.—Reservoir site No. 5, Summit Valley, at Soda Springs, on western slope Sierra Nevada.

Reservoir Site No. 6.

Known as Squaw Valley and situated on Squaw Creek in Placer County, California.

The drainage basin comprises about 12 square miles. Altitude ranges from 6,100 to 9,000 feet. The site is surrounded by rough high mountains. Some timber on the ridges on the north and south, sloping into the basin. The major part of the drainage basin is rough and rocky, bare of timber. The melting snow furnishes abundant supply of water in the spring. Water scarce towards autumn.

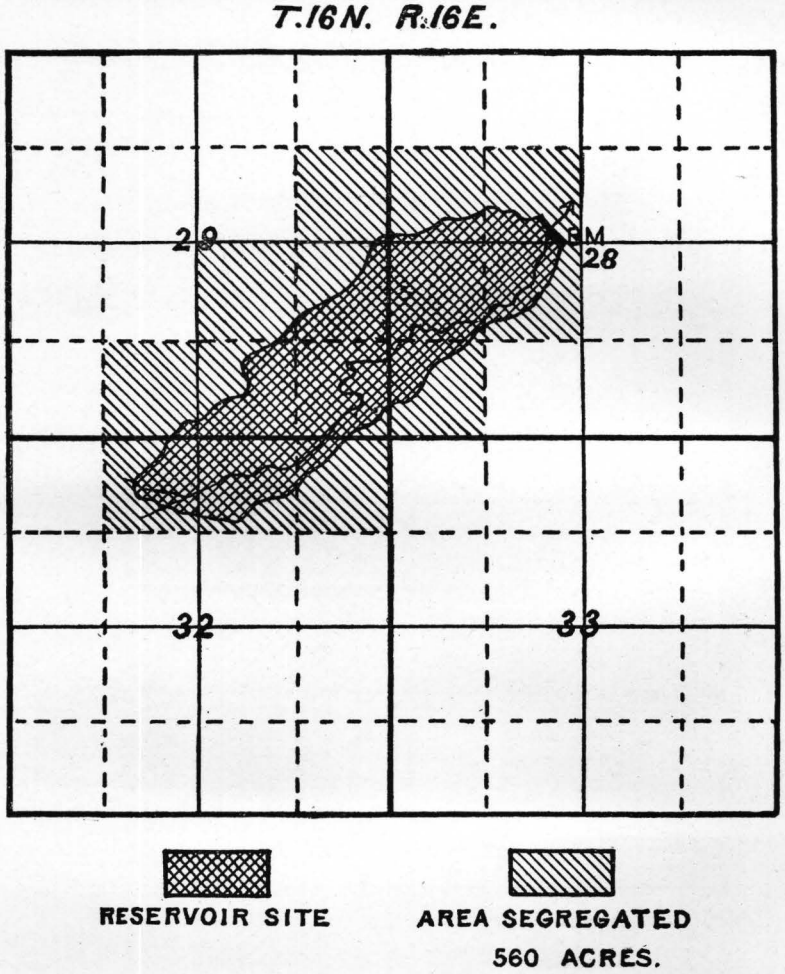


Fig. 82.—Reservoir site No. 6, in Squaw Valley, about 5 miles northwest of Tahoe City and ¼ mile west of Truckee River.

Reservoir site is in T. 16 N., R. 16 E., Secs. 28, 29, and 32, Mount Diablo meridian.

Dam is in the NW. ¼, Sec. 28, T. 16 N., R. 16 E.

Height of dam, 16 feet.

Bench mark is on a granite rock at east end of dam, and has an approximate altitude of 6,190 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 225 acres.

Approximate content of reservoir is 1,350 acre-feet.

Materials for construction of dam are to be found in the immediate vicinity of the site.

Land office records show reservoir site to be partially settled.

Irrigable lands are along the Truckee River and in the Reno Valley.

Recommended for segregation in letter to Secretary of the Interior, dated February 27, 1891.

Schedule of lands segregated for reservoir.

				Acres.
SE. ¼ NE. ¼	Sec. 29,	T. 16 N.,	R. 16 E	40
SE. ¼ SW. ¼	29	16	16	40
SE. ¼	29	16	16	160
S. ½ NW. ¼	28	16	16	80
W. ½ SW. ¼	28	16	16	80
NE. ¼ SW. ¼	28	16	16	40
NE. ¼ NW. ¼	32	16	16	40
N. ½ NE. ¼	32	16	16	80
Area segregated				560

Action affecting the titles to lands segregated for reservoir site No. 6 has been taken as follows:

					Acres.
SE. ¼ NE. ¼	Sec. 29,	T. 16 N.,	R. 16 E.	(patented C. P. R. R. December, 1886)	40
S. ½ NW. ¼	28	16	16	(timber claim, October, 1882)	80
W. ½ SW. ¼	28	16	16	(patented June, 1874)	60
NE. ¼ SW. ¼	28	16	16	(patented June, 1874)	60
NE. ¼ NE. ¼	32	16	16	(patented February, 1880)	40
NE. ¼ NW. ¼	32	16	16	(patented February, 1869)	40
					320

Reservoir Site No. 14.

Situated on Red Lake, Alpine County, California.

The drainage area of the Red Lake is very limited. Small streams fed by melting snows and the seepage from the ground are ample to supply any practicable reservoir upon this site. The altitude ranges from 7,850 to 9,500 feet. The slopes of the mountains are steep and rough and heavily timbered.

The reservoir site is in T. 10 N., R. 16 E., Secs. 22 and 23, Mount Diablo meridian.

The dam is in the SW. ¼ and NW. ¼ of Sec. 23, T. 10 N., R. 16 E.

Height of dam, 35 feet.

Bench mark at south end of dam, on a large rock marked U. S. G. S. B. M., has an approximate altitude of 7,850 feet.

The top contour has the same altitude as the bench mark.

Area inclosed by top contour is 80 acres.

Content of reservoir is, approximately, 1,050 acre-feet.

Material for construction is in the immediate vicinity, there being great quantities of rock and mill timber.

Land Office records show reservoir site to be public land.

Lands in Hope Valley and below are controlled by this site.

Schedule of lands segregated for reservoir.

				Acres.
SE. ¼ Sec.	22,	T. 10 N.,	R. 16 E.	160
W. ½ SW. ¼	23	10	16	80
NE. ¼ SW. ¼	23	10	16	40
S. ½ NW. ¼	23	10	16	80
Area segregated				360

Land office records show area segregated to be all public lands.

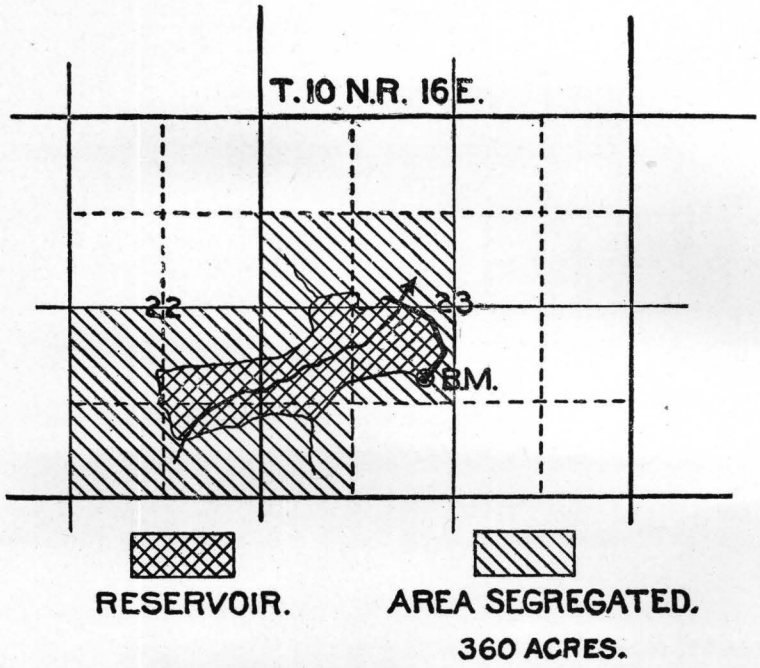


FIG. 83.—Reservoir Site No. 14, Red Lake reservoir near Williams ranch.

RESERVOIR SITE NO. 15.

Known as Pleasant Valley and situated in Alpine County, California.

The Pleasant Valley is upon a side drainage of Markleeville Creek. The drainage basin, ranging from 5,900 to 8,500 feet altitude, is small. The sides of the bounding ridges are extremely steep and rough. The water supply is from the seepage and surface drainage of melting snows upon the higher portions of the basin.

Reservoir site is in T. 10 N., R. 20 E., Sec. 32, and T. 9 N., R. 20 E., Secs. 5 and 6, Mount Diablo meridian.

Lower dam is in SE. ¼ Sec. 32, T. 10 N., R. 20 E. Upper dam is in NW. ¼ Sec. 5, T. 9 N., R. 20 E., and SW. ¼ Sec. 32, T. 10 N., R. 20 E.

Height of lower dam, 35 feet; height of upper dam, 35 feet.

Bench mark is on a stone at south end of each dam, and the upper bench mark has an approximate altitude of 5,950 feet, while that of the lower dam is approximately 5,850 feet.

Top contours in each case have the same altitude as the bench mark.

Area inclosed by top contour of lower site is 10 acres. Area inclosed by top contour of upper site is 50 acres.

Approximate content of lower site is 130 acre-feet. Approximate content of upper site is 660 acre-feet.

Materials for construction are to be found practically upon the site of the reservoir, timber and rock prevailing to a large extent.

Land Office records show the upper reservoir site to be partially settled and the lower site to be public land.

The irrigable lands lie about Markleeville and on the East Carson River.

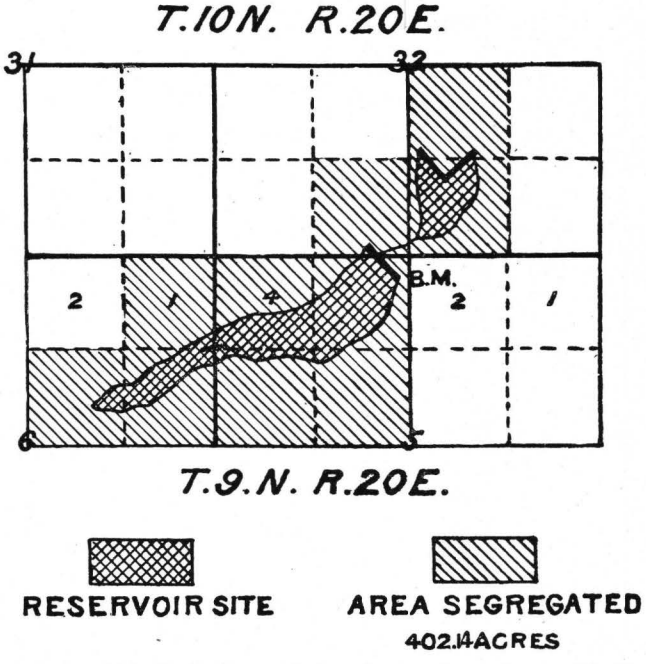


FIG. 84.—Reservoir Site No. 15, Pleasant Valley, about 3 miles southwest of Markleeville.

Schedule of lands segregated for reservoir.

					Acres.
W. ½ of SE. ¼	Sec. 32,	T. 10 N.,	R. 20 E.		80
SE. ¼ SW. ¼	32	10	20		40
S. ½ NW. ¼	5	9	20		80
Lot 3	5	9	20		41·01
Lot 4	5	9	20		40·68
Lot 1	6	9	20		40·45
S. ½ NE. ¼	6	9	20		80
Area segregated					402·14

Action affecting titles to lands segregated for reservoir site No. 15 has been taken as follows:

					Acres.
NW. ¼ NW. ¼	Sec. 6,	T. 9 N.,	R. 20 E.	(selected by State October, 1882)	40
S. ½ NE. ¼	6	9	20	(selected by State September, 1850)	80
Lot 3	5	9	20	(patented April, 1878)	41·01
					161·01

Reservoir Site No. 16.

Known as Mount Bullion, and is situated in Alpine County, California.

This site is upon the East Carson River, and is fed by the drainage from Silver King, Wolf, and Silver creeks. The altitude ranges from 6,000 to 11,000 feet. The water supply is large, as winter snows are heavy. The mountains are rough and steep-sided. The valleys, as a rule, narrow.

Reservoir site is in Sec. 1, T. 9 N., R. 20 E., Mount Diablo meridian.

Dam is in Lot 4, Sec. 1, T. 9. N., R. 20 E.

Height of dam is 65 feet.

Bench mark is a stake marked U. S. G. S. B. M. at east end of dam.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 40 acres.

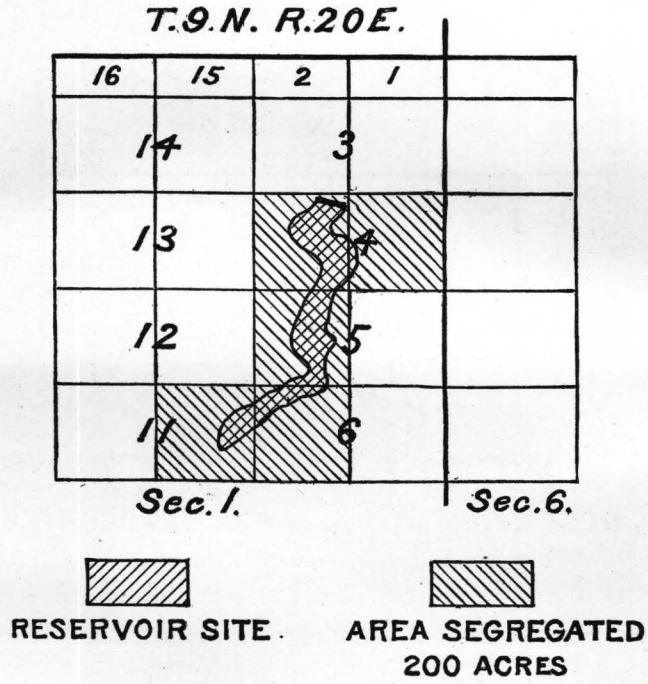


Fig. 85.—Reservoir Site No. 16, located at Mount Bullion, on East Fork of Carson River.

Approximate content of reservoir is 975 acre-feet.

Materials for construction are abundant at the site of the dam.

Land Office records show reservoir site to be all public land.

The irrigable lands are upon the East Carson River and in the Carson Valley.

Lands segregated for reservoir.

	Acres.
Lot 4, Sec. 1, T. 9 N., R. 20 E.	80
W. ½ Lot 5, 1, 9 20	40
W. ½ Lot 6, 1, 9 20	40
E. ½ Lot 11, 1, 9 20	40
Area segregated	200

Land Office records show area segregated to be all public land.

Reservoir Site No. 17.

Known as Indian Pool, and situated on the head waters of Deer Creek, in Alpine County, California.

The drainage is indefinite. The site lies in a flat valley of broken granite. The water supply is from the melting snow in the immediate vicinity. Timber prevails.

Land is as yet unsurveyed.

The height of dam is 22 feet.

Bench mark is on a bowlder at west end of dam, marked U. S. G. S. B. M., and has an approximate altitude of 8,000 feet.

Altitude of top contour is the same as that of bench mark.

Area inclosed by top contour is about 20 acres.

Content of reservoir is approximately 160 acre-feet.

Construction materials are plentiful.

Reservoir site is unsettled.

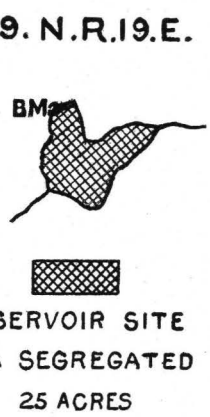


Fig. 86.—Reservoir Site No. 17, known as Indian Pool, situated northeast of Indian Valley.

The drainage is into Pleasant Valley, and the irrigable land lies about Markleeville.

Land unsurveyed, but township lines projected from surveyed lands.

Area segregated 25 acres, all in sections 22 and 27.

Reservoir Site No. 18.

Known as Heenan Lake and situated in Alpine County, California.

The drainage area is small; altitude ranges from 7,100 to 8,000 feet.

The water supply furnished by melting snows is ample in many seasons, but might be doubtful in an extremely dry one. The mountains are rough and steep-sided. There is a small quantity of timber on the slopes.

Reservoir site is in T. 9 N., R. 21 E., Secs. 3 and 10.

Dam is in SW. ¼ of Sec. 3, T. 9 N., R. 21 E.

Height of dam is 30 feet.

Bench mark, marked U. S. G. S. B. M., is on a stone under mound, and has an approximate altitude of 7,100 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 130 acres.

Approximate content of reservoir is 1,460 acre-feet.

Materials for construction of dam may be found on the mountains at no great distance from the site.

Land Office records show reservoir site to be partially settled.

The irrigable lands lie on the East Carson River and in Carson Valley.

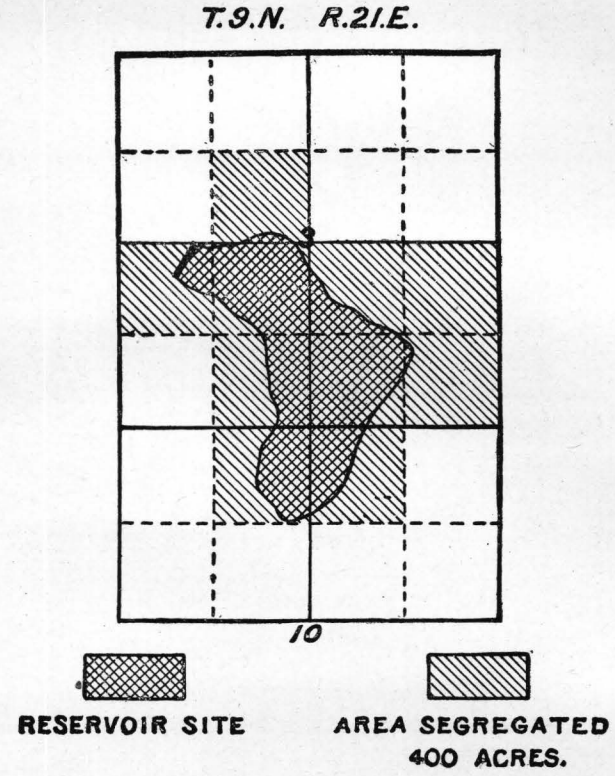


FIG. 87.—Reservoir Site No. 18, Heenan Lake, situated about 2 miles northeast of Monitor.

Lands segregated for reservoir.

					Acres.
SE. ¼	Sec. 3,	T. 9	N., R. 21	E.	160
SE. ¼ NW. ¼	3	9	21		40
E. ½ SW. ¼	3	9	21		80
NW. ¼ SW. ¼	3	9	21		40
NE. ¼ NW. ¼	10	9	21		40
NW. ¼ NE. ¼	10	9	21		40
Area segregated					400

Action affecting titles to lands segregated for Reservoir Site No. 18 has been taken as follows:

					Acres.
NE. ¼ SE. ¼	Sec. 3,	T. 9 N.,	R. 21 E.	(selected by the State March, 1876)	40
NE. ¼ NW. ¼	10	9	21	(selected by the State March, 1876)	40
NW. ¼ NE. ¼	10	9	21	(selected by the State March, 1876)	40
					120

Reservoir Site No. 19.

Known as Silver King, and situated in Silver King Valley, on Silver Creek, in Alpine County, California.

The drainage basin of this site includes the whole of that of the Dumonts Meadow site. The altitude ranges from 6,400 to 11,000 feet. The mountains are steep and rough; the valleys in many places flat and open. The whole area is deeply covered with snow during the winter. There is much timber on the mountain slopes.

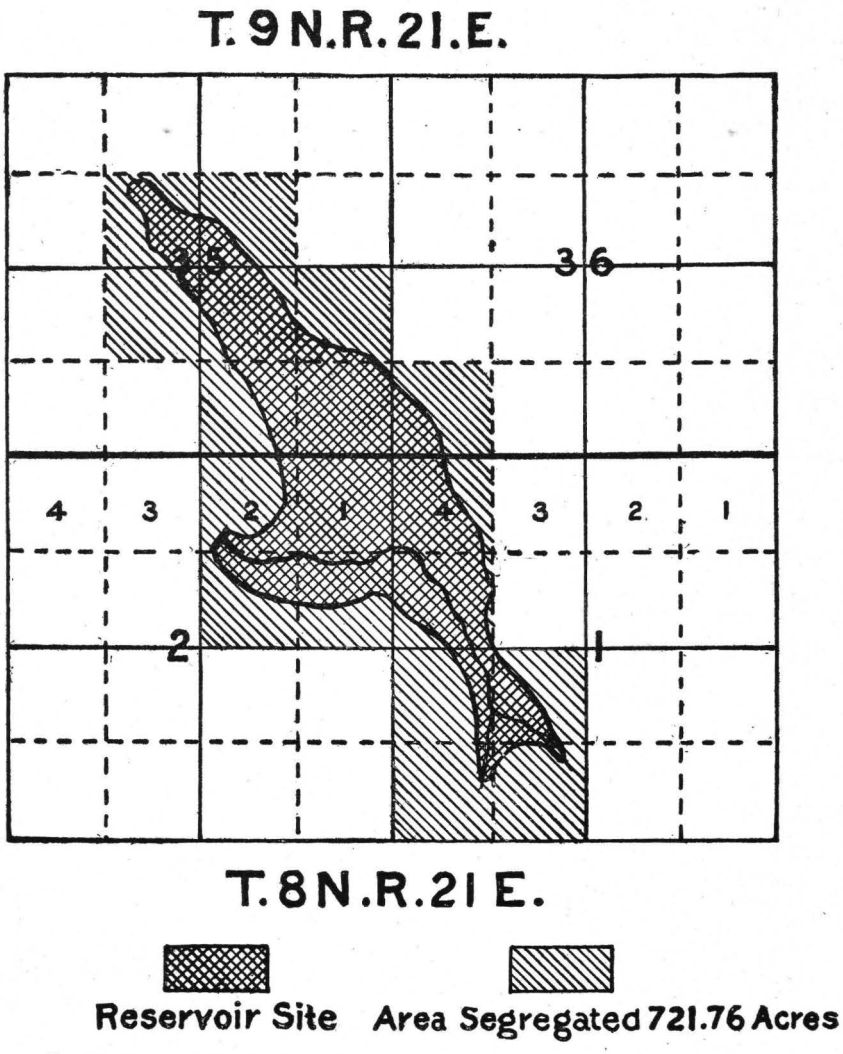


FIG. 88.—Reservoir Site No. 19, in Silver King Valley, just south of Rickey's cattle ranch.

Reservoir site is in T. 9 N., R. 21 E.

Dam is in NE. ¼, Sec. 2, T. 8 N., R. 21 E.

Height of dam is 60 feet.

Bench mark, marked U. S. G. S. B. M., is on a stake in a mound of stone at east end of dam, and has an approximate altitude of 6,400 feet.

Top contour has the same altitude as the bench mark.

Area inclosed by top contour is 255 acres.

Approximate content of reservoir is 5,740 acre-feet.

Ample material for construction of dam is on the site, timber and rock being in quantity.

Land Office records show reservoir site to be all public land.

The irrigable lands are mostly in the Carson Valley, some miles below the site.

Lands segregated for reservoir.

				Acres.
SE. ¼ NW. ¼ Sec.	35,	T 9 N.,	R. 21 E.	40·00
NE. ¼ SW. ¼	35	9	21	40·00
SE. ¼	35	9	21	160·00
SW. ¼ NE. ¼	35	9	21	40·00
SW. ¼ SW. ¼	36	9	21	40·00
Lot 4	1	8	21	40·47
SW. ¼ NW. ¼	1	8	21	40·00
SW. ¼	1	8	21	160·00
Lot 1	2	8	21	40·59
2	2	8	21	40·70
S. ½ NE. ¼	2	8	21	80·00
Area segregated				721·76

Land Office records show area segregated to be all public land.

RESERVOIR SITE NO. 20.

Known as Wolf Creek, and situated on Wolf Creek, in Alpine County, California.

The drainage basin consists of the whole area drained by that branch of the East Carson River known as Wolf Creek. From 6,500 to 11,000 feet in elevation. The melting snow gives ample water supply. The surrounding ridges are rough-sided and steep. The valleys are open and in many places quite flat. Timber prevails in quantities, being especially abundant between the elevations of 7,500 to 8,500 feet.

Reservoir site is in T. 9 N., R. 21 E., Secs. 29 and 32.

Dam is in NE. ¼ of Sec. 29, T. 9 N., R. 21 E.

Dam is 65 feet high.

Bench mark is a stake in mound at west end of dam and has an approximate altitude of 6,500 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 190 acres.

Approximate content of reservoir is 4,630 acre-feet.

Materials for construction are found at no great distance from the site. Rock and timber in quantities ample for this use are almost at hand.

Land Office records show reservoir site to be partially settled.

The irrigable lands are upon the East Fork of Carson River and in the Carson Valley.

Lands segregated for reservoir.

				Acres.
S. ½ NE. ¼ Sec.	29,	T. 9 N.,	R. 21 E.	80
SE. ¼	29	9	21	160
SE. ¼ SW. ¼	29	9	21	40
E. ½ NW. ¼	32	9	21	80
NE. ¼	32	9	21	160
N. ½ SE. ¼	32	9	21	80
Area segregated				600

Action affecting titles to land segregated for Reservoir Site No. 20 has been taken as follows:

	Acres.
N. ½ SE. ¼ Sec. 29, T. 9 N., R. 21 E.	80

Homestead, June 3, 1878.

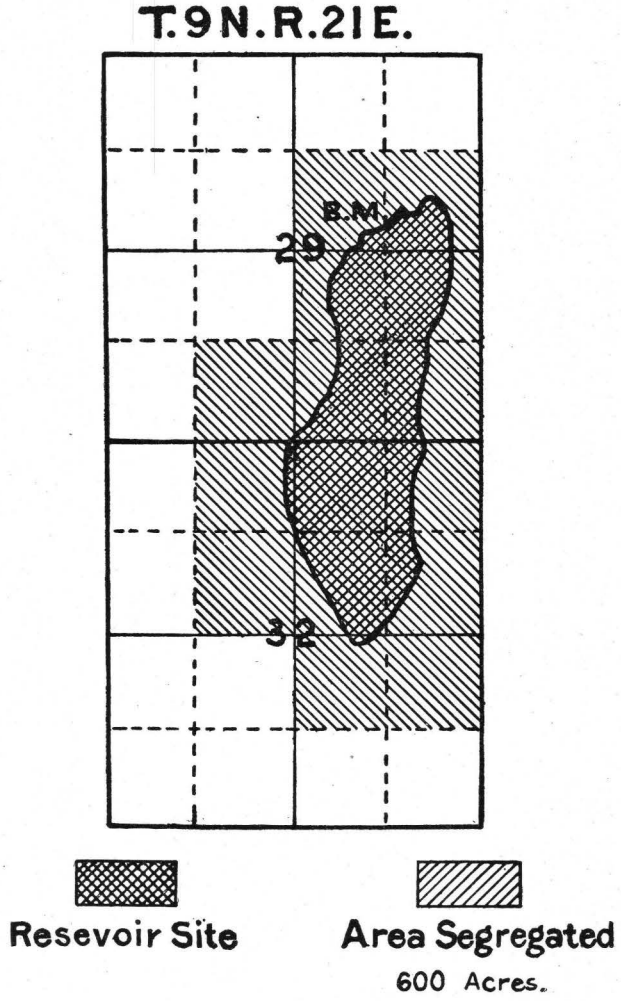


FIG. 89.—Reservoir Site No. 20, Wolf Creek reservoir, on Wolf Creek, at Berry's Ranch.

RESERVOIR SITE NO. 21.

Known as Dumont's Meadow, and is situated on East Carson River, in Alpine County, California.

The drainage basin of this reservoir is quite extensive. It consists of the head waters of that branch of the East Carson which is between Wolf and Silver King creeks. The altitude ranges from 6,600 to about 11,000 feet. Over the whole area the snowfall is heavy and affords an ample supply of water in all seasons. There is scattering timber on the slopes of the mountains quite abundant in a belt between the elevations of 7,500 and 9,000 feet.

Reservoir site is in T. 8 N., R. 21 E., Secs. 22 and 27.

Dam is in NW. ¼ Sec. 22, T. 8 N., R. 21 E.

Height of dam is 65 feet.

Bench mark is on a granite bowlder—marked U. S. G. S. B. M.—at west end of dam. Approximate altitude is 7,500 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 225 acres.

Approximate content of reservoir is 5,480 acre-feet.

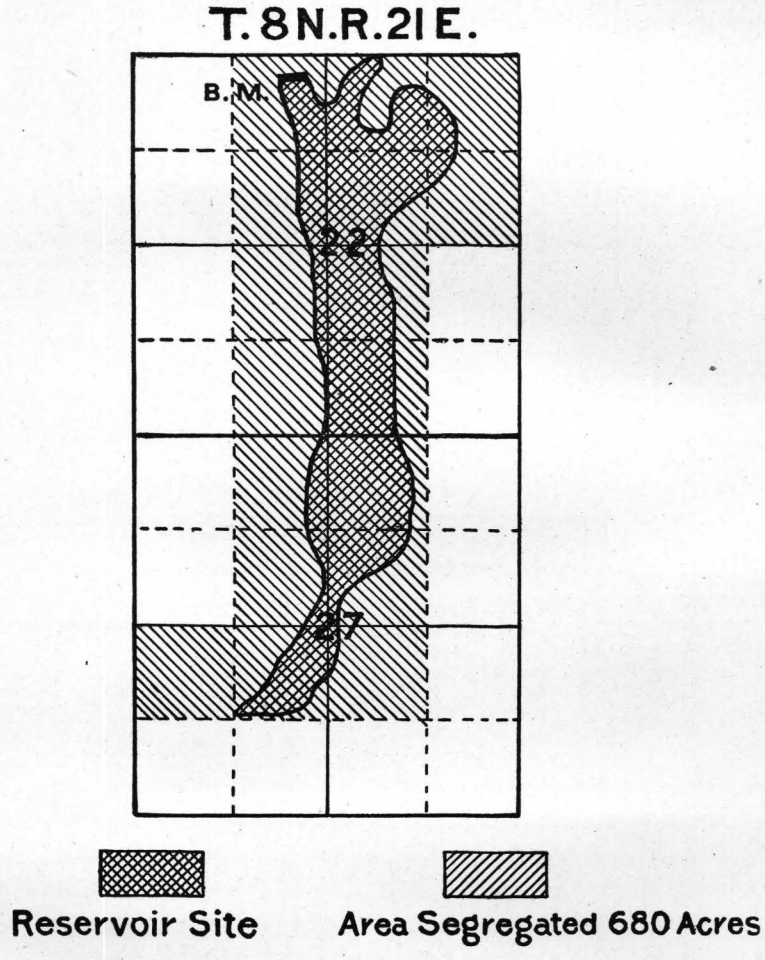


FIG. 90.—Reservoir Site No. 21, in Dumont's Meadow, about 5 miles south of Silver King Valley.

Materials for construction are practically on the spot. There is much good mill timber and the mass of rock of a character usable for dam-building.

Land Office records show reservoir site to be partially settled.

The irrigable lands controlled by this reservoir are on the East Carson River and in the Carson Valley.

Lands segregated for reservoir.

				Acres.
NE. ¼ Sec.	22,	T. 8 N.,	R. 21 E	160
E. ½ NW. ¼	22	8	21	80
E. ½ SW. ¼	22	8	21	80
W. ½ SE. ¼	22	8	21	80
W. ½ NE. ¼	27	8	21	80
E. ½ NW. ¼	27	8	21	80
N. ½ SW. ¼	27	8	21	80
NW. ¼ SE. ¼	27	8	21	40
Area segregated				680

Action affecting titles to lands segregated for Reservoir Site No. 21 has been taken as follows:

					Acres.
W. ½ SW. ¼ Sec.	27,	T. 8 N.,	R. 21 E.,	September 22, 1876	80
SE. ¼ SW. ¼	27	8	21	September 22, 1876	40
S. ½ NW. ¼	22	8	21	September 25 and October 23, 1876	80
N. ½ SW. ¼	22	8	21	September 25 and October 23, 1876	80

The two entries above are only declaratory statements. Final proof not made within time allowed by law. The land is therefore open.

Reservoir Site No. 22.

Known as Hermit Valley, is situated on the Mokelumne River in Alpine County, California.

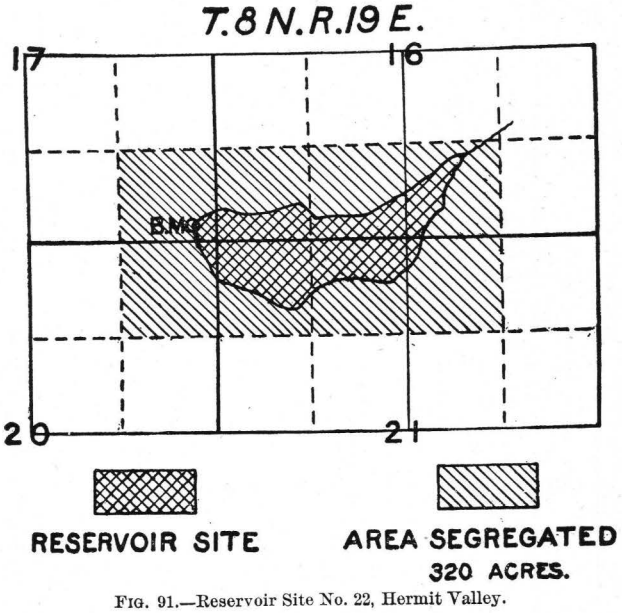


Fig. 91.—Reservoir Site No. 22, Hermit Valley.

The drainage basin, above site, includes all the headwaters of the North Fork of the Mokelumne River to the head of Wolf Creek and the Highland Lakes. The mountains are steep and rough and abound in springs, the seepage from winter snow-banks. Altitude ranges from 7,000 to 10,000 feet.

The reservoir site is in T. 8 N., R. 19 E., Secs. 16, 17, 20, and 21, Mount Diablo meridian.

The dam is in the SE. ¼, Sec. 17, and the NE. ¼, Sec. 20, T. 8 N., R. 19 E.

The height of dam is 40 feet.

Bench mark is on a granite bowlder at north end of dam. Approximate altitude, 7,020 feet.

Top contour has same altitude as that of bench mark.

Area inclosed by top contour is 75 acres.

Content of reservoir is 1,120 acre-feet, approximately.

Materials for construction are in the immediate vicinity of the site and are plentiful.

Land Office records show reservoir site to be partially settled.

The irrigable lands lie upon the area controlled by Mokelumne River far below (west of) Hermit Valley.

Lands segregated for reservoir.

				Acres.
NE. ¼ NE. ¼ Sec.	20,	T. 8 N.,	R. 19 E.	40
N. ½ NW. ¼	21	8	19	80
NW. ¼ NE. ¼	21	8	19	40
SE. ¼ SE. ¼	17	8	19	40
S. ½ SW. ¼	16	8	19	80
SW. ¼ SE. ¼	16	8	19	40
Area segregated				320

Action affecting titles to lands segregated for reservoir site No. 22 has been taken as follows:

	Acres.
NW. ¼ Sec. 21, T. 8 N., R 19 E., patented November 2, 1888	160

Reservoir Site No. 23.

Situated on the Mokelumne River, in Alpine County, California.

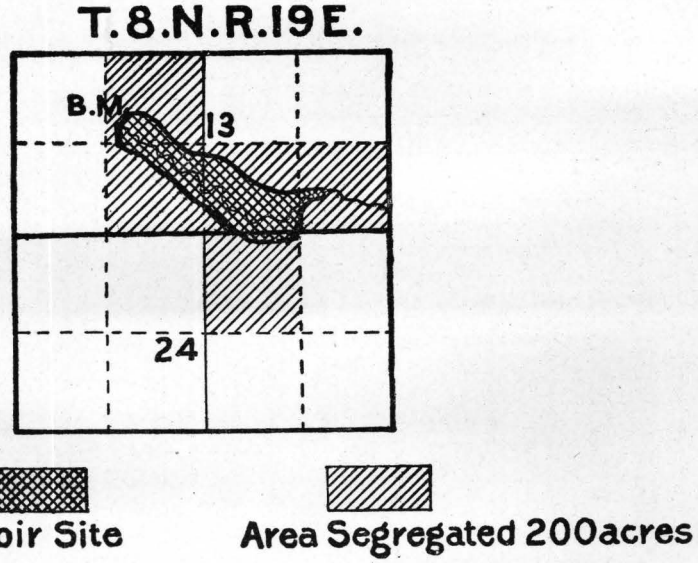


FIG. 92.—Reservoir Site No. 23, called Upper Mokelumne, on Mokelumne River, 1 mile south of the Big Tree Road and 4 miles above Hermit Valley.

The drainage basin of above site includes all the headwaters of the North Fork of the Mokelumne River to the head of Wolf Creek and the Highland Lakes. The mountains are steep, rough, and abound in springs, the seepage from winter snowbanks. The altitude ranges from 6,800 to 10,000 feet.

The reservoir site is in T. 8 N., R. 19 E., Secs. 13 and 24.

The dam is in the SW. ¼ of Sec. 13, T. 8 N., R. 19 E.

The height of the dam is 38 feet.

Bench mark is on a granite rock at north end of dam. Approximate altitude, 6,840 feet.

Top contour is of the same altitude as bench mark.

Area inclosed by top contour is 30 acres.

Approximate content of reservoir is 430 acre-feet.

Stone and timber sufficient for construction of dam are to be found in the immediate vicinity.

Land Office records show reservoir site to be all public land.

The irrigable lands are far to the west upon the area controlled by the Mokelumne River.

Recommended for segregation in letter to Secretary of the Interior, dated February 27, 1891.

Lands segregated for reservoir.

				Acres.
E. ½ SW. ¼ Sec.	13,	T. 8 N.,	R. 19 E	80
S. ½ SE. ¼	13	8	19	80
NW. ¼ NE. ¼	24	8	19	40
Area segregated				200

Land Office records show area segregated to be all public land.

Reservoir Site No. 24.

Known as Pacific Valley, and situated on Pacific Valley Creek, in Alpine County, California.

The drainage basin of Pacific Valley is limited. The surrounding mountains are steep-sided and rough. The elevation ranges from 7,500 to 9,500 feet. The snowfall is heavy; the water supply large. Timber abounds upon the mountain slopes.

Reservoir site is in T. 8 N., R. 19 E., Secs. 28, 29, 32, and 33.

Dam is in the NW. ¼ of Sec. 28, T. 8 N., R. 19 E.

Height of dam is 35 feet.

Bench mark—marked U. S. G. S. B. M.—is on a stone at west end of dam, and has an approximate altitude of 7,000 feet.

Top contour has the same altitude as the bench mark.

Area inclosed by top contour is 75 acres.

Content of reservoir is, approximately, 980 acre-feet.

Material for construction at the site.

Land Office records show reservoir site to be all public land.

Lands controlled by this site are far below upon the drainage of the Mokelumne River.

Lands segregated for reservoir.

				Acres.
W. ½ SW. ¼ Sec.	28,	T. 8 N.,	R. 19 E	80
SW. ¼ NW. ¼	28,	8	19	40
NE. ¼ NE. ¼	32,	8	19	40
NW. ¼ NW. ¼	33,	8	19	40
E. ½ SE. ¼	29,	8	19	80
SE. ¼ NE. ¼	29,	8	19	40
Area segregated				320

Land Office records show that the area segregated is all public land

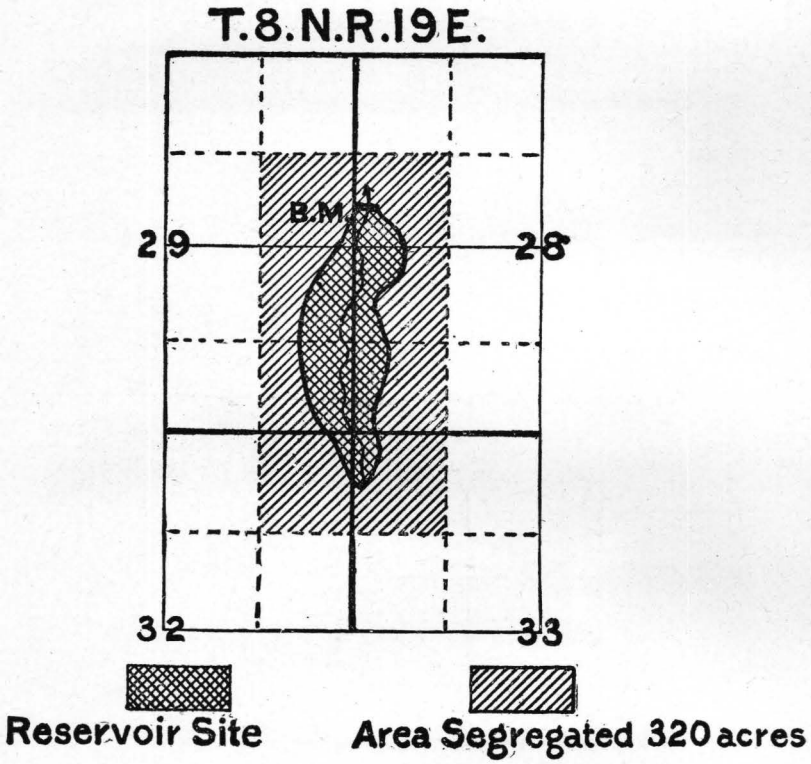


FIG. 93.—Reservoir Site No. 24, in Pacific Valley

RESERVOIR SITE NO. 25.

Known as Bell's Meadow, and situated on Big Canyon Creek, in Tuolumne County, California.

The drainage basin is rough and rugged; three quarters of it being covered by a heavy growth of pine and fir, while the remaining portions are of bare or brush-covered granite. The water supply comes from Big Canyon Creek and two of its branches. This creek takes its rise at an approximate altitude of 7,500 feet and about 10 miles above the reservoir site, which has an altitude of about 5,500 feet.

The reservoir site is in T. 3 N., R. 18 E., Secs. 1, 2, 3, 11, and 12.

Main dam is in the SW. ¼ of Sec. 2, T. 3 N., R. 18 E. Secondary dam is in the SE. ¼ of Sec. 3, T. 3 N., R. 18 E.

Height of main dam is 60 feet. Height of secondary dam is 23 feet.

Bench mark—marked U. S. G. S. B. M.—is on a granite rock at southeast end of main dam, and has an approximate altitude of 5,500 feet.

The top contour is of the same altitude as the bench mark.

The area inclosed by top contour is 280 acres.

Approximate content of reservoir is 6,300 acre-feet.

Stone and timber for construction are to be found in the immediate vicinity.

Land Office records show reservoir site to be all public land.

Irrigable lands are in the San Joaquin Valley, 60 miles to the west

Lands segregated for reservoir.

				Acres.
SW. ¼ Sec.	1,	T. 3 N.,	R. 18 E	160
S. ½	2	3	18	320
E. ½ SE. ¼	3	3	18	80
N. ½ NW. ¼	11	3	18	80
N. ½ NE. ¼	11	3	18	80
N. ½ NW. ¼	12	3	18	80
Area segregated				800

Land Office records shows area segregated to be all public land.

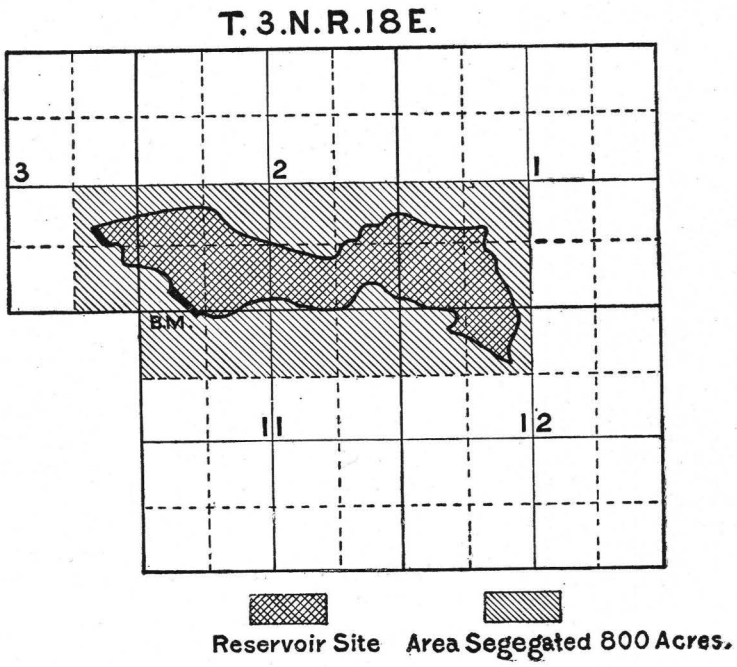


FIG. 94.—Reservoir Site No. 25, known as Bell's Meadows.

RESERVOIR SITE NO. 26.

Known as Coffin's Hollow, and situated on a branch of Big Canyon Creek, in Tuolumne County, California.

The drainage basin is rough and rugged, and for the most part covered with a thick growth of pine, fir, and tamarack. The water supply comes from one of the east branches of Big Canyon Creek, that takes its rise some 15 miles to the northeast of the reservoir site. The headwaters of the creek have an approximate altitude of 8,000 feet.

The reservoir site is in T. 3 N., R. 18 E., Secs. 21, 22, 23, 26, and 27.

The dam is in the SE. ¼ of Sec. 21, T. 3 N., R. 18 E.

Height of dam is 35 feet.

Bench mark—marked U. S. G. S. B. M.—is on a granite bluff at the south end of dam, and has an approximate altitude of 5,000 feet.

The top contour is of the same altitude as the bench mark.

The area inclosed by the top contour is 175 acres.
The approximate content of reservoir is 2,200 acre-feet.
Stone, sand, and timber for construction are to be found in the immediate vicinity.
The reservoir site is still public land.
Irrigable lands are in the San Joaquin Valley, 60 miles to the west.

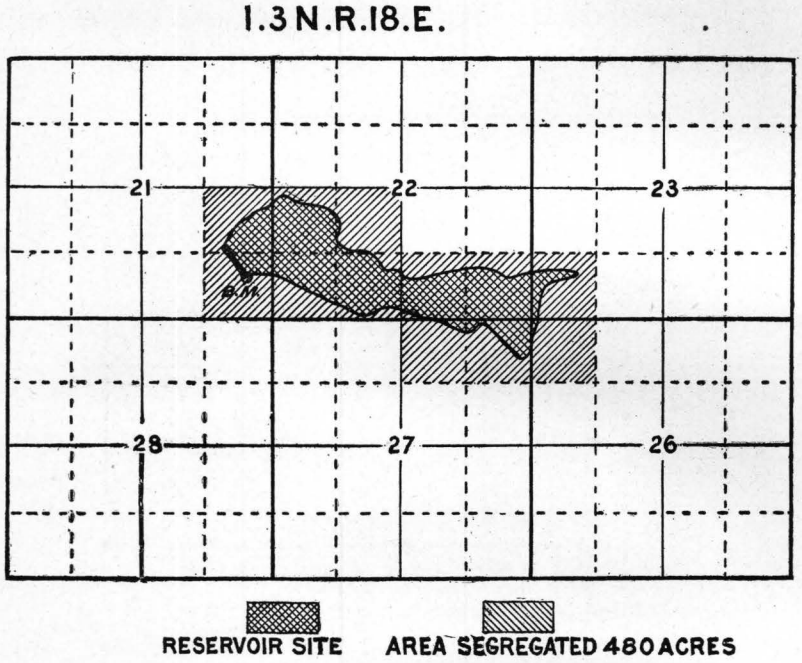


FIG. 95.—Reservoir Site No. 26, known as Coffin's Hollow.

Lands segregated for reservoir.

				Acres.
E. ½ SE. ¼ Sec.	21,	T. 3 N.,	R. 18 E.	80
SW. ¼	22	3	18	160
S. ½ SE. ¼	22	3	18	80
SW. ¼ SW. ¼	23	3	18	40
NW. ¼ NW. ¼	26	3	18	40
N. ½ NE. ¼	27	3	18	80
Area segregated				480

Land Office records show area segregated to be all public land.

RESERVOIR SITE NO. 27.

Known as Hull's Meadows, on Hull Creek, in Tuolumne County, California.

The drainage basin is covered with a thick growth of pine, fir, tamarack, and scattering cedar. The source of water supply is Hull Creek and branches, the headwaters of which have an approximate altitude of 6,000 feet.

The reservoir site is in T. 3 N., R. 17 E., Sec. 35, and T. 2 N., R. 17 E., Sec. 2, Mount Diablo meridian.

The dam is in the NE. ¼ of Sec. 2, T. 2 N., R. 17 E.

The height of dam is 50 feet.

The bench mark is on a pine stump, marked U. S. G. S. B. M., at the east end of the dam and has an approximate altitude of 5,000 feet.

The top contour is of the same altitude as the bench mark, and was run with a hand level and plane table.

The area inclosed by the top contour is 115 acres.

The approximate content of reservoir is 2,160 acre-feet.

Stone, timber, and sand for construction are to be found in the immediate vicinity.

The reservoir site is partially settled.

Irrigable lands are in the San Joaquin Valley, 60 miles to the west.

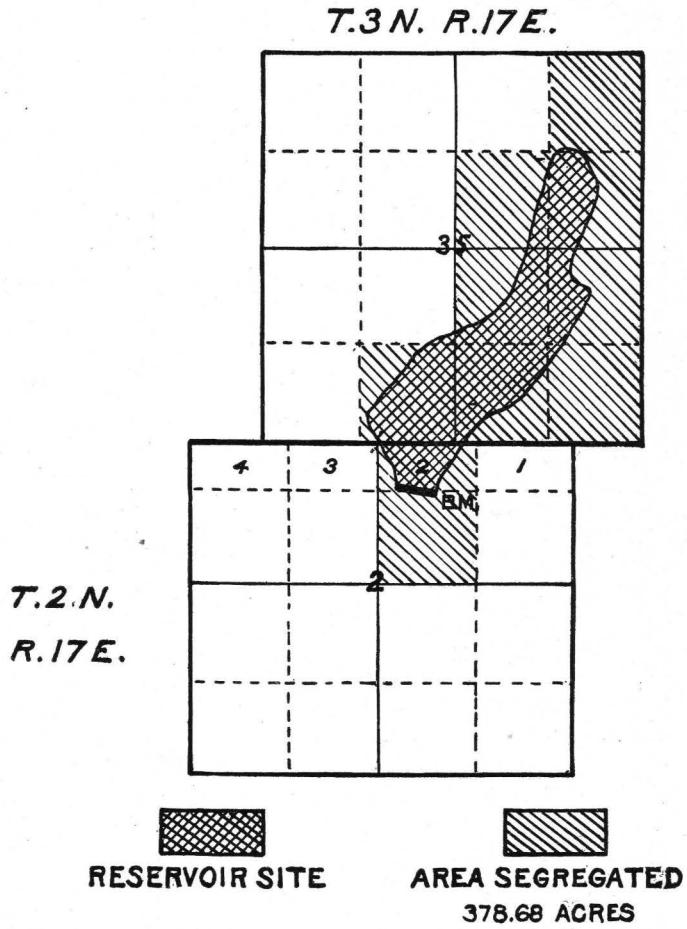


FIG. 96.—Reservoir Site No. 27, known as Hull's Meadow; lies along Rush Creek.

Lands segregated for reservoir.

				Acres.
NE. ¼ NE. ¼ Sec.	35,	T. 3 N.,	R. 17 E	40·00
S. ½ NE. ¼	35,	3	17	80·00
SE. ¼	35,	3	17	160·00
SE. ¼ SW. ¼	35,	3	17	40·00
Lot 2	2,	2	17	18·68
SW. ¼ NE. ¼	2,	2	17	40·00
Area segregated				378·68

Action affecting titles to lands segregated for Reservoir Site No. 27 has been taken as follows:

					Acres.
E. ½ NE. ¼	Sec. 35,	T 3 N.,	R. 17 E.	(patented August 14, 1877)	80·00
Lot 2	2,	2	17	(patented September 11, 1882)	18·86
SW. ¼ NE. ¼	2,	2	17	(patented September 11, 1882)	40·00
					138·68

Reservoir Site No. 28.

Known as Granite Lake, and is situated on and about Granite Lake, Tuolumne County, California.

The drainage basin is that of Granite Lake, which has an approximate altitude of 5,000 feet. About one-half of it is covered with a thick growth of pine, fir, and tamarack, while the remaining portions are of bare granite.

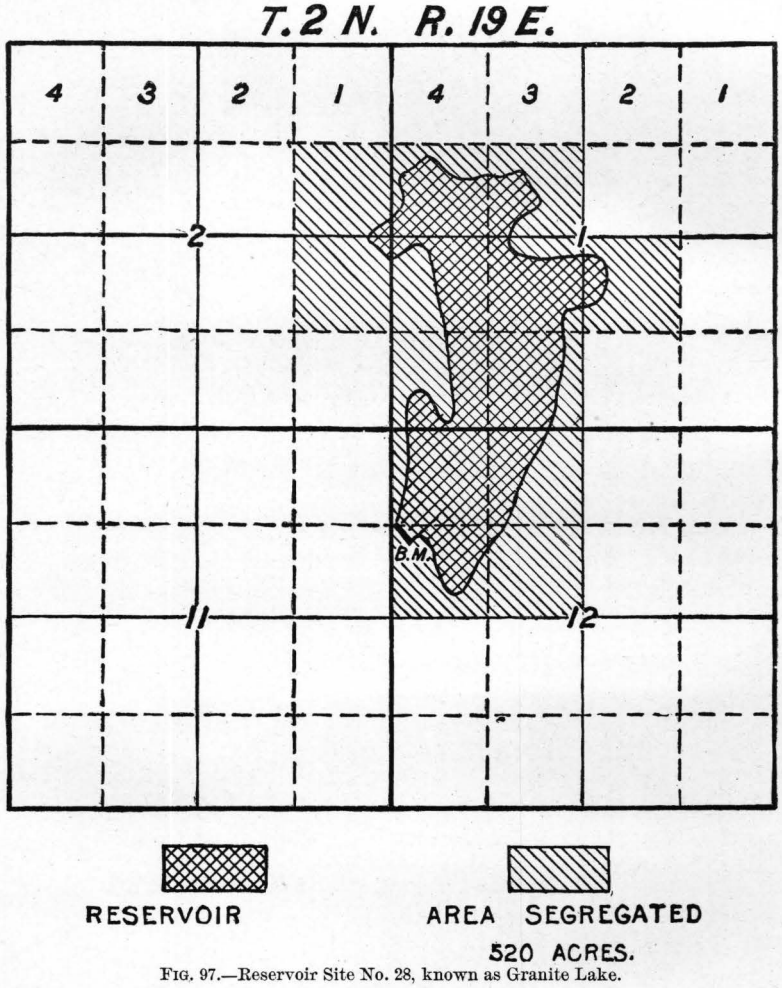


Fig. 97.—Reservoir Site No. 28, known as Granite Lake.

The reservoir site is in T. 2 N., R. 19 E., Secs. 1, 2, and 12, Mount Diablo meridian.
The dam is in the NW. ¼ of Sec. 12, T. 2 N., R. 19 E.
The height of dam is 40 feet.

The bench mark is on a granite rock marked U. S. G. S. B. M., at east end of dam, and has an approximate altitude of 5,040 feet.

The top contour has an altitude the same as that of the bench mark.

Area inclosed by top contour is 220 acres.

The approximate content of reservoir is 3,300 acre-feet.

Timber and stone for construction of the dam are to be found in the immediate vicinity of reservoir site.

Reservoir site is shown by records of the Land Office to be all public land.

Irrigable lands are in the San Joaquin Valley, 65 miles to the west.

Lands segregated for reservoir.

					Acres.
S. ½ NW. ¼ Sec.	1,	T. 2 N.,	R. 19 E.		80
SW. ¼	1,	2	19		160
NW. ¼ SE. ¼	1,	2	19		40
SE. ¼ NE. ¼	2,	2	19		40
NE. ¼ SE. ¼	2,	2	19		40
NW. ¼	12,	2	19		160
Area segregated					520

Action affecting titles to land segregated for Reservoir Site No. 28, has been taken as follows:

All area segregated reserved as forest reservation. Act of October 1, 1890.

Reservoir Site No. 29.

Known as the Cherry Valley, and situated on the Cherry River, in Tuolumne County, California.

The drainage basin is that of the Cherry River and its tributaries, which take their rise in the high Sierras at an altitude of 11,000 feet above sea level. The stream falls rapidly. The surrounding mountains are of granite, partially covered with fir, pine, tamarack, and cedar. The water supply comes from the Cherry River and its tributaries.

Reservoir site is in T. 2 N., R. 19 E., Secs. 20, 21, 28, 29, and 32, Mount Diablo meridian.

The dam is in the SE. ¼ of Sec. 32, T. 2 N., R. 19 E.

The height of the dam is 40 feet.

The bench mark is on a pine tree, marked U. S. G. S. B. M., at the east end of the dam, and has an approximate altitude of 4,500 feet.

The top contour has the same altitude as the bench mark.

The area inclosed by the top contour is 165 acres.

The approximate content of reservoir is 2,500 acre-feet.

Stone, timber, sand, and gravel for construction of dam are to be found in the immediate vicinity of the reservoir site.

Lands segregated for reservoir.

					Acres.
E. ½ SE. ¼ Sec.	20,	T. 2 N.,	R. 19 E.		80
SW. ¼ SW. ¼	21	2	19		40
SE. ¼ NE. ¼	29	2	19		40
SE. ¼	29	2	19		160
NE. ¼	32	2	19		160
NW. ¼ SE. ¼	32	2	19		40
W. ½ NW. ¼	28	2	19		80
SE. ¼ NW. ¼	28	2	19		40
N. ½ SW. ¼	28	2	19		80
Area segregated					720

The reservoir site is partially settled.
Irrigable lands are in the San Joaquin Valley 60 miles to the west.

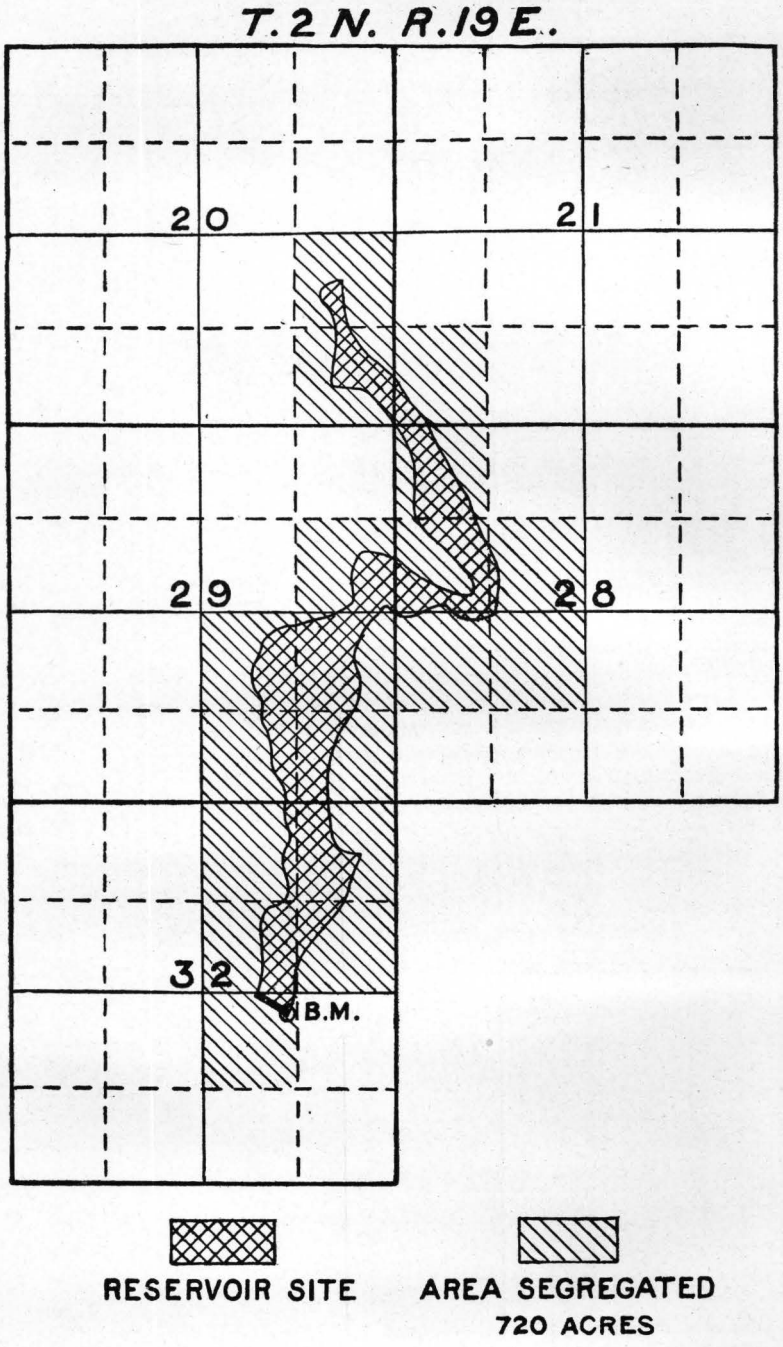


FIG. 98.—Reservoir Site No. 29, known as Cherry Valley, situated along the Cherry River.

Action affecting titles to lands segregated for Reservoir Site No. 29 has been taken as follows:

	Acres.
W. ½ NW. ¼ Sec. 28, T. 2 N., R. 19 E.	80
N. ½ SW. ¼ 28 2 19	80
Homestead, October, 1882	160

Reservoir Site No. 30.

Known as Lake Vernon, and situated on and about Lake Vernon, Tuolumne County, California.

Is in the upper Sierras at an altitude of approximately 6,500 feet. Is well supplied with water from the inlets of the lake. Timber is plentiful; that in the immediate vicinity of the lake is chiefly tamarack.

Reservoir site is in T. 2 N., R. 20 E., Secs. 21, 22, 27, 28, 29, Mount Diablo meridian.

The dam is in the SE. ¼ of Sec. 29, T. 2 N., R. 20 E.

Height of dam is 30 feet.

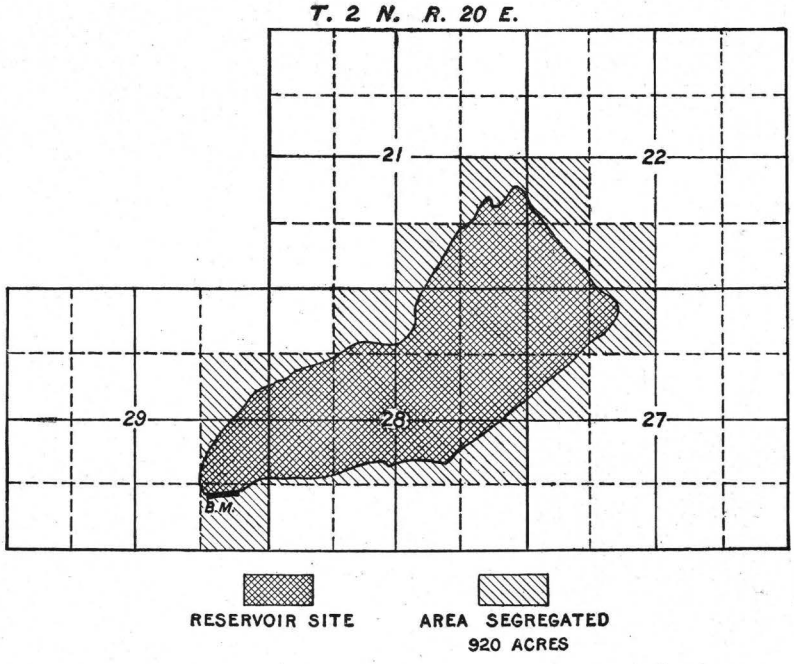


Fig. 99.—Reservoir Site No. 30, known as Lake Vernon Reservoir Site.

Bench mark is on a granite bluff at the west end of the dam, and has an approximate altitude of 6,530 feet.

Top contour is of the same altitude as the bench mark.

The area inclosed by the top contour is 480 acres.

The approximate content of reservoir is 5,700 acre-feet.

Stone and timber for construction of dam are to be found in the immediate vicinity of the site.

Land Office records show the reservoir site to be public land.

Irrigable lands are in the San Joaquin Valley, 60 miles to the west.

Lands segregated for reservoir.

				Acres.
NE. ¼ SE. ¼	Sec. 21,	T. 2 N.,	R. 20 E	40
S. ½ SE. ¼	21	2	20	80
S. ½ SW. ¼	22	2	20	80
NW. ¼ SW. ¼	22	2	20	40
NE. ¼	28	2	20	160
NE. ¼ NW. ¼	28	2	20	40
S. ½ NW. ¼	28	2	20	80
N. ½ SW. ¼	28	2	20	80
N. ½ SE. ¼	28	2	20	80
E. ½ SE. ¼	29	2	20	80
SE. ¼ NE. ¼	29	2	20	40
W. ½ NW. ¼	27	2	20	80
NE. ¼ NW. ¼	27	2	20	40
Area segregated				920

Action affecting titles to land segregated for Reservoir Site No. 30 has been taken as follows:

All area segregated reserved as forest reservation. Act of October 1, 1890.

Reservoir Site No. 31.

Known as Big Meadows, and situated on a small creek in the high Sierras in Tuolumne County, California.

The drainage basin is comparatively small, in a rough granite country, sparsely timbered, having an approximate elevation of 7,500 feet. The drift marks show that there is not much water even in its highest stage, while late in the summer and fall there is a flow of not over 20 miners' inches.

Reservoir site is in T. 2 N., R. 22 E., Secs. 16, 20, and 21.

The dam is in the NE. ¼ of Sec. 20, T. 2 N., R. 22 E.

The height of the dam is 30 feet.

The bench mark is on a granite rock, marked U. S. G. S. B. M., at the west end of the dam, and has an approximate altitude of 7,500 feet.

The top contour has the same altitude as the bench mark.

The area inclosed by the top contour is 980 acres.

The approximate content of reservoir is 11,000 acre-feet.

Stone and timber for the construction of the dam are to be found in the immediate vicinity.

The Land Office records show reservoir site to be all public land.

Irrigable lands are in the San Joaquin Valley, 75 miles to the west.

Lands segregated for reservoir.

				Acres.
E. ½ NE. ¼	Sec. 20,	T. 2 N.,	R. 22 E	80
W. ½ NW. ¼	21,	2	22	80
SW. ¼	16,	2	22	160
S. ½ NW. ¼	16,	2	22	80
Area segregated				400

Land Office records show area segregated to be all public land.

Action affecting titles to lands segregated for Reservoir Site No. 31 has been taken as follows:

All has been reserved for forest reservation under act of October 1, 1890.

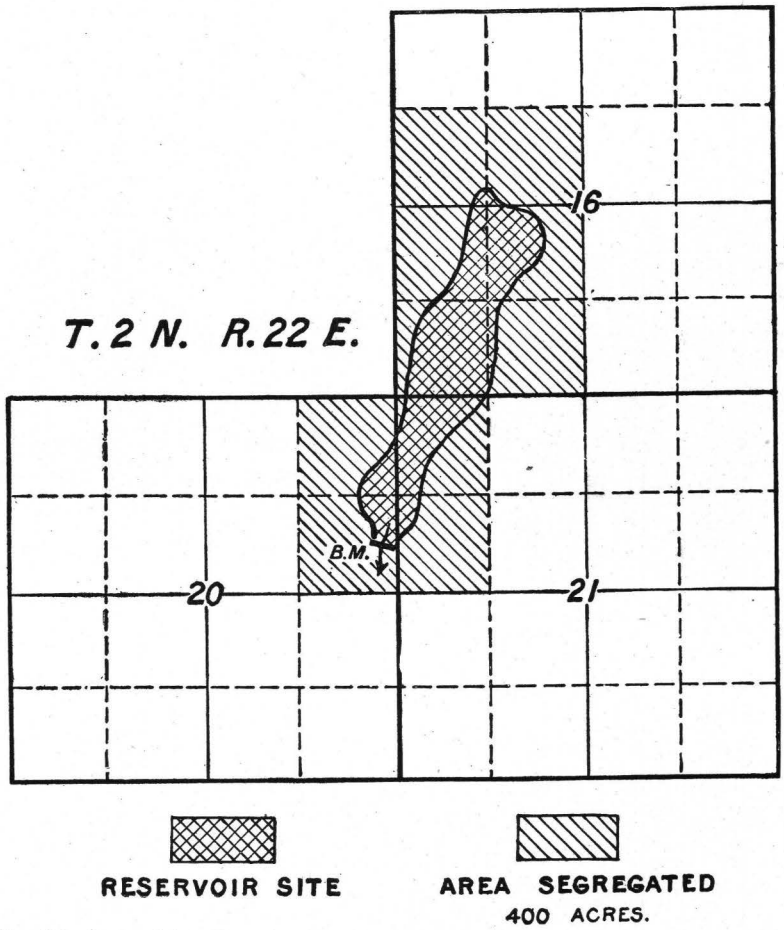


FIG. 100.—Reservoir Site No. 31, in Big Meadows, about 5 miles north of Hetch Hetchy Valley.

RESERVOIR SITE NO. 32.

Known as Errarar's Meadow, is in Tuolumne County, California.

Its drainage basin extends not over 1 mile in any direction from the reservoir site, and is dry in summer. The mountains are covered with a heavy growth of pine and cedar. The approximate altitude is 5,000 feet.

The reservoir site is in Secs. 7, 8, and 18, T. 1 N., R. 20 E., Mount Diablo meridian.

The dam is in the SW. ¼ of Sec. 7, T. 1 N., R. 20 E.

The height of the main dam is 30 feet and that of the secondary dam, 7 feet.

Bench mark is on an oak tree at the north end of the main dam, and has an approximate altitude of 5,000 feet.

The top contour has the same altitude as the bench mark.

The area inclosed by the top contour is 95 acres.

The approximate content of reservoir is 1,070 acre-feet.

Stone and timber for construction of dam are to be found in the immediate vicinity of the reservoir site.

The Land Office records show the reservoir site to be public land.

The irrigable lands are in the San Joaquin Valley, 65 miles to the west.

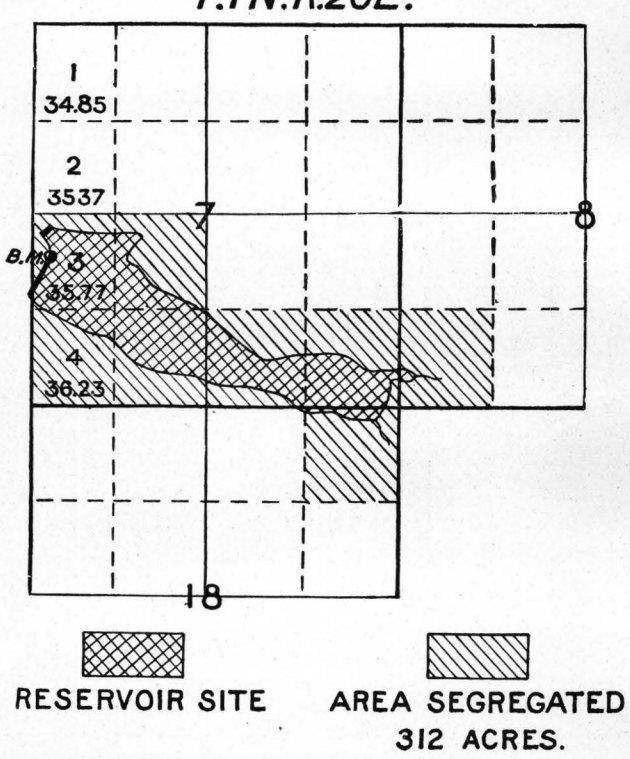


FIG. 101.—Reservoir Site No. 32, known as Ernarar Meadow.

Lands segregated for reservoir.

					Acres.
SW. ¼ SW. ¼ Sec.	8,	T. 1 N.,	R. 20 E		40·00
NE. ¼ NE. ¼	18	1	20		40·00
Lot 3 in SW. ¼	7	1	20		35·77
Lot 4 in SW. ¼	7	1	20		36·23
E. ½ SW. ¼	7	1	20		80·00
S. ½ SE. ¼	7	1	20		80·00
Area segregated					312·00

Action affecting titles to land segregated for Reservoir Site No. 32 has been taken as follows:

All area segregated reserved as forest reservation. Act of October 1, 1890.

RESERVOIR SITE NO. 33.

Known as Hetch Hetchy Valley, on the Tuolumne River, in Tuolumne County, California.

The drainage basin is that of the Tuolumne River, whose headwaters take their rise in the summit of the Sierra Nevada Mountains, at an altitude of 12,000 feet above sea level. Part of this basin is heavily timbered and part is of bare granite,

together with some large meadows. The water supply comes from the Tuolumne River and its several large tributaries.

The reservoir site is in Secs. 9, 10, 11, 12, and 16, T. 1 N., R. 20 E.

The dam is in the NW. ¼ of Sec. 16, T. 1 N., R. 20 E.

The height of the dam is 100 feet.

Bench mark is on a granite bluff marked U. S. G. S. B. M., at north end of dam, and has an approximate altitude of 1,500 feet.

The top contour has the same altitude as the bench mark.

The area inclosed by the top contour is 680 acres.

The approximate content of reservoir is 25,500 acre-feet.

Stone, timber, gravel, and sand for construction of dam are to be found in the immediate vicinity of reservoir site.

The reservoir site is partly settled.

The irrigable lands are in the San Joaquin Valley, 70 miles to the west.

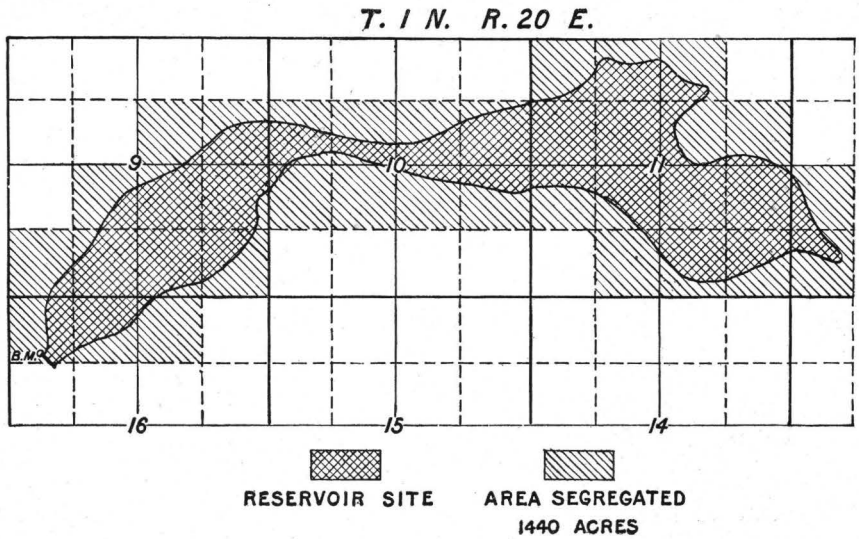


FIG. 102.—Reservoir Site No. 33, known as Hetch Hetchy Valley; situated on the Tuolumne River.

Lands segregated for reservoir.

				Acres.
N. ½ NW. ¼ Sec.	16,	T. 1 N.,	R. 20 E.	80
NW. ¼ NE. ¼	16	1	20	40
S. ½ SW. ¼	9	1	20	80
NE. ¼ SW. ¼	9	1	20	40
SE. ¼	9	1	20	160
S. ½ NE. ¼	9	1	20	80
S. ½ N. ½	10	1	20	160
N. ½ S. ½	10	1	20	160
NW. ¼	11	1	20	160
SE. ¼	11	1	20	160
N. ½ SW. ¼	11	1	20	80
SE. ¼ SW. ¼	11	1	20	40
S. ½ NE. ¼	11	1	20	80
NW. ¼ NE. ¼	11	1	20	40
W. ½ SW. ¼	12	1	20	80
Area segregated				1,440

Action affecting titles to lands segregated for Reservoir Site No. 33 has been taken as follows:

					Acres.
SE. ¼	Sec. 9,	T. 1 N.,	R. 20 E.	(patented October 13, 1882)	160
S. ½ NE. ¼	10	1	20		80
NW. ¼ SE. ¼	10	1	20		40
SW. ¼ NW. ¼	11	1	20	(patented February 27, 1885)	40
N. ½ SE. ¼	11	1	20		80
N. ½ SW. ¼	11	1	20	(patented February 23, 1884)	80
					480

All has been reserved as forest reservation. October 1, 1890.

Reservoir Site No. 34.

On Little Truckee River, in Sierra County, California.

The drainage basin is mountainous and almost completely covered with a thick growth of pine and fir. The snow fall is very heavy and melted snow will furnish an ample supply of water. Elevation ranges from 6,500 to 9,000.

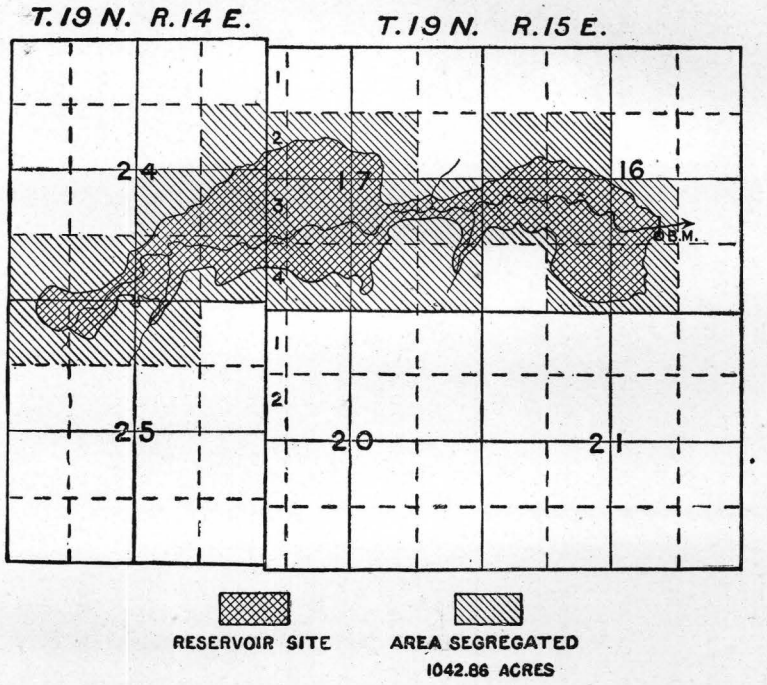


Fig. 103.—Reservoir Site No. 34, Upper Little Truckee Reservoir, on Little Truckee River, about 3 miles east of Webber Lake and 4 miles due north of Mount Lola.

Reservoir site is in Secs. 24 and 25, T. 19 N., R. 14 E., and Secs. 16 and 17, T. 19 N., R. 15 E., Mount Diablo meridian.

The dam is in the SE. ¼ of Sec. 16, T. 19 N., R, 15 E.

Height of dam, 60 feet.

Bench mark is on a pine stake at south end of dam. Approximate altitude, 6,430 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 450 acres.

Approximate content of reservoir is 10,100 acre-feet.

Stone and timber for construction of dam are to be found in the immediate vicinity of site.

Land Office records show reservoir site to be partially settled.

Irrigable lands are along the Truckee River and in the Reno Valley.

Lands segregated for reservoir.

					Acres.
S. ½ SW. ¼	Sec. 24,	T. 19 N.,	R. 14 E.		80·00
SE. ¼	24	19	14		160·00
SE. ¼ NE. ¼	24	19	14		40·00
N. ½ NW. ¼	25	19	14		80·00
NW. ¼ NE. ¼	25	19	14		40·00
Lot 2 in NW. ¼	17	19	15		14·17
Lot 3 in SW. ¼	17	19	15		14·32
Lot 4 in SW. ¼	17	19	15		14·37
SE. ¼ NW. ¼	17	19	15		40·00
E. ½ SW. ¼	17	19	15		80·00
SW. ¼ NE. ¼	17	19	15		40·00
SE. ¼	17	19	15		160·00
S. ½ NW. ¼	16	19	15		80·00
N. ½ SW. ¼	16	19	15		80·00
SE. ¼ SW. ¼	16	19	15		40·00
W. ½ SE. ¼	16	19	15		80·00
Area segregated					1,042·86

Actions affecting titles to lands segregated for Reservoir Site No. 34 have been taken as follows:

					Acres.
SE. ¼	Sec. 24,	T. 19 N.,	R. 14 E.	(patented Dec. 2, 1887)	160·00
N. ½ NW. ¼	25	19	14	(patented April 17, 1885)	80·00
NW. ¼ NE. ¼	25	19	14	(patented April 17, 1885)	40·00
Lot 2 in NW. ¼	17	19	15	(patented Dec. 21, 1886)	14·17
Lot 3 in SW. ¼	17	19	15	(patented Dec. 21, 1886)	14·32
Lot 4 in SW. ¼	17	19	15	(patented Dec. 21, 1886)	14·37
SE. ¼ NW. ¼	17	19	15	(patented Dec. 21, 1886)	40·00
E. ½ SW. ¼	17	19	15	(patented Dec. 21, 1886)	80·00
SW. ¼ NE. ¼	17	19	15		40·00
SE. ¼	17	19	15		160·00
					642·86

Reservoir Site No. 35.

Known as Stampede Valley, situated on the Little Truckee River, in Sierra County, California.

This site is located on the Little Truckee River. Country not very rough in the immediate vicinity of the site. Sufficient water supply in spring; limited in summer. Altitude of drainage basin is from 5,800 feet to 9,000 feet.

Reservoir site is in Secs. 8 and 9, T. 19 N., R. 17 E., Mount Diablo meridian.

The dam is in the SW. ¼, Sec. 9, T. 19 N., R. 17 E.

Dam is 50 feet high.

Bench mark is a pine stake marked U. S. G. S., B. M., at east end of dam, and has an approximate altitude of 5,800 feet.

The top contour has the same altitude as bench mark.

The area inclosed by the top contour is 120 acres.

The approximate content of reservoir is 2,250 acre-feet.

Stone and timber for construction of dam are to be found in the immediate vicinity of site.

Land Office records show reservoir site to be partially settled.

The irrigable lands are along the Truckee River and in the Reno Valley.

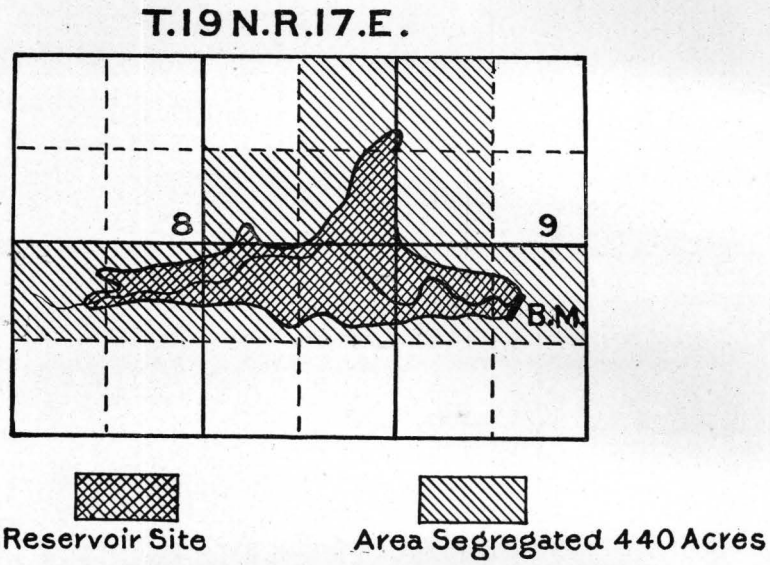


FIG. 104.—Reservoir Site No. 35, in Stampede Valley, on the Little Truckee River.

Lands segregated for reservoir.

					Acres.
W. ½ NW. ¼	Sec. 9,	T. 19 N.,	R. 17 E		80
N. ½ SW. ¼	9	19	17		80
N. ½ SE. ¼	8	19	17		80
N. ½ SW. ¼	8	19	17		80
E. ½ NE. ¼	8	19	17		80
SW. ¼ NE. ¼	8	19	17		40
Area segregated					440

Action affecting titles to lands segregated for Reservoir Site No. 35 has been taken as follows:

					Acres.
NE. ¼ NE. ¼	Sec. 8,	T. 19 N.,	R. 17 E.	(timber claim, May, 1884)	40
S. ½ NE. ¼	8	19	17	(ad. homestead, February, 1890)	80
N. ½ SW. ¼	9	19	17	(C. P. R. R. Co., December, 1886)	160
					280

Acts of July, 1862, and July, 1864.

RESERVOIR SITE NO. 36.

Known as Twin Valley, is situated on the north fork of Prosser Creek, in Nevada County, California.

The drainage basin comprises about 12 square miles, the altitude ranging from 6,200 to 9,000 feet. This site is surrounded by rough, high mountains. Abundance of timber on ridges south of site. The surrounding hills are very rough and rocky. Very heavy snow falls in winter. Summer flow of water probably sufficient to supply reservoir.

The reservoir site is in T. 18 N., R. 15 E., Secs. 23, 24, and 25, and T. 18 N., R. 16 E., Secs. 19 and 30, Mount Diablo meridian.

The dam is in the NE. ¼ of Sec. 25, T., 18 N., R. 15 E.

Height of dam, 30 feet.

Bench mark is on a bowlder, 3 feet in diameter, marked U. S. G. S., B. M., at east end of dam, and has an approximate altitude of 6,200 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 310 acres.

Approximate content of reservoir is 3,480 acre-feet.

Stone and timber suitable for construction of dam are to be found in the immediate vicinity of site.

Land Office records show reservoir site to be partially settled.

Irrigable lands are along the Truckee River and in the Reno Valley.

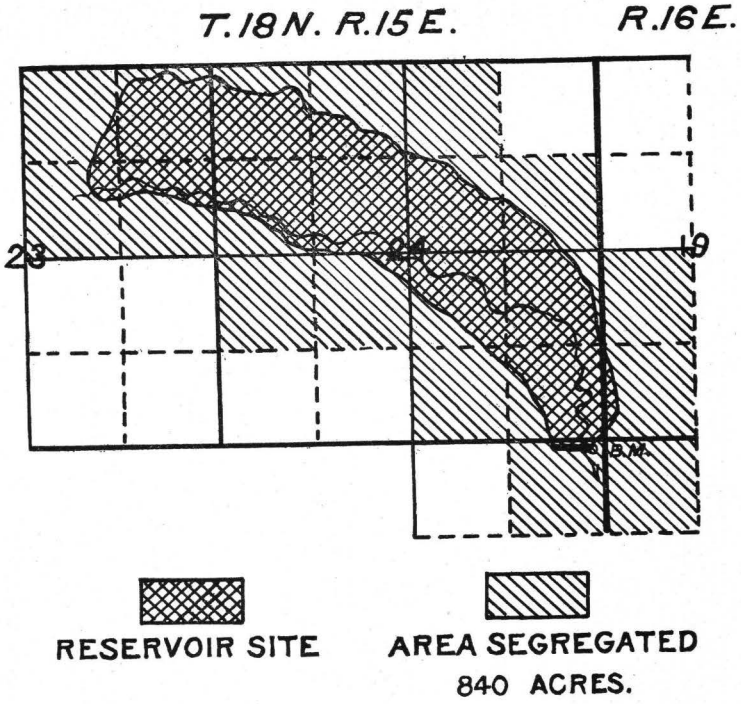


FIG. 105.—Reservoir Site No. 36, Twin Valley Reservoir.

Lands segregated.

				Acres.
NE. ¼ Sec.	23,	T. 18 N.,	R. 15 E.	160
NW. ¼	24	18	15	160
SE. ¼	24	18	15	160
N. ½ SW. ¼	24	18	15	80
S. ½ NE. ¼	24	18	15	80
NW. ¼ NE. ¼	24	18	15	40
W. ½ SW. ¼	19	18	16	80
NW. ¼ NW. ¼	30	18	16	40
NE. ¼ NE. ¼	25	18	15	40
Area segregated				840

Action affecting the titles to lands segregated for Reservoir Site No. 36 has been taken as follows:

					Acres.
NE. ¼	Sec. 23,	T. 18 N.,	R. 15 E.	(patented C. P. R. R. Co., April, 1881)	160
NW. ¼ NE. ¼	24	18	15	(ad. homestead, October, 1875)	40
SW. ¼ NE. ¼	24	18	15	(patented September, 1879)	160
NW. ¼ SE. ¼	24	18	15	(patented September, 1879)	
E. ½ SE. ¼	24	18	15	(patented September, 1879)	
W. ½ NW. ¼	24	18	15	(homestead, January, 1880)	80
SE. ¼ NW. ¼	24	18	15	(ad. homestead, January, 1880)	40
N. ½ SW. ¼	24	18	15	(ad. homestead, October, 1875)	80
NE. ¼ NE. ¼	25	18	15	(patented C. P. R. R. Co., April, 1882)	40
W. ½ SW. ¼	19	18	16	(patented C. P. R. R. Co., April, 1881)	80
					680

Reservoir Site No. 37.

Is situated at the mouth of the Little Truckee River, in Nevada County, California.

The drainage area is ample to supply water for the reservoir, as there is always a heavy snowfall. In summer months the Little Truckee is very small. Elevation ranges from 4,500 to 9,000 feet.

The reservoir site is in T. 18 N., R. 17 E., Secs. 16, 21, and 28.

The dam is in the NW. ¼ and NE. ¼ of Sec. 28, T. 18 N., R. 17 E.

The height of the dam is 50 feet.

Bench mark is on a rock at east end of dam. Approximate altitude, 5,550 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 350 acres.

Approximate content of reservoir is 6,500 acre-feet.

Materials for construction of dam are to be found in the immediate vicinity.

Land Office records show the reservoir site to be partially settled.

Irrigable lands are along the Truckee River and in the Reno Valley.

Lands segregated for reservoir.

				Acres.
S. ½ NE. ¼	Sec. 16,	T. 18 N.,	R. 17 E.	80
SE. ¼ NW. ¼	16	18	17	40
SW. ¼	16	18	17	160
W. ½ SE. ¼	16	18	17	80
NW. ¼	21	18	17	160
W. ½ NE. ¼	21	18	17	80
N. ½ SW. ¼	21	18	17	80
SE. ¼ SW. ¼	21	18	17	40
W. ½ SE. ¼	21	18	17	80
NE. ¼ NW. ¼	28	18	17	40
NW. ¼ NE. ¼	28	18	17	40
Area segregated				880

Action affecting titles to lands segregated for Reservoir Site No. 37 has been taken as follows:

				Acres.
NW. ¼	Sec. 21,	T. 18 N.,	R. 17 E.	160
W. ½ NE. ¼	21	18	17	80
N. ½ SW. ¼	21	18	17	80
SE. ¼ SW. ¼	21	18	17	40

					Acres.
W. ½ SE. ¼	Sec. 21,	T. 18 N.,	R. 17 E	(C. P. R. R. Co., acts of July, 1862, and July, 1864)	80
NE. ¼ NW. ¼	28	18	17	(patented December, 1875)	40
NW. ¼ NE. ¼	28	18	17	(patented July, 1869)	40
					520

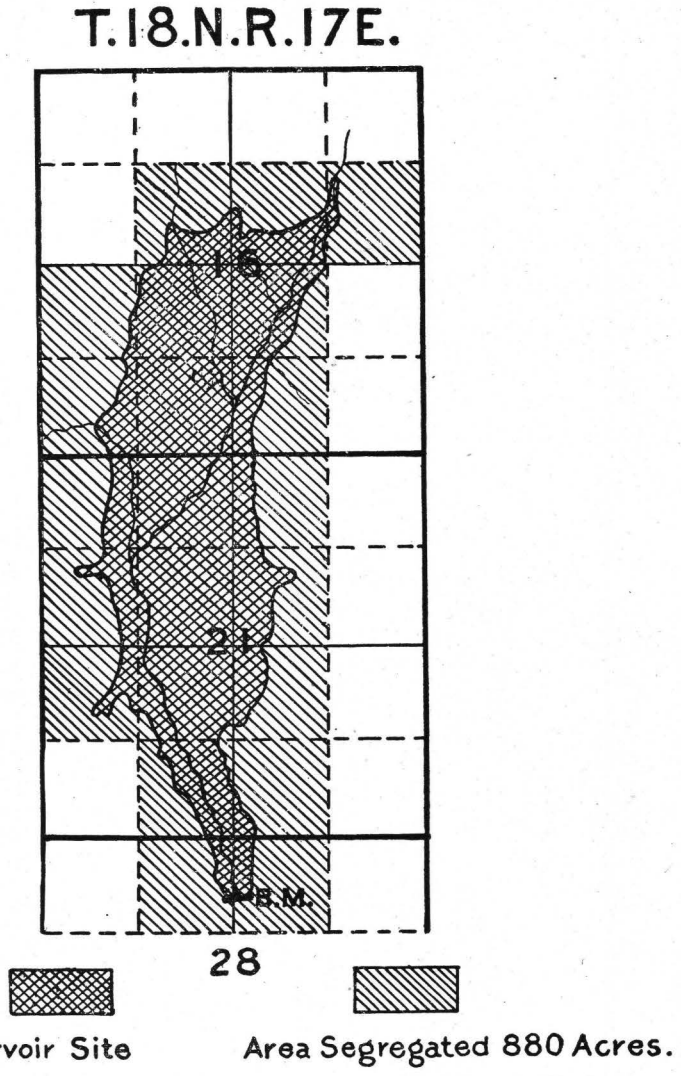


FIG. 106.—Reservoir Site No. 37, at Boca Station on C. P. R. R., east of Truckee.

RESERVOIR SITE NO. 38.

Known as Monument Peak, and is situated in Alpine County, California.

The drainage basin is small. The site is in a V of the main ridge of the Sierra Nevada. The ridge slopes are very steep. The snowfall heavy. The elevation ranges from 7,700 to 10,000 feet. The water supply is ample for filling any reservoir that could be constructed upon this spot.

Reservoir site is in T. 12 N., R. 18 E., Mount Diablo meridian.

Dam is in Sec. 12, Lot 7, T. 12 N., R. 18 E.

Dam 80 feet high.

Bench mark on a large rock near blazed tree at south end of dam; and has an approximate altitude of 7,700 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 160 acres.

Content of reservoir is about 4,800 acre-feet.

The materials for construction are at hand—granite rock and good mill timber.

Land Office records show the reservoir site to be partially filed upon.

The irrigable lands are in Lake Valley, to the west of the site, and in the Truckee Valley.

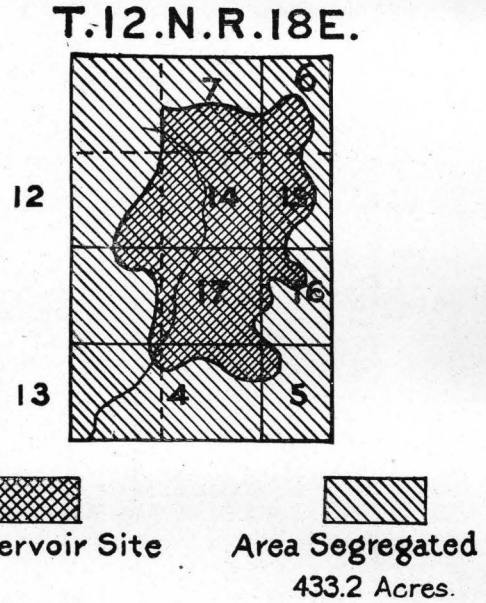


FIG. 107.—Reservoir Site No. 68, located in a hollow under Monument Peak.

Lands segregated for reservoir.

	Acres.
Lot 6, Sec. 12, T. 12 N., R. 18 E.	28·53
Lot 7 12 12 18	30·00
Lot 15 12 12 18	28·32
Lot 14 12 12 18	80·00
Lot 16 12 12 18	28·10
Lot 17 12 12 18	80·00
Lot 4 13 12 18	80·00
Lot 5 13 12 18	28·07
Area segregated	433·02

Action affecting titles to lands segregated for Reservoir Site No. 38 has been taken as follows:

					Acres.
Lot 15, Sec.	12,	T. 12 N.,	R. 18 E.	(timber sold February, 1890)	28·32
Lots 14 and 17	12	12	18	(selected by State. Approved September, 1882)	160·00
Lot 5	13	12	18	(timber sold February, 1890)	28·07
Lot 4	13	12	18	(selected by State. Approved September, 1882)	80·00
					296·39

Reservoir Site No. 39.

Known as Youngs Crossing, and is situated partly in Alpine County, California, and partly in Douglas County, Nevada.

The drainage basin incloses the whole of that of the East Carson River, ranging from 5,200 to 11,000 feet. The supply of water is ample for reservoir purposes. The ridges are steep-sided and broken; the valleys are of two kinds, narrow and with comparatively gentle slopes; and broad, open, and flat in the higher portions.

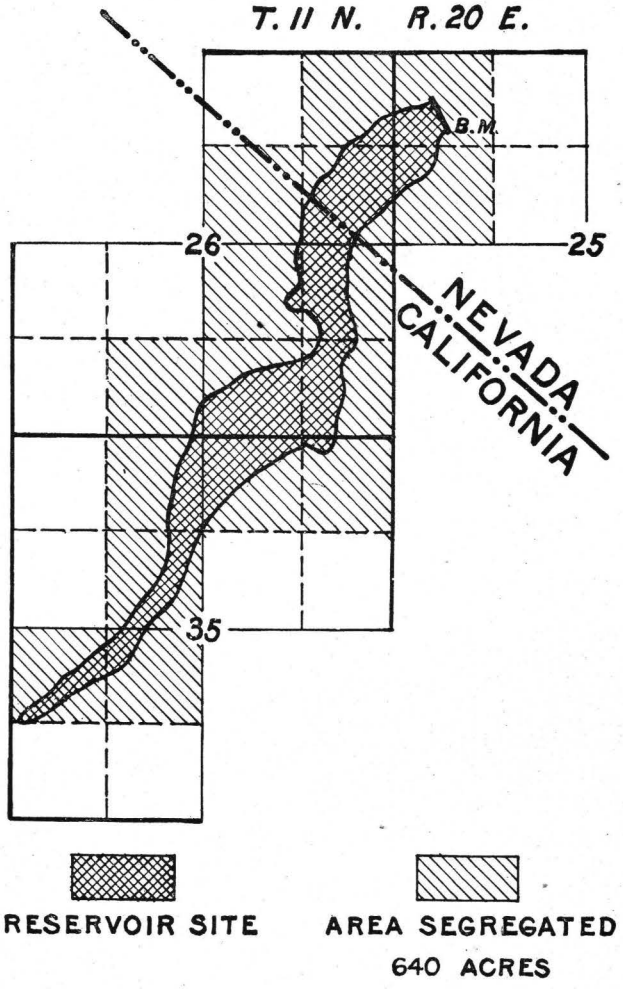


Fig. 108.—Reservoir Site No. 39, known as Youngs Crossing, situated on the East Fork of the Carson River, near Woodford's.

Reservoir site is in T. 11 N., R. 20 E., Secs. 25, 26, and 35.

The dam is in the NW. ¼, Sec. 25, T. 11 N., R. 20 E.

Height of dam 60 feet.

Bench mark, marked U. S. G. S. B. M., is on a rock near a mound of stone, and has an approximate altitude of 5,200 feet.

The top contour has the same altitude as the bench mark.

The area inclosed by the top contour is 150 acres.

The approximate content of reservoir is 3,370 acre-feet.

Materials for construction can be found at no great distance from the site, timber being obtainable higher up on the Carson drainage.

Land Office records show reservoir site to all public land.

The irrigable lands controlled by this site are in Carson Valley.

Lands segregated for reservoir.

					Acres.
W. ½ NW. ¼	Sec. 25,	T. 11 N.,	R. 20 E.		80
E. ½ NE. ¼	26	11	20		80
SW. ¼ NE. ¼	26	11	20		40
SE. ¼	26	11	20		160
SE. ¼ SW. ¼	26	11	20		40
N. ½ NE. ¼	35	11	20		80
E. ½ NW. ¼	35	11	20		80
N. ½ SW. ¼	35	11	20		80
Area segregated					640

Land Office records show area segregated to be all public land.

Reservoir Site No. 40.

Known as Grass Lake, and is situated north of Luther's Pass in Alpine County, California.

The drainage area of this site is extremely small. The snowfall upon the site and in the immediate vicinity is ample to supply water during most seasons. The elevation ranges from 7,800 to 9,500 feet. The summits are flat and rolling, the ridge sides are steep and rough.

Reservoir site is in T. 11 N., R. 18 E., Secs. 14, 15, 22, 23, 24, Mount Diablo meridian.

Dam is in NE. ¼, Sec. 15, T. 11 N., R. 18 E.

Height of dam, 30 feet.

Bench mark is on a stone at north end of dam, and has an approximate altitude of 7,800 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 350 acres.

The content of reservoir is 4,000 acre-feet (approximately).

Material for construction of dam can be found in the immediate vicinity, the supply of timber and rock being ample.

The Land Office records show that part of the reservoir has been filed upon.

The lands controlled by this site are in Carson Valley on the east and Lake Valley on the west.

Lands segregated for reservoir.

					Acres.
SE. ¼	Sec. 15,	T. 11 N.,	R. 18 E.		160
N. ½ NE. ¼	22	11	18		80
S. ½ SW. ¼	14	11	18		80
NW. ¼ SW. ¼	14	11	18		40
S. ½ SE. ¼	14	11	18		80
N. ½ NW. ¼	23	11	18		80
SE ¼ NW. ¼	23	11	18		40
NE. ¼	23	11	18		160
N. ½ SE. ¼	23	11	18		80
W. ½ NW. ¼	24	11	18		80
NW. ¼ SW. ¼	24	11	18		40
Area segregated					920

Action affecting titles to lands segregated for Reservoir Site No. 40 has been taken as follows:

Deeded to State, October 15, 1875:

				Acres.
SW. ¼ SE. ¼ Sec.	15,	T. 11 N.,	R. 18 E.	40
N. ½ NE. ¼	22	11	18	80
NE. ¼	23	11	18	160
E. ½ NW. ¼	23	11	18	80
NW. ¼ NW. ¼	23	11	18	40
				400

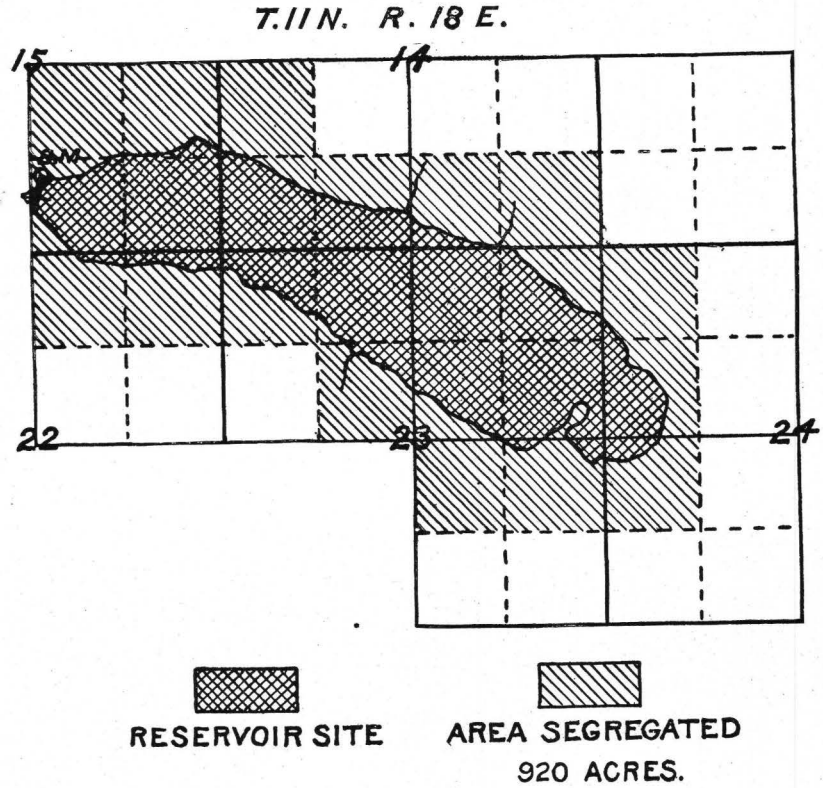


FIG. 109.—Reservoir Site No. 40, Grass Lake, situated on divide between Upper Truckee River and Hope Valley.

RESERVOIR SITE NO. 41.

Known as Hope Valley, situated on the west fork of the Carson River, in California.

The drainage basin is of large extent, reaching to the crest of Sierra Nevada Mountains, and ranging from 5,000 to 12,000 feet in altitude. An ample supply of water to fill the reservoir is assured.

Reservoir site is situated in Ts. 10 and 11 N., Rs. 18 and 19 E.

The dam is in lots 9 and 2 of Sec. 25, T. 11 N., R. 18 E.

Dam is 150 feet high.

Bench mark on pine tree on north side of river about 50 yards above dam site.

Top contour same altitude as bench mark.
Area inclosed, 2,400 acres.
Content of reservoir not estimated.
Material for construction of dam in immediate vicinity.
Land Office records show about one-third of reservoir site to be public land.
Irrigable lands lower down river valley.

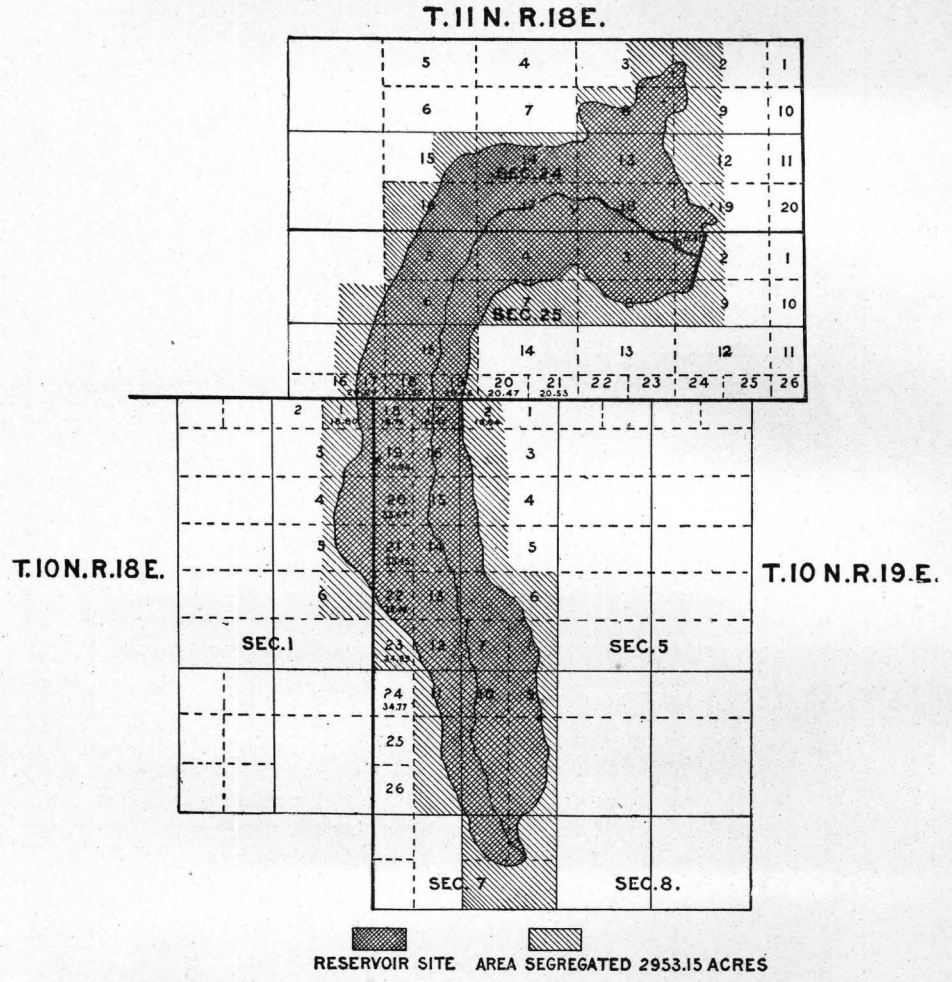


FIG. 110.—Reservoir site No. 41, known as Hope Valley, situated along west fork of Carson River.

Lands segregated for reservoir.

					Acres.
W. ½ lot	2, Sec.	24,	T. 11 N.,	R. 18 E	40·00
E. ½ lot	3	24	11	18	40·00
W. ½ lot	9	24	11	18	40·00
Lot	8	24	11	18	80·00
E. ½ lot	7	24	11	18	40·00
E. ½ lot	15	24	11	18	40·00

				Acres.
Lot 14, Sec.	24,	T. 11 N.,	R. 18 E	80·00
Lot 13	24	11	18	80·00
W. ½ lot 12	24	11	18	40·00
W. ½ lot 19	24	11	18	40·00
Lot 18	24	11	18	80·00
Lot 17	24	11	18	80·00
Lot 16	24	11	18	80·00
Lot 5	25	11	18	80·00
Lot 4	25	11	18	80·00
Lot 3	25	11	18	80·00
W. ½ lot 2	25	11	18	40·00
W. ½ lot 9	25	11	18	40·00
Lot 8	25	11	18	80·00
Lot 7	25	11	18	80·00
Lot 6	25	11	18	80·00
SE. ¼ of NW. ¼	25	11	18	40·00
NE. ¼ of SW. ¼	25	11	18	40·00
Lot 15	25	11	18	80·00
Lot 17	25	11	18	20·29
Lot 18	25	11	18	20·35
Lot 19	25	11	18	20·46
Lot 1	1	10	18	18·80
E. ½ lot 3	1	10	18	40·00
E. ½ lot 4	1	10	18	40·00
E. ½ lot 5	1	10	18	40·00
E. ½ lot 6	1	10	18	40·00
Lot 2	6	10	19	18·64
Lot 17	6	10	19	18·62
Lot 18	6	10	19	18·76
Lot 19	6	10	19	35·90
Lot 16	6	10	19	40·00
W. ½ lot 3	6	10	19	40·00
W. ½ lot 4	6	10	19	40·00
Lot 15	6	10	19	40·00
Lot 20	6	10	19	35·67
Lot 21	6	10	19	35·45
Lot 14	6	10	19	40·00
W. ½ lot 5	6	10	19	40·00
Lot 6	6	10	19	80·00
Lot 13	6	10	19	40·00
Lot 22	6	10	19	35·22
Lot 23	6	10	19	34·99
Lot 12	6	10	19	40·00
Lot 7	6	10	19	40·00
Lot 8	6	10	19	40·00
Lot 9	6	10	19	40·00
Lot 10	6	10	19	40·00
Lot 11	6	10	19	40·00
E. ½ of SW. ¼	6	10	19	80·00
SE. ¼	6	10	19	160·00
NE. ¼	7	10	19	160·00
Area segregated				2,953·15

Action affecting title to lands reserved for Reservoir Site No. 41 has been taken as follows:

						Acres.
W. ½ lot	2,	Sec. 24,	T. 11	N., R. 18	E. (patented November 3, 1876)	40·00
E. ½ lot	8	24	11	18	(patented November 3, 1876)	40·00
W. ½ lot	9	24	11	18	(patented November 3, 1876)	40·00
Lot	14	24	11	18	(deeded to State October 15, 1875)	80·00
E. ½ lot	15	24	11	18	(deeded to State October 15, 1875)	40·00
E. ½ lot	17	24	11	18	(deeded to State October 15, 1875)	40·00
Lot	13	24	11	18	(patented February 11, 1876)	80·00
Lot	18	24	11	18	(patented February 11, 1876)	80·00
E. ½ lot	16	24	11	18	(homestead July 8, 1878)	40·00
W. ½ lot	17	24	11	18	(homestead July 8, 1878)	40·00
W. ½ lot	16	24	11	18	(patented August 22, 1878)	40·00
W. ½ lot	5	25	11	18	(patented August 22, 1878)	40·00
W. ½ lot	2	25	11	18	(patented February 9, 1876)	40·00
Lot	3	25	11	18	(patented February 9, 1876)	80·00
Lot	4	25	11	18	(patented February 11, 1876)	80·00
E ½ lot	5	25	11	18	(patented February 11, 1876)	40·00
E ½ lot	6	25	11	18	(patented February 11, 1876)	40·00
Lot	7	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	10	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	11	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	12	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	13	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	14	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	15	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	16	6	10	19	(deeded to State under act September 28, 1850)	40·00
Lot	17	6	10	19	(deeded to State under act September 28, 1850)	18·62
Lot	18	6	10	19	(deeded to State under act September 28, 1850)	18·76
Lot	19	6	10	19	(deeded to State under act September 28, 1850)	35·90
Lot	20	6	10	19	(deeded to State under act September 28, 1850)	35·67
Lot	21	6	10	19	(deeded to State under act September 28, 1850)	35·45
Lot	22	6	10	19	(deeded to State under act September 28, 1850)	35·22
Lot	23	6	10	19	(deeded to State under act September 28, 1850)	34·99
E. ½ SW. ¼		6	10	19	(homestead October 8, 1887)	80·00
						1,492·61

Reservoir Site No. 42.

Known as Harvey's Meadow, and is situated 2 miles east of Woodford's, near Harvey's Ranch, in Alpine County, California.

The drainage area is limited. The surrounding hills are low and but sparsely timbered. The only certain water supply would be obtained from the West Carson River above Woodford. The elevation ranges from 5,500 to 6,300 feet.

Reservoir site is in Sec. 4, T. 10 N., R. 20 E.

Dam is in lot 3, Sec. 4, T. 10 N., R. 20 E.

Height of dam is 40 feet.

Bench mark—marked U. S. G. S. B. M.—is on a rock near rock pile on east of dam. Approximate altitude, 5,900 feet.

Top contour has same altitude as bench mark.

Area inclosed by top contour is 40 acres.

Approximate content of reservoir is 600 acre-feet.

Rock for construction is obtainable upon the main ridge to the west. Mill timber exists in sufficient quantities near by.

Land Office records show reservoir site to be partially filed upon.

The lands controlled are in Diamond Valley and Dutch Valley.

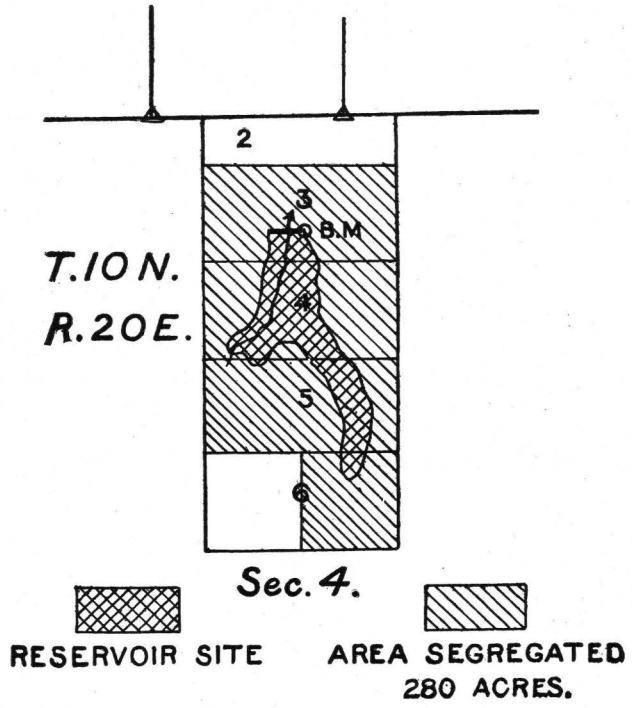


Fig. 111.—Reservoir Site No. 42, known as Harvey's Meadow.

Lands segregated for reservoir.

				Acres.
Lot 3 Sec. 4, T. 10 N., R. 20 E.				80
Lot 4	4	10	20	80
Lot 5	4	10	20	80
E. ½ Lot 6	4	10	20	40
Area segregated				280

Action affecting titles to lands segregated for Reservoir Site No. 42, has been taken as follows:

	Acres.
W. ½ lot 4 Sec. 4, T. 10 N., R. 20 E. (Homestead, September, 1877)	40

Reservoir Site No. 43.

Known as Kirkwood's, in Alpine County, California.

Situated in the upper Sierra, near the Amador road, on a branch of the Silver Fork of the American River. Sufficiently supplied by springs and snow water. Timber near. Drainage basin small. About a mile from the Twin Lakes reservoir site, the drainage from which unites with this drainage about 1½ miles below this site.

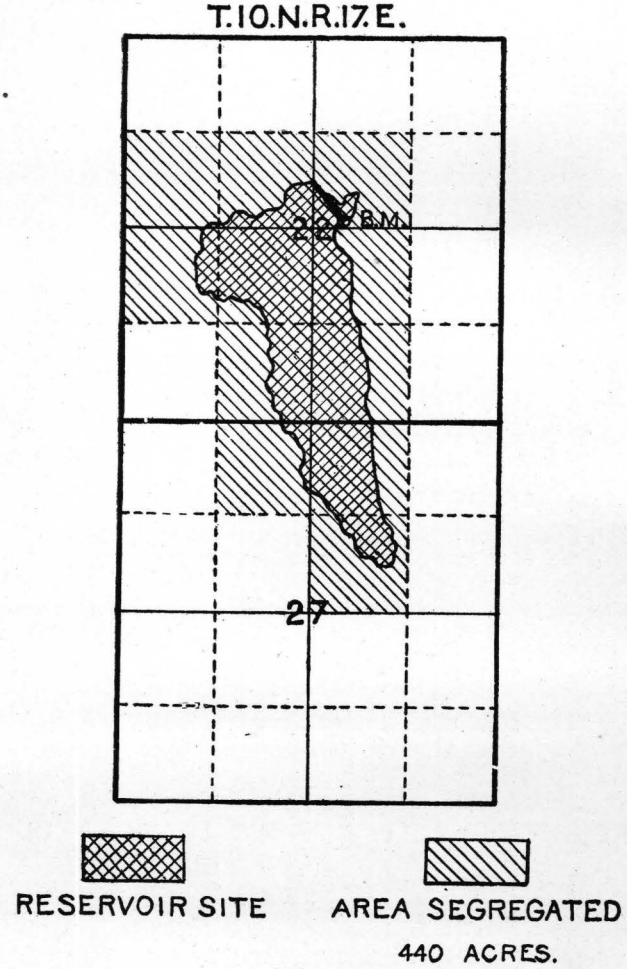


Fig. 112.—Reservoir Site No. 43, at Kirkwood's, on Kirkwood Creek, on south side of the road.

The reservoir site is in T. 10 N., R. 17 E., Sec. 22 and 27.

The dam is in the NE. ¼, Sec. 22, T. 10 N., R. 17 E.

Height of dam is 47 feet.

Bench mark is on a granite bowlder at south end of dam, and has an approximate altitude of 7,800 feet.

The top contour has an altitude the same as that of the bench mark.

The area inclosed by the top contour is 135 acres.

The approximate content of reservoir is 2,400 acre-feet.

Material for construction (good granite and timber) in the immediate vicinity.

Land Office records show the reservoir site to be partially filed upon.

Irrigable lands 50 miles west in the Sacramento Valley, and in the foothills of the Sierra Nevada.

Lands segregated for reservoir.

					Acres.
S. ½ NW. ¼	Sec. 22,	T. 10 N.,	R. 17 E		80
SW. ¼ NE. ¼	22	10	17		40
N. ½ SW. ¼	22	10	17		80
SE. ¼ SW. ¼	22	10	17		40
W. ½ SE. ¼	22	10	17		80
W. ½ NE. ¼	27	10	17		80
NE. ¼ NW. ¼	27	10	17		40
Area segregated					440

Action affecting titles to lands segregated for Reservoir Site No. 43 has been taken as follows:

					Acres.
E. ½ SW. ¼	Sec. 22,	T. 10 N.,	R. 17 E		80
SE. ¼ NW. ¼	22	10	17		40
SW. ¼ NE. ¼	22	10	17	(Homestead, March, 1878)	40
					160

Reservoir Site No. 44.

Known as Twin Lakes, and situated in Alpine County, California.

In the upper Sierras, at an elevation of about 7,900 feet. Well supplied with springs and snow water. The basin well watered during all the year. Timber plentiful. Easy of approach by the Amador road. Near the crest of the Sierras. Near the headwaters of the Silver Fork of the American River.

The reservoir site is in T. 10 N., R. 17 E., Secs. 22 and 23, and in T. 10 N., R. 18 E., Secs. 18, 19, 20, and 30.

The dam is in the NW. ¼, Sec. 19, T. 10 N., R. 18 E.

Height of dam is 30 feet.

Bench mark—marked U. S. G. S. B. M.—is on a large bowlder at southwest end of dam, and has an approximate altitude of 7,900 feet.

The top contour is of the same altitude as bench mark.

Area inclosed by top contour is 420 acres.

Approximate content of reservoir is 4,700 acre-feet.

Materials for construction: Plenty of good granite and timber in the immediate vicinity.

Land Office records show reservoir site to be public land.

Irrigable lands 50 miles west in the Sacramento Valley, and in the foothills of the Sierra Nevada Mountains.

Lands segregated for reservoir.

				Acres.
SE. ¼ NE. ¼	Sec. 22	T. 10 N.,	R 17 E	40·00
S. ½ NW. ¼	23	10	17	80·00
N. ½ SW. ¼	23	10	17	80·00
Lot 2 NE. ¼	23	10	17	7·15
Lot 7 SE. ¼	23	10	17	7·15
SE. ¼ SW. ¼	18	10	18	40·00
NE. ¼	19	10	18	160·00
SE. ¼	19	10	18	160·00

				Acres.
NE. ¼ SW. ¼ Sec.	19	T. 10 N.,	R 18 E	40·00
E. ½ NW. ¼	19	10	18	80·00
Lot 1 NW. ¼	19	10	18	34·85
Lot 8 NW. ¼	19	10	18	34·75
NE. ¼ NE. ¼	20	10	18	40·00
NW. ¼ SW. ¼	20	10	18	40·00
SW. ¼ NW. ¼	20	10	18	40·00
Area segregated				883·90

Land Office records show area segregated to be all public land.

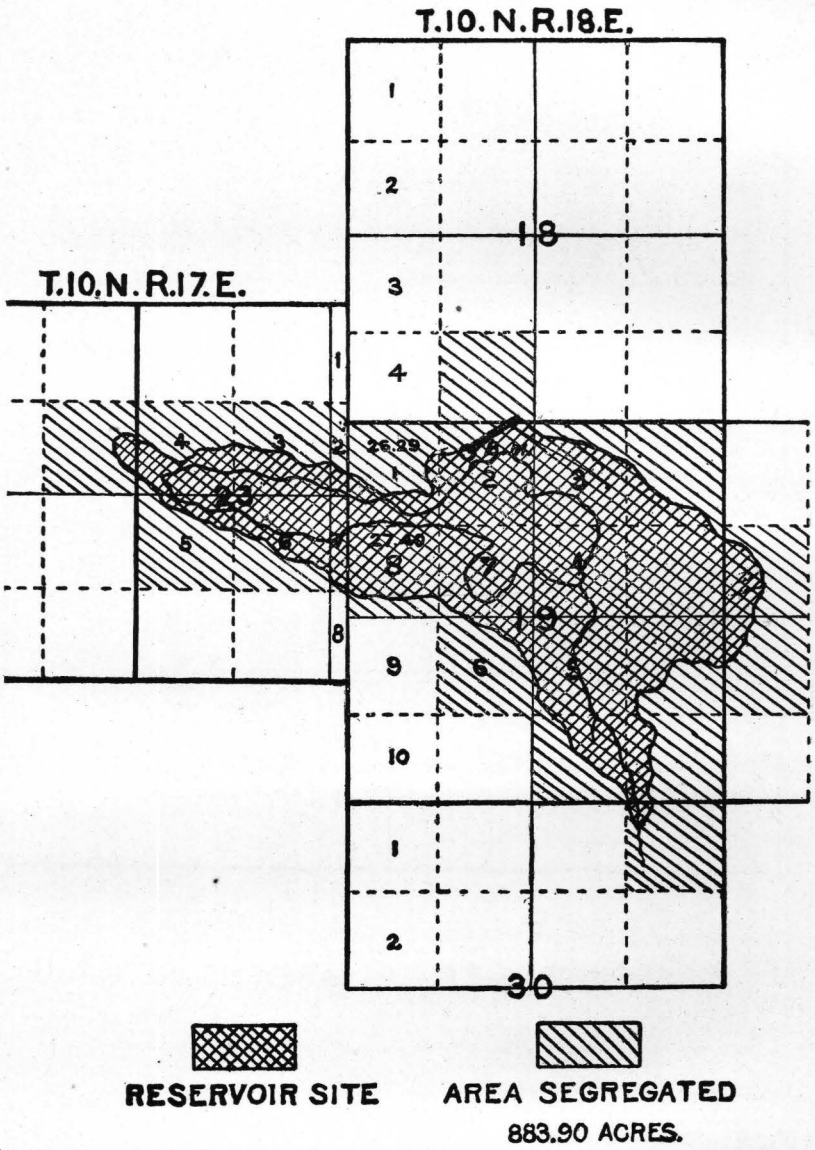


FIG. 113.—Reservoir Site No. 44, known as Twin Lakes. On the Amador road, about half way between Carson Pass and Silver Lake, about 1½ miles east of Kirkwood's.

COLORADO.

RESERVOIR SITES NUMBERED 6, 8 TO 24, 26 TO 37, AND 40 TO 55 INCLUSIVE.

(*Recommended for segregation in letter to Secretary of the Interior, dated February 27, 1891.*)

Reservoir Site No. 6.

Is situated in Chaffee County, Colorado, on Seven Mile Creek, near junction with Arkansas River.

Drainage area about 30 square miles, extending from crest of Park Range nearly to Arkansas River. Lightly wooded on higher slopes. Streams have intermittent flow above, and continuous but light flow through reservoir site.

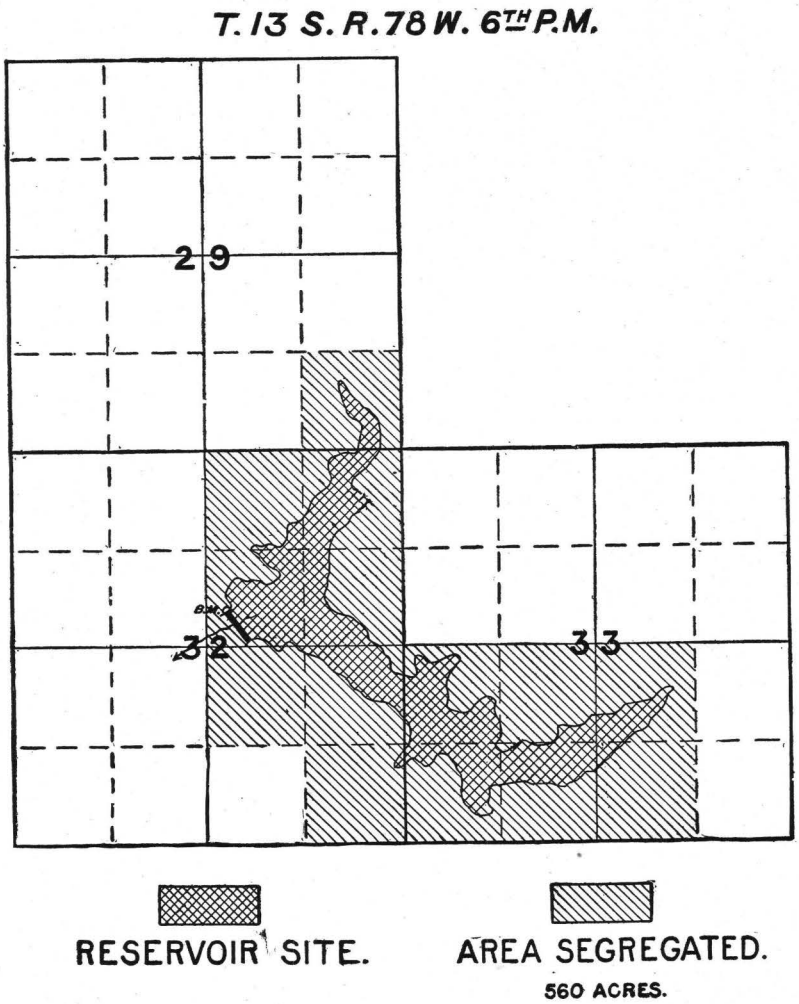


FIG. 114.—Reservoir Site No. 6, on Seven Mile Creek.

Location of site, T. 13 S., R. 78 W., Secs. 29, 32, and 33.
Location of dam, Sec. 32, SW. ¼ of NE. ¼.
Height of dam, 100 feet.

Bench mark at north end of dam crest, a stone marked thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 8,400 feet.

Area of reservoir site, approximately, 160 acres.

Capacity of reservoir, approximately, 4,550 acre-feet.

Material for dam construction near at hand.

No cultivated land, and no buildings on the site.

Irrigable lands along the valley of the Arkansas River.

Lands segregated for reservoir.

					Acres.
SE. ¼ SE. ¼	Sec. 29	T. 13 S.,	R. 78 W		40
NE. ¼	32	13	78		160
N. ½ SE. ¼	32	13	78		80
SE. ¼ SE. ¼	32	13	78		40
SW. ¼	33	13	78		160
W. ½ SE. ¼	33	13	78		80
Area segregated					560

Action affecting titles to lands segregated for Reservoir Site No. 6 has been taken as follows:

					Acres.
SE. ¼ SE. ¼	Sec. 29	T. 13 S.,	R. 78 W.	(preemption February 3, 1885)	40
NE. ¼ NE. ¼	32	13	78 W.	(preemption February 3, 1885)	40
NW. ¼ NE. ¼	32	13	78 W.	(filing July 12, 1881)	40
S. ½ NE. ¼	32	13	78 W.	(filing July 12, 1881)	80
NW. ¼ SE. ¼	32	13	78 W.	(preemption May 14, 1884)	40
NE. ¼ SE. ¼	32	13	78 W.	(filing July 20, 1881)	40
SE. ¼ SE. ¼	32	13	78 W.	(filing July 20, 1881)	40
Mineral section, Leadville mineral entry No. 3446.					
SW. ¼	Sec. 33,	T. 13 S.,	R. 78 W.	(filing November 15, 1882)	160
					480

Reservoir Site No. 8.

Is situated in Custer County, Colorado, on Grape Creek, at northern end of the Wet Mountain Valley. (See Pl. LIV.)

Drainage area about 380 square miles, bordered by the crest of the Sangre de Cristo range for 26 miles, and by the Greenhorn range for 14 miles. Heavily timbered over a small area; lightly wooded over a quarter of the area; and bare of timber over two-thirds of the area. The main stream has strong, continuous flow. Many of the tributaries are intermittent, but furnish large quantities of water during periods of floods.

Location of site, T. 21 S., R. 73 W., Secs. 25, 35, and 36; and T. 21 S., R. 72 W., Secs. 19, 20, 21, 29, 30, and 31; and T. 22, R. 73 W., Secs. 1, 2, and 12.

Location of dam, T. 21 S., R. 72 W., Sec. 20; SE. ¼ NE. ¼, and E. ½ SE. ¼; and Sec. 21, SW. ¼ SW. ¼.

Height of dam, 140 feet.

Bench mark on water line, T. 21 S., R. 73 W., Sec. 36; SE. ¼ SE. ¼; a stone cut thus: B. M. U. S. G. S. 1890. Altitude above sea approximately 8,000 feet.

Area of reservoir site approximately 2,540 acres.

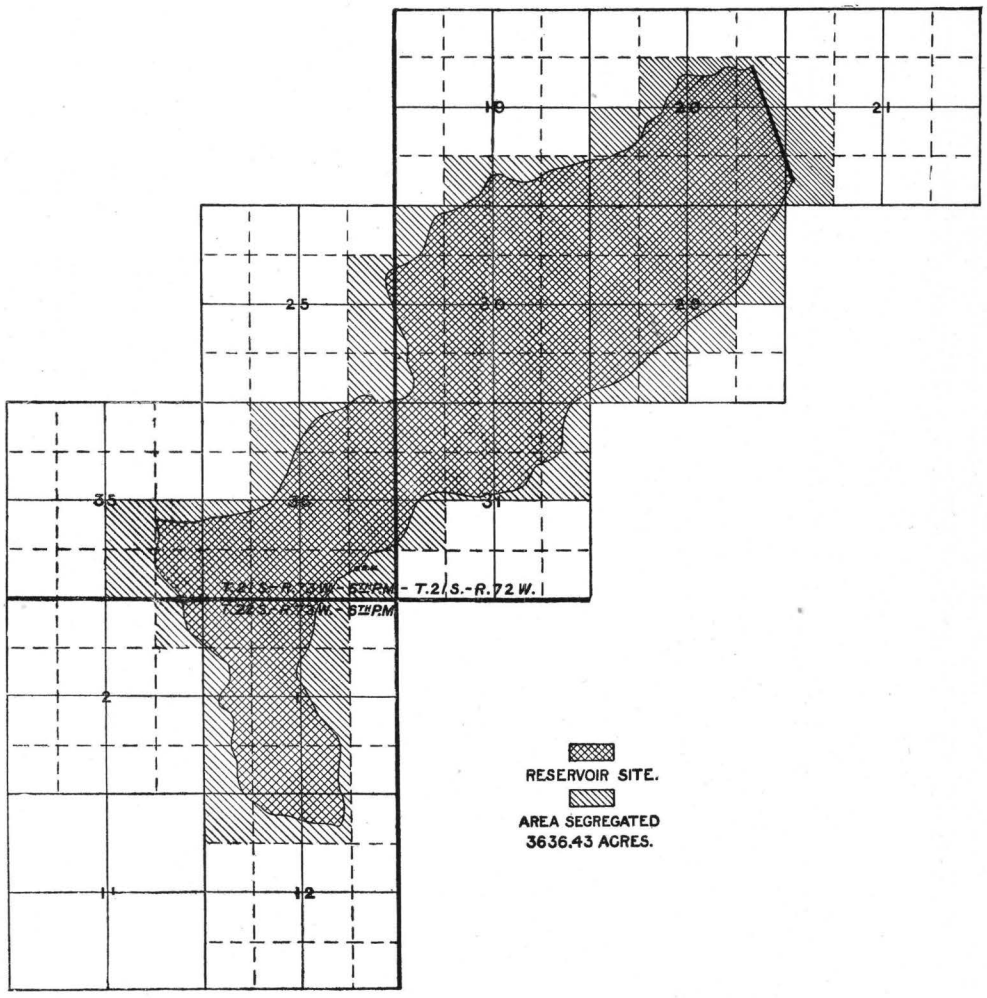
Capacity of reservoir approximately 119,100 acre-feet.

Spillway at end of dam.

Material for dam construction near at hand.

Cultivated land with buildings covers about one-fourth acre of site.

Irrigable lands all lie to the eastward out of the mountains, and between the foothills and the city of Pueblo.



RESERVOIR SITE, COLORADO, NO. 8.

Lands segregated. (*See* Pl. LIV.)

					Acres.
SE. ¼ SW. ¼	Sec. 19,	T. 21 S.,	R. 72 W.		40·00
S. ½ SE. ¼	19	21	72		80·00
S. ½	20	21	72		320·00
S. ½ NE. ¼	20	21	72		80·00
SE. ¼ NW. ¼	20	21	72		40·00
W. ½ SW. ¼	21	21	72		80·00
N. ½	29	21	72		320·00
SW. ¼	29	21	72		160·00
NW. ¼ SE. ¼	29	21	72		40·00
All	30	21	72		633·73
N. ½	31	21	72		320·32
NW. ¼ SW. ¼	31	21	72		41·78
SE. ¼ NE. ¼	25	21	73		40·00
E. ½ SE. ¼	25	21	73		80·00
SE. ¼	35	21	73		160·00
E. ½	36	21	73		320·00
SW. ¼	36	21	73		160·00
E. ½ NW. ¼	36	21	73		80·80
W. ½	1	22	73		320·29
W. ½ NE. ¼	1	22	73		80·07
W. ½ SE. ¼	1	22	73		80·00
NE. ¼ NE. ¼	2	22	73		80·24
N. ½ NW. ¼	12	22	73		80·00
NW. ¼ NE. ¼	12	22	73		40·00
Area segregated					3,636·43

Action affecting title to lands segregated for Reservoir Site No. 8 has been taken as follows:

Mineral land. Pueblo mineral application (in NE. ¼) No. 97. No mineral claims identified. Section 20.

					Acres.
SE. ¼ NW. ¼	Sec. 20,	T. 21 S.,	R. 72 W.	(Filing September 1, 1885	40·00

Mineral land. Pueblo mineral application, No. 97. Section 21.

					Acres.
NW. ¼ NW. ¼	Sec. 29,	T. 21 S.,	R. 72 W.	(homestead September 21, 1885)	40·00
NE. ¼ NW. ¼	29	21	72	(filing August 7, 1877)	40·00
W. ½ NE. ¼	30	21	72	(homestead September 6, 1884)	80·00
E. ½ NE. ¼	30	21	72	(homestead September 21, 1885)	80·00
E. ½ NW. ¼	30	21	72	(homestead September 6, 1884)	80·00
NW. ¼ NW. ¼	30	21	72	(homestead September 21, 1885)	37·90
N. ½ SW. ¼	30	21	72	(preemption March 7, 1878)	78·61
S. ½ SW. ¼	30	21	72	(preemption December 6, 1878)	78·92
W. ½ SE. ¼	30	21	72	(preemption March 7, 1878)	80·00
N. ½ NW. ¼	31	21	72	(preemption December 6, 1878)	79·62
S. ½ SE. ¼	35	21	73	(preemption September 3, 1873)	80·00
NE. ¼ SE. ¼	35	21	73	(preemption September 3, 1873)	40·00
NW. ¼ SE. ¼	35	21	73	(preemption May 25, 1877)	40·00
N. ½ NE. ¼	36	21	73	(preemption May 8, 1882)	80·00
SE. ¼ NE. ¼	36	21	73	(preemption May 8, 1882)	40·00
SW. ¼ NE. ¼	36	21	73	(preemption March 1, 1876)	40·00
NE. ¼ SE. ¼	36	21	73	(preemption May 8, 1882)	40·00
NW. ¼ SE. ¼	36	21	73	(preemption March 1, 1876)	40·00
E. ½ SW. ¼	36	21	73	(preemption March 1, 1876)	80·00
W. ½ SW. ¼	36	21	73	(homestead June 12, 1878)	80·00

					Acres.
N. ½ NW. ¼	Sec. 1,	T. 22 S.,	R. 73 W	(homestead June 12, 1878)	80·00
S. ½ NW. ¼	1	22	73	(preemption April24, 1874)	80·00
N. ½ SW. ¼	1	21	73	(preemption April 24, 1874	80·00
S. ½ SW. ¼	1	21	73	(preemption March 25, 1878)	80·00
W. ½ NE. ¼	1	22	73	(preemption September 24, 1888)	80·07
NW. ¼ SE. ¼	1	22	73	(preemption July 6, 1875)	40·00
NE. ¼ NE. ¼	2	22	73	(homestead February 24, 1879)	30·24
N. ½ NW. ¼	12	22	73	(preemption November 7, 1873)	80·00
NW. ¼ NE. ¼	12	22	73	(preemption November 7, 1873)	40·00
					1,875·36

RESERVOIR SITE NO. 9.

Is situated in Fremont County, Colorado, on Pine Creek, 3 miles above junction with Grape Creek.

Drainage area about 30 square miles, in wooded hills. Stream has light continuous flow.

Location of site, T. 20 S., R. 72 W., Secs. 2 and 3.

Location of dam, Sec. 2, NW. ¼ of NE. ¼.

Height of dam, 100 feet.

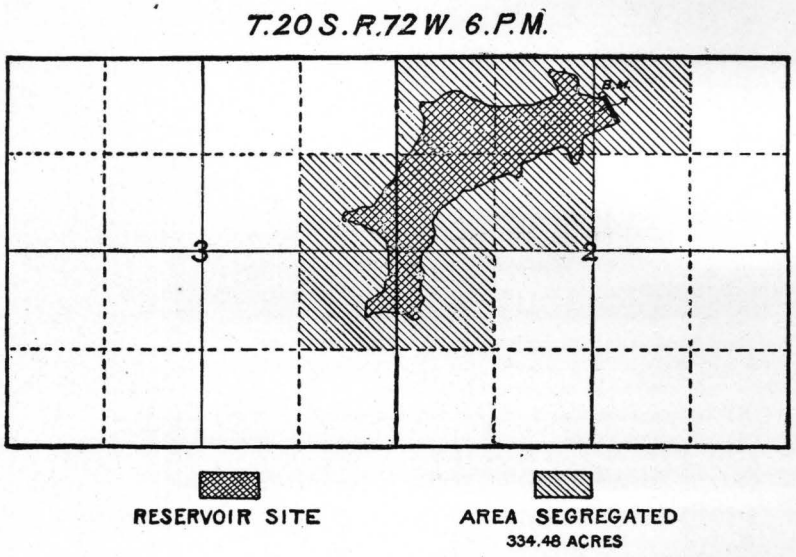


FIG. 115.—Reservoir Site No. 9, on Pine Creek.

Bench mark at north end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately 7,900 feet.

Area of reservoir site approximately 80 acres.

Capacity of reservoir approximately 1,520 acre-feet.

Spillway at end of dam.

Material for dam construction at the site.

No cultivated land and no buildings on site.

Irrigable lands beyond the mountains in the Arkansas Valley.

Lands segregated for reservoir.

				Acres.
NW. ¼ NE. ¼	Sec. 2,	T. 20 S.,	R. 72 W	44·26
NW. ¼	2	20	72	170·22
NW. ¼ SW. ¼	2	20	72	40·00
SE. ¼ NE. ¼	3	20	72	40·00
NE. ¼ SE. ¼	3	20	72	40·00
Area segregated				334·48

Action affecting titles to lands segregated for Reservoir Site No. 9 has been taken as follows:

					Acres.
SW. ¼ NW. ¼	Sec. 2,	T. 20 S.,	R. 72 W.	(pre-emption Sept. 11, 1872)	40
NW. ¼ SW. ¼	2	20	72	(pre-emption Sept. 11, 1872)	40
SE. ¼ NE. ¼	3	20	72	(pre-emption Sept. 11, 1872)	40
NE. ¼ SE. ¼	3	20	72	(pre-emption Sept. 11, 1872)	40
					160

Reservoir Site No. 10.

Situated in Park and El Paso counties, Colorado, on Slate Creek, just above junction with West Oil Creek.

Drainage area about 25 square miles in wooded hills. Stream has light continuous flow.

Location of site, T. 14 S., R. 71 W., Secs. 26, 27, 34, and 35, and T. 15 S., R. 71 W., Secs. 2 and 3.

Location of dam, T. 15 S., R. 71 W., Sec. 2, SE. ¼ of NW ¼.

Height of dam, 86 feet.

Bench mark at south end of dam crest, a rock cut thus: U. B. M. S. G. S. 1890.

Altitude above sea approximately 8,100 feet.

Area of reservoir site approximately 560 acres.

Capacity of reservoir approximately 8,570 acre-feet.

Spillway over rock 100 yards to southwest of dam

Material for dam construction at the site.

No cultivated land and no buildings on the site.

Irrigable lands within a few miles along the valley of Oil Creek, to southeast.

Lands segregated.

				Acres.
SW. ¼ SW. ¼	Sec. 26,	T. 14 S.,	R. 71 W	40·00
SE. ¼ NE. ¼	27	14	71	40·00
NE. ¼ SE. ¼	27	14	71	40·00
S. ½ SE. ¼	27	14	71	80·00
NW. ¼ NE. ¼	34	14	71	40·00
E. ½ NE. ¼	34	14	71	80·00
E. ½ SE. ¼	34	14	71	80·00
N. ½ NW. ¼	35	14	71	80·00
SW. ¼ NW. ¼	35	14	71	40·00
SW. ¼	35	14	71	160·00
W. ½ NE. ¼	2	15	71	122·63
NW. ¼	2	15	71	246·89
N. ½ SW. ¼	2	15	71	80·00
E. ½ NE. ¼	3	15	71	124·39
NE. ¼ SE. ¼	3	15	71	40·00
Area segregated				1,293·91

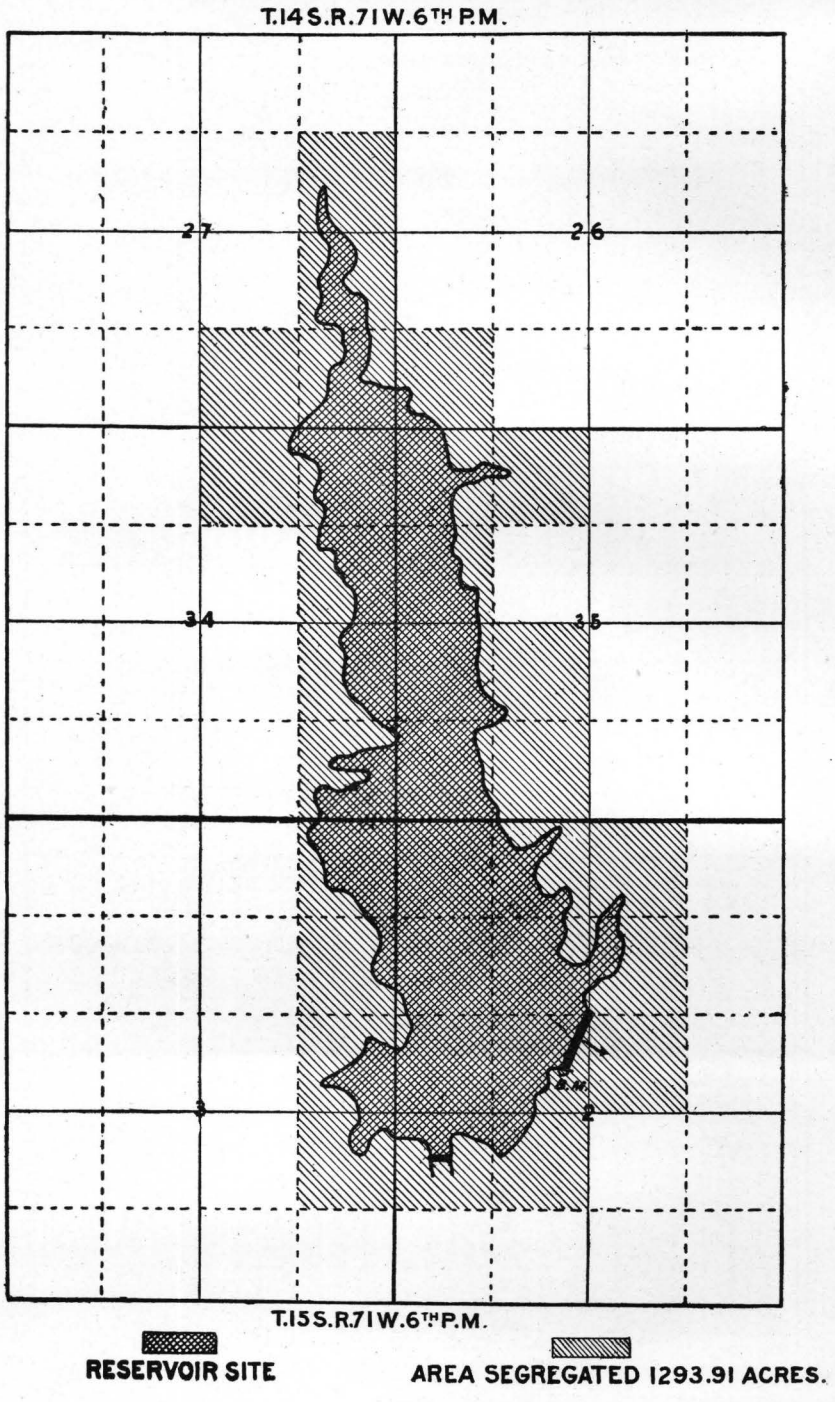


FIG. 116.—Reservoir Site No. 10, on Slate Creek.

Action affecting titles to lands segregated for Reservoir Site No. 10 has been taken as follows:

					Acres.
SE. ¼ NE. ¼	Sec. 34,	T. 14 S.,	R. 71 W.	(homestead Oct. 30, 1886)	40·00
SW. ¼ NW. ¼	35	14	71 W.	(homestead Oct. 30, 1886)	40·00
W. ½ SW. ¼	35	14	71	(homestead Oct. 30, 1886)	80·00
NE. ¼ SE. ¼	3	15	71	(homestead Dec. 21, 1878)	40·00
W. ½ NW. ¼	2	15	71	(preemption July 27, 1875)	83·72
SE. ¼ NW. ¼	2	15	71	(preemption July 27, 1875)	40·00
NE. ¼ SW. ¼	2	15	71	(preemption July 27, 1875)	40·00
NW. ¼ SW. ¼	2	15	71	(homestead Dec. 21, 1878)	40·00
					403·72

RESERVOIR SITE NO. 11.

Situated in Park County, Colorado, on West Oil or Ten Mile Creek.

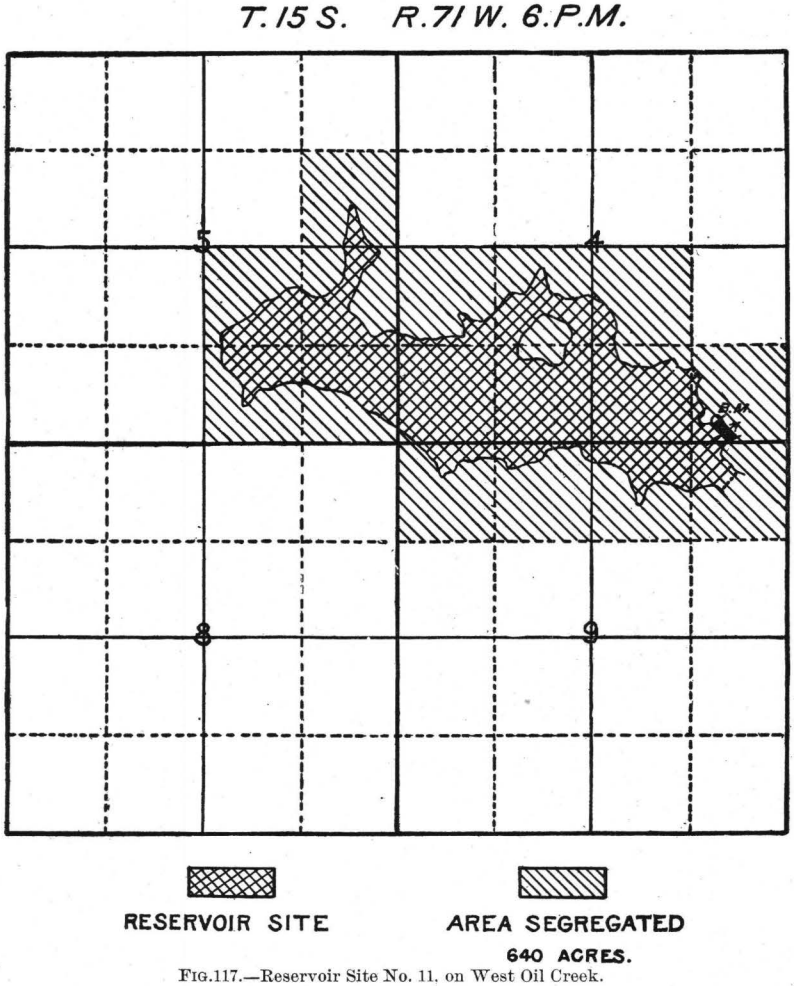


FIG. 117.—Reservoir Site No. 11, on West Oil Creek.

Drainage area about 20 square miles. Heavily timbered. Streams have light continuous flow.

Location of site T. 15 S., R. 71 W., Secs. 5, 4, and 9

Location of dam SE. ¼ of SE. ¼, Sec. 4.

Height of dam, 67 feet.

Bench mark at north end of dam, at flood line, cut it bowlder thus: B. M. U. S. G. S. 1890. Altitude above sea level, approximately, 8,500 feet.

Area of reservoir site, approximately, 200 acres.

Capacity of reservoir, approximately, 2,250 acre-feet.

Spillway north of dam about one-fifth mile over rock, and south of dam same distance over rock.

Material for construction near the site.

Cultivated land over the greater portion of the site.

Irrigable lands to southward, beyond foothills, in Arkansas Valley, about 30 miles distant.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼	Sec. 4,	T. 15 S.,	R. 71 W.		80
NW. ¼ SE. ¼	4	15	71		40
SW. ¼	4	15	71		160
SE. ¼	5	15	71		160
SE. ¼ NE. ¼	5	15	71		40
N. ½ NE. ¼	9	15	71		80
N. ½ NW. ¼	9	15	71		80
Area segregated					640

Action affecting titles to lands segregated for Reservoir Site No. 10 has been taken as follows·

					Acres.
SW. ¼ SE. ¼	Sec. 4,	T. 15 S.,	R. 71 W.	(homestead, March 5, 1883)	40
SE. ¼ SW. ¼	4	15	71	(homestead, March 5, 1883)	40
SW. ¼ SW. ¼	4	15	71	(pre-emption, December 31, 1877)	40
SE. ¼ SE. ¼	5	15	71	(pre-emption, December 31, 1871)	40
W. ½ SE. ¼	5	15	71	(pre-emption, December 31, 1871)	80
NE. ¼ SE. ¼	5	15	71	(filing, April 10, 1871)	40
SE. ¼ NE. ¼	5	15	71	(filing, April 10, 1871)	40
NW. ¼ NE. ¼	9	15	71	(homestead, March 5, 1883)	40
NE. ¼ NW. ¼	9	15	71	(homestead, March 5, 1883)	40
NW. ¼ NW. ¼	9	15	71	(filing, February 12, 1885)	40
					440

RESERVOIR SITE NO. 12.

Is situated in El Paso County, Colorado, on Oil Creek, at junction with West Oil Creek.

Drainage area of about 160 square miles, extending northward to the divide between the Arkansas and Platte Basins. Well wooded, with some heavy timber. Streams have continuous flow.

Location of site, T. 14 S., R. 71 W., Sec. 36; T. 14 S., R. 70 W., Sec. 31; T. 15 S., R. 70 W., Secs. 6 and 7; and T. 15 S., R. 71 W., Secs. 1, 2, 11, and 12.

Location of dam, T. 15 S., R. 70 W., NE. ¼ of SW. ¼, Sec. 7.

Height of dam, 159 feet.

Bench mark at south end of dam-crest line, cut on bowlder thus. B. M. U. S. G. S. 1890.

Altitude above sea level, approximately, 8,500 feet.

Area of reservoir site, approximately, 1,400 acres.

Capacity of reservoir, approximately, 56,200 acre-feet.

Spillway over rock about 100 yards to east of dam.
Material for construction at either end of dam.
Cultivated land over the greater portion of the site.
Irrigable lands beyond the mountains to southward.

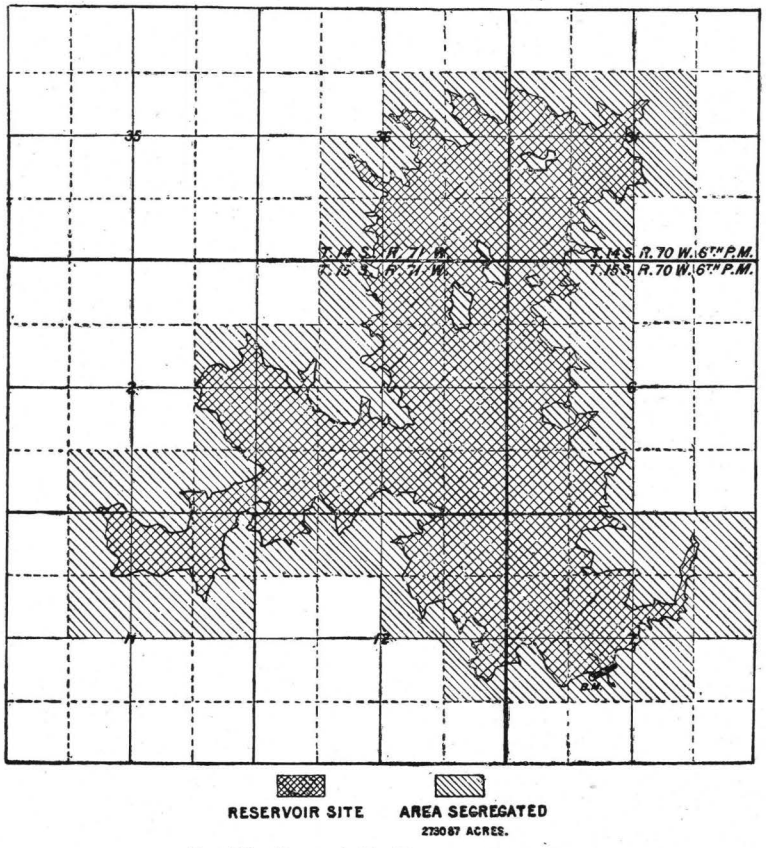


FIG. 118.—Reservoir Site No. 12, on Oil Creek.

Lands segregated.

					Acres.
S.	½ NE. ¼	Sec. 36,	T. 14 S.,	R. 71 W	80·00
	SE. ¼	30	14	71	160·00
E.	½ SW. ¼	36	14	71	80·00
S.	½ NW. ¼	31	14	70	81·97
	SW. ¼	31	14	70	162·96
SW.	¼ NE. ¼	31	14	70	40·00
NW.	¼ SE. ¼	31	14	70	40·00
	NE. ¼	1	15	71	159·77
S.	½ NW. ¼	1	15	71	80·00
NE.	¼ NW. ¼	1	15	71	39·72
	S. ½	1	15	71	320·00
SE.	¼ NE. ¼	2	15	71	40·00
NE.	¼ SE. ¼	2	15	71	40·00

					Acres.
S. ½ SE. ¼	Sec. 2,	T. 15 S.,	R. 71 W.		40·00
SE. ¼ SW. ¼	2	15	71		80·00
NE. ¼	11	15	71		160·00
E. ½ NW. ¼	11	15	71		80·00
N. ½ NW. ¼	12	15	71		80·00
NE. ¼	12	15	71		160·00
NE. ¼ SE. ¼	12	15	71		40·00
W. ½	6	15	70		324·51
N. ½	7	15	70		321·15
N. ½ SW. ¼	7	15	70		80·79
NW. ¼ SE. ¼	7	15	70		40·00
Area segregated					2,730·87

Action affecting titles to lands segregated for Reservoir Site No. 12 has been taken as follows:

					Acres.
SE. ¼ NW. ¼	Sec. 31,	T. 14 S.,	R. 70 W.	(homestead, March 20, 1878)	40·00
N. ½ SW. ¼	31	14	70	(homestead, January 17, 1888)	80·00
SW. ¼ SW. ¼	31	14	71	(homestead, January 17, 1888)	40·00
NE. ¼	1	15	71	(preemption, January 24, 1878)	159·77
N. ½ SE. ¼	1	15	71	(preemption, September 6, 1876)	80·00
S. ½ SE. ¼	1	15	71	(preemption, September 5, 1876)	80·00
N. ½ SW. ¼	1	15	71	(preemption, September 6, 1876)	80·00
NE. ¼ SE. ¼	2	15	71	(preemption, July 27, 1875)	40·00
SW. ¼ SE. ¼	2	15	71	(preemption, July 27, 1875)	40·00
SE. ¼ SW. ¼	2	15	71	(preemption, July 27, 1875)	40·00
N. ½ NE. ¼	12	15	71	(preemption, September 5, 1876)	679·77
SE. ¼ NE. ¼	12	15	71	(preemption, July 25, 1887)	40·00
NE. ¼ SE. ¼	12	15	71	(preemption, July 25, 1887)	40·00
NW. ¼ NW. ¼	6	15	70	(homestead, January 17, 1888)	41·61
SW. ¼ NW. ¼	7	15	70	(preemption, August 24, 1881)	40·68
NW. ¼ SW. ¼	7	15	70	(preemption, August 24, 1881)	40·79
					962·85

Reservoir Site No. 13.

Is situated in El Paso County, Colorado, on West Beaver Creek, near junction with P ver Creek.

Drai age area of about 60 square miles, extending back to the high ridges about Pikes Peak. Heavily wooded. Continuous flow in streams.

Location of site: T. 15 S., R. 69 W., Secs 14, 23, 24, 25, 26, 35, 36, and T. 15 S., R. 68 W., Sec 31.

Location of dam: E. ½ of SE. ¼, Sec 36.

Height of dam, 96 feet.

Bench mark at southern end of dam crest on a bowlder thus: B. M. U. S. G. S. 1890.

Altitude above sea level, approximately, 9,000 feet.

Area of reservoir site, approximately, 1,320 acres.

Capacity of reservoir, approximately, 28,450 acre-feet.

Spillway little to northeast of dam.

Material for construction at either end of dam.

No cultivated land on the site.

Irrigable lands beyond the foothills to southward.

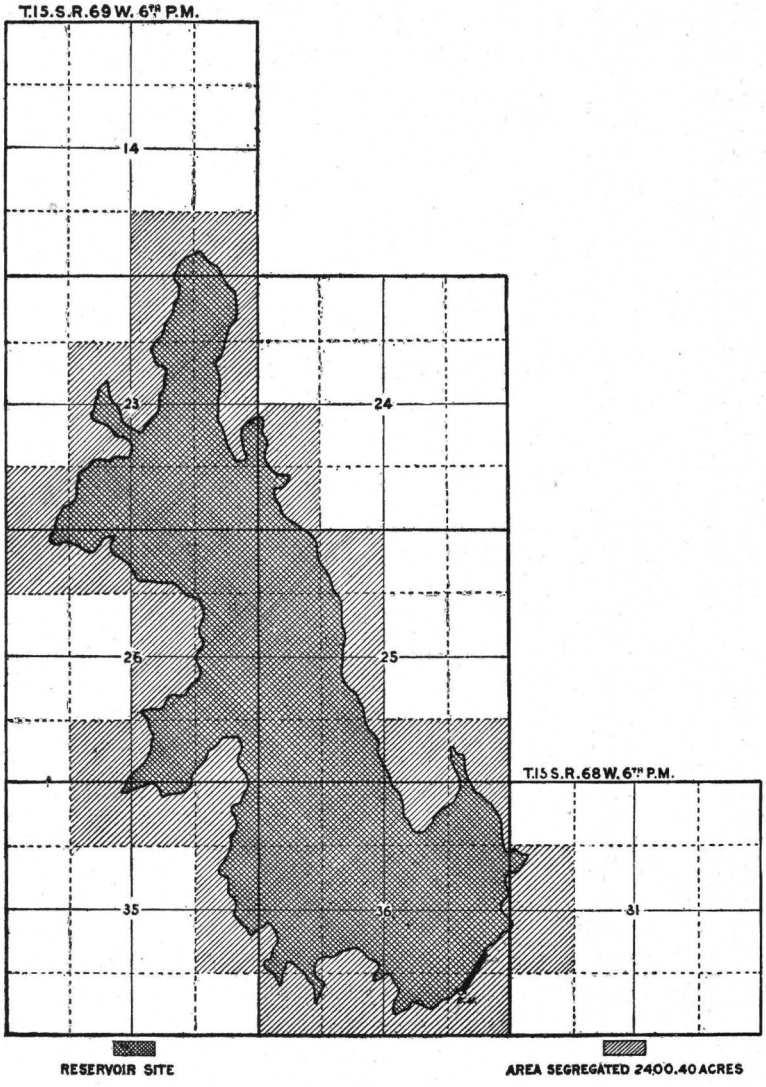


FIG. 119.—Reservoir Site, No. 13, on Beaver Creek, near mouth of West Beaver Creek.

Lands segregated for reservoir.

				Acres.
S. ½ SE. ¼ Sec.	14,	T. 15 S.,	R. 69 W	80·00
E. ½	23	15	69	320·00
SE. ¼ NW. ¼	23	15	69	40·00
E. ½ SW. ¼	23	15	69	80·00
SW. ¼ SW. ¼	23	15	69	40·00
W. ½ SW. ¼	24	15	69	80·00
S. ½ SE. ¼	25	15	69	80·00
W. ½	25	15	69	320·00
E. ½	26	15	69	320·00
N. ½ NW. ¼	26	15	69	80·00

					Acres.
SE. ¼ SW. ¼	Sec. 26,	T. 15 S.,	R. 69 W		40·00
E. ½ NE. ¼	35	15	69		80·00
NW. ¼ NE. ¼	35	15	69		40·00
NE. ¼ NW. ¼	35	15	69		40·00
NE. ¼ SE. ¼	35	15	69		40·00
All	36	15	69		640·00
SW. ¼ NW. ¼	31	15	68		40·25
NW. ¼ SW. ¼	31	15	68		40·15
Area segregated					2, 40040

Action affecting titles to lands segregated for Reservoir Site No. 13 has been taken as follows:

					Acres.
W. ½ NE. ¼	Sec. 23,	T. 15 S.,	R. 69 W.	(preemption December 20, 1882)	80·00
SE. ¼ SE. ¼	23	15	69	(homestead February 7, 1889)	40·00
W. ½ SE. ¼	23	15	69	(preemption December 20, 1882)	80·00
N. ½ NE. ¼	26	15	69	(homestead February 7, 1889)	80·00
SW. ¼ NW. ¼	31	15	68	(homestead September 25, 1889)	40·25
NW. ¼ SW. ¼	31	15	68	(homestead September 25, 1889)	40·15
					360 40

Reservoir Site No. 14.

Is situated in El Paso County, Colorado, on Beaver Creek, near junction with West Beaver Creek.

Drainage area of about 25 square miles, extending back to Pike's Peak. Heavily timbered. Streams have continuous flow.

Location of site, T. 15 S., R. 68 W., Secs. 19, 20, 30, and 29.

Location of dam, NE. ¼ of NE. ¼, Sec. 30; and NW. ¼ of NW. ¼, Sec. 29.

Height of dam, 63 feet.

Bench mark on east end of dam crest, cut on bowlder, thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 9,000 feet.

Area of reservoir site, approximately, 50 acres.

Capacity of reservoir, approximately, 620 acre-feet.

Spillway a little to eastward of dam.

Material for dam construction at either end of dam.

No cultivated land on site.

Irrigable lands out of the mountains to southward.

Lands segregated for reservoir.

				Acres.
SW. ¼ SW. ¼	Sec. 20,	T. 15 S.,	R. 68 W	40
SE. ¼ SE. ¼	19	15	68	40
NW. ¼ NW. ¼	29	15	68	40
NE. ¼ NE. ¼	30	15	68	40
Area segregated				160

Action affecting titles to lands segregated for Reservoir Site No. 14 has been taken as follows:

					Acres.
SW. ¼ SW. ¼	Sec. 20,	T. 15 S.,	R. 68 W.,	(preemption May 9, 1883)	40
SE. ¼ SE. ¼	19,	15	68	(preemption May 9, 1883)	40
					80

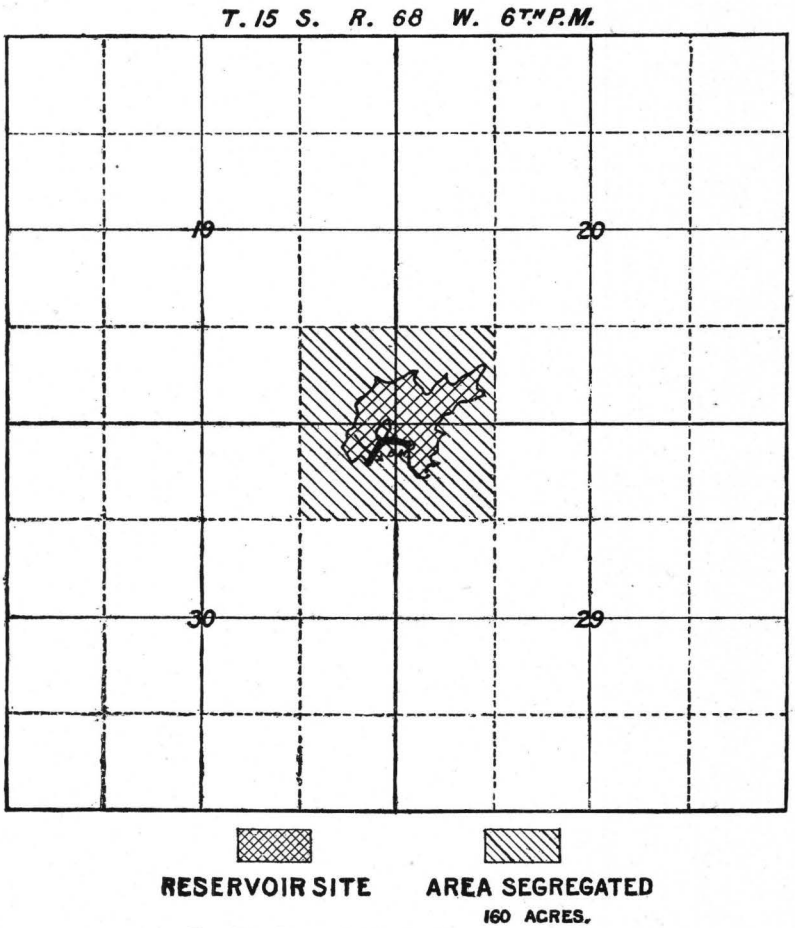


FIG. 120.—Reservoir Site No. 14, on Beaver Creek.

RESERVOIR SITE NO. 15.

Is situated in Fremont County, Colorado, on Oil Creek, about 10 miles above junction with Arkansas River.

Drainage area of about 270 square miles. A semimountainous, well wooded region, with narrow valleys and little agricultural land, extending from Pike's Peak westward to the Arkansas Hills. Oil Creek and its larger branches have continuous flow.

Location of site, T. 17 S., R. 70 W., Secs. 21, 22, 27, and 28.
Location of dam, SW. ¼ of NW. ¼, Sec. 27.
Height of dam, 100 feet.
Bench mark cut on bowlder at east end of dam crest, thus: B. M. U. S. G. S. 1890.
Altitude above sea, approximately, 5,800 feet.
Area of reservoir site, approximately, 167 acres.
Capacity of reservoir, approximately, 4,300 acre-feet.
Spillway at end of dam.
Material for dam construction at the site.
Cultivated land about one-eighth the area of the site.
Irrigable lands to southward, between the foot-hills and the Arkansas River.

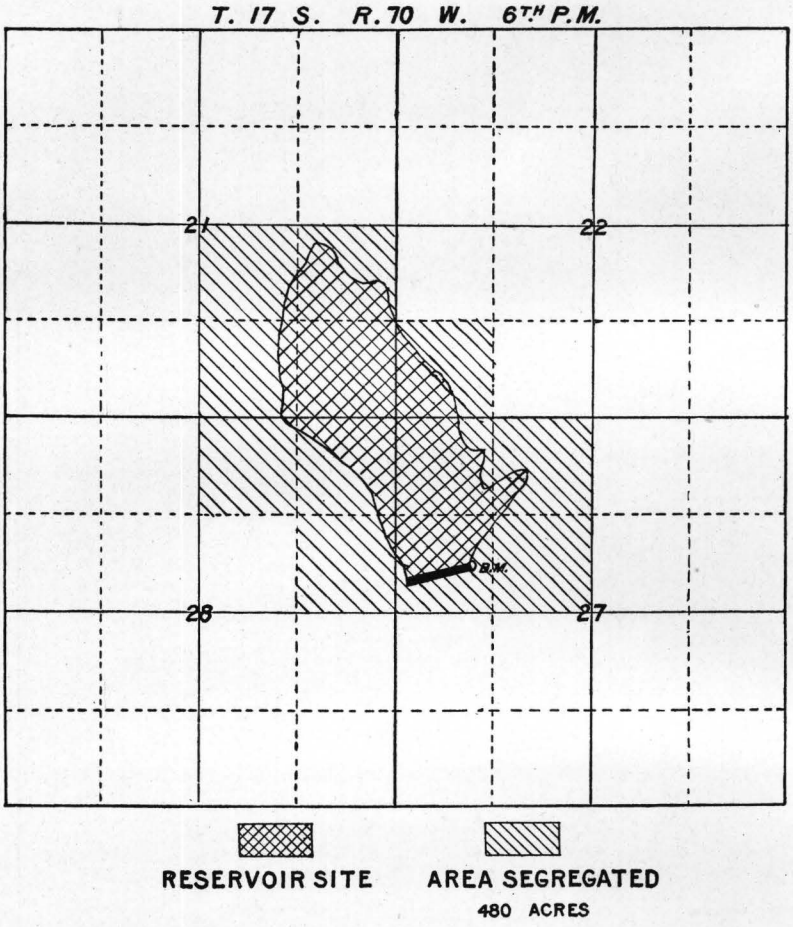


FIG. 121.—Reservoir Site No. 15, on Oil Creek.

Lands segregated for reservoir.

					Acres.
SE. ¼	Sec. 21,	T. 17 S.,	R. 70 W		160
SW. ¼ SW. ¼	22	17	70		40
NW. ¼	27	17	70		160
N. ½ NE. ¼	28	17	70		80
SE. ¼ NE. ¼	28	17	70		40
Area segregated					480

Action affecting titles to lands segregated for Reservoir Site No. 15 has been taken as follows:

					Acres.
SW. ¼ SE. ¼	Sec. 21,	T. 17 S.,	R. 70 W	(preemption February 4, 1873)	40
SE. ¼ SE. ¼	21	17	70	(homestead September 23, 1875)	40
N. ½ SE. ¼	21	17	70	(homestead March 6, 1873)	80
SW. ¼ SW. ¼	22	17	70	(homestead September 23, 1875)	40
W. ½ NW. ¼	27	17	70	(homestead September 23, 1875)	80
N. ½ NE. ¼	28	17	70	(timber culture August 25, 1890)	80
SE. ¼ NE. ¼	28	17	70	(timber culture August 25, 1890)	40
					400

Reservoir Site No. 16.

Is situated in Fremont County, Colorado, on Wilson Creek, just above junction with Oil Creek.

Drainage area, about 35 square miles; mountainous and partly wooded; intermittent flow.

Location of site, T. 18 S., R. 70 W., Secs. 3, 9, and 10.

Location of dam, W. ½ of NE. ¼, Sec. 10.

Height of dam, 90 feet.

Bench mark cut on bowlder at west end of dam crest, thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 5,900 feet.

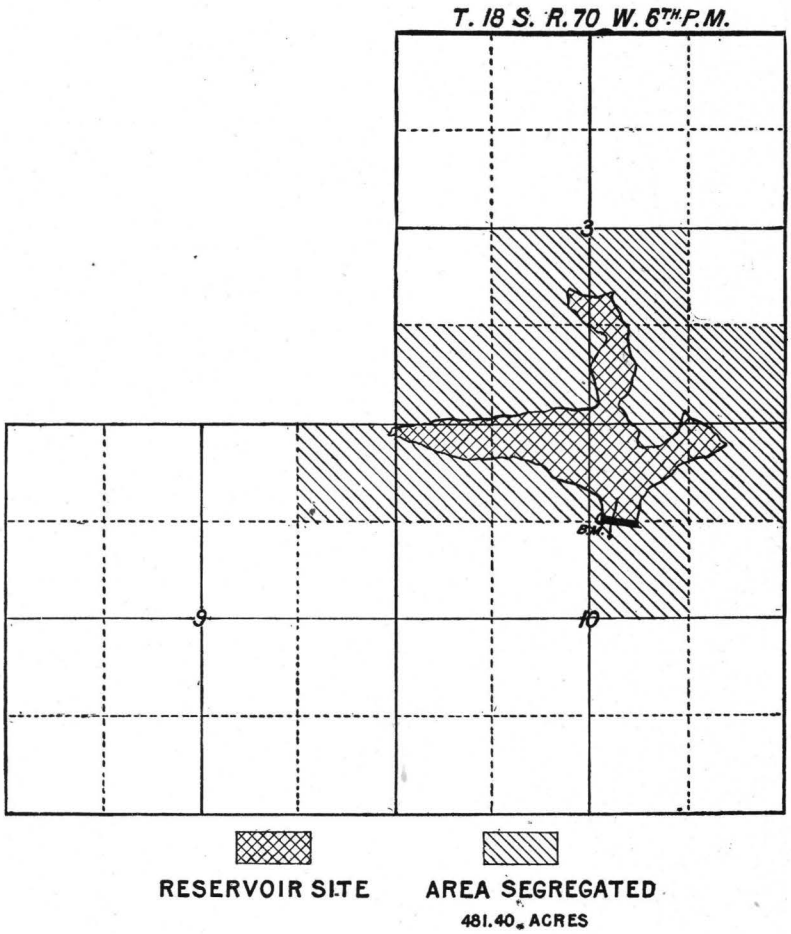


Fig. 122.—Reservoir Site No. 16, on Wilson Creek.

Area of reservoir site, approximately, 80 acres.

Capacity of reservoir, approximately, 2,900 acre-feet.

Spillway at end of dam.

Material for dam construction at the site.

Cultivated land over the greater portion of the site.

Irrigable lands near to the south and east.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼	Sec. 3,	T. 18 S.,	R. 70 W.		80·70
NW. ¼ SE. ¼	3	18	70		40·00
S. ½ SW. ¼	3	18	70		80·70
NE. ¼ SW. ¼	3	18	70		40·00
NE. ¼ NE. ¼	9	18	70		40·00
N. ½ NE. ¼	10	18	70		80·00
SW. ¼ NE. ¼	10	18	70		40·00
N. ½ NW. ¼	10	18	70		80·00
Area segregated					481·40

Action affecting titles to lands segregated for Reservoir Site No. 16 has been taken as follows:

					Acres.
NW. ¼ SE. ¼	Sec. 3,	T. 18 S.,	R. 70 W.	(homestead July 29, 1871)	40·00
SW. ¼ SE. ¼	3	18	70	(homestead October 13, 1869)	40·35
SE. ¼ SE. ¼	3	18	70	(private sale June 4, 1887)	40·35
S. ½ SW. ¼	3	18	70	(preemption December 26, 1865)	80·70
NE. ¼ SW. ¼	3	18	70	(preemption July 29, 1871)	40·00
NE. ¼ NE. ¼	9	18	70	(homestead March 8, 1884)	40·00
NE. ¼ NE. ¼	10	18	70	(private sale June 4, 1887)	40·00
NW. ¼ NE. ¼	10	18	70	(preemption February 7, 1871)	40·00
SW. ¼ NE. ¼	10	18	70	(preemption February 27, 1871)	40·00
NW. ¼ NW. ¼	10	18	70	(homestead March 11, 1871)	40·00
NE. ¼ NW. ¼	10	18	70	(preemption February 27, 1871)	40·00
					401·40

Reservoir Site No. 17.

Is situated in Fremont County, Colorado, on Sand Creek just west of Canyon City, and a little above junction of Sand Creek with the Arkansas River.

Drainage area about 30 square miles; wood all cut off; intermittent flow to streams.

Location of site, T. 18 S., R. 70 W., Sec. 31 and 32.

Location of dam, SE. ¼ of SE. ¼, Sec. 31, and SW. ¼ of SW, ¼, Sec. 32.

Height of dam, 84 feet.

Bench mark at east end of dam cut in rock thus: U. S. G. S. B. M. 1890.

Altitude above sea, approximately, 5,450 feet.

Area of reservoir site, approximately, 115 acres.

Capacity of reservoir, approximately, 1,950 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam.

About one-third of the site is cultivated land.

Irrigable lands lie immediately below and eastward.

Lands segregated for reservoir.

				Acres.
SE. ¼ SE. ¼	Sec. 30,	T. 18 S.,	R. 70 W.	40
E. ½ NE. ¼	31	18	70	80
E. ½ SE. ¼	31	18	70	80
W. ½ NW. ¼	32	18	70	80
W. ½ SW. ¼	32	18	70	80
Area segregated				360

Action affecting titles to lands segregated for Reservoir Site No. 17 has been taken as follows:

					Acres.
SE. ¼ SE. ¼	Sec. 30,	T. 18 S.,	R. 70 W.	(preemption July 18, 1882)	40
NE. ¼ NE. ¼	31	18	70	(filing)	40
SE. ¼ NE. ¼	31	18	70	(preemption April 4, 1882)	40
E. ½ SE. ¼	31	18	70	(preemption July 29, 1871)	80
W. ½ NW. ¼	32	18	70	(homestead October 8, 1869)	80
W. ½ SW. ¼	32	18	70	(preemption November 29, 1865)	80
					360

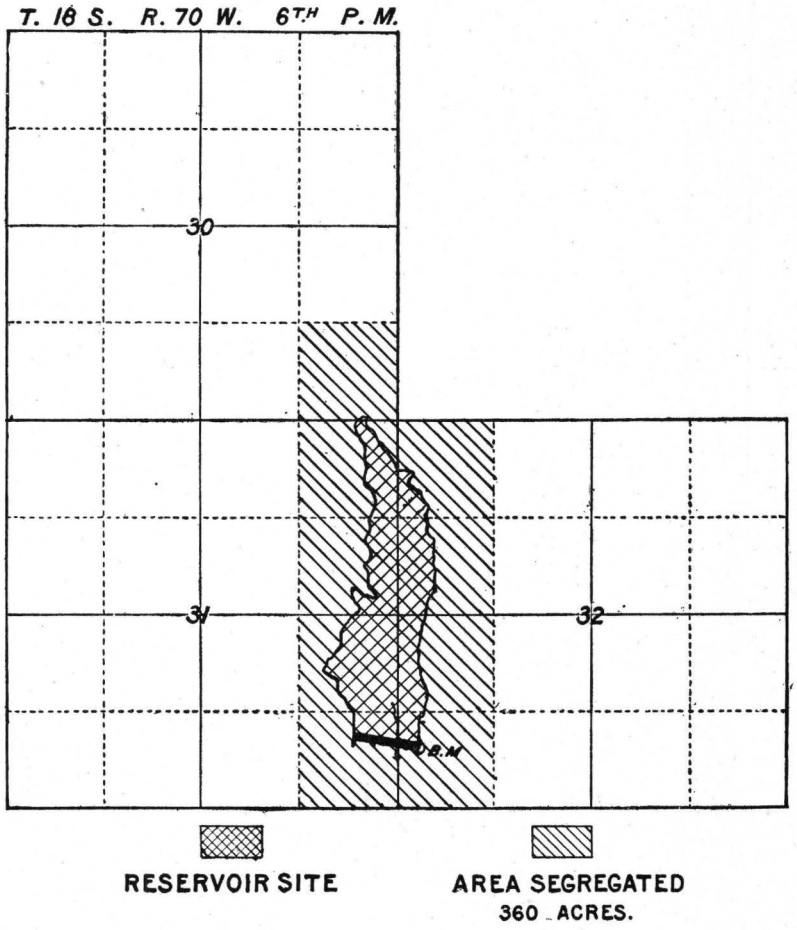


FIG. 123.—Reservoir Site No. 17, on Sand Creek.

Reservoir Site No. 18.

Is situated in Fremont County, Colorado, on Six Mile Creek, about 6 miles above junction with Arkansas River.

Drainage area of about 10 square miles in the Six Mile Creek Basin, and, by diversion, from the Eight Mile Creek Basin 50 square miles, and from the Beaver Creek Basin 120 square miles. All well wooded and rising in elevation northward to the high ridges about Pike's Peak. Intermittent flow through site.

Location of site, T. 18 S., R. 69 W., Secs. 16 and 21.

Location of dam, N. ½ of NW. ¼, Sec. 21.

Height of dam, 100 feet.

Bench mark cut in natural rock at western end of dam crest, thus: B. M. U. S. G. S. 1890.

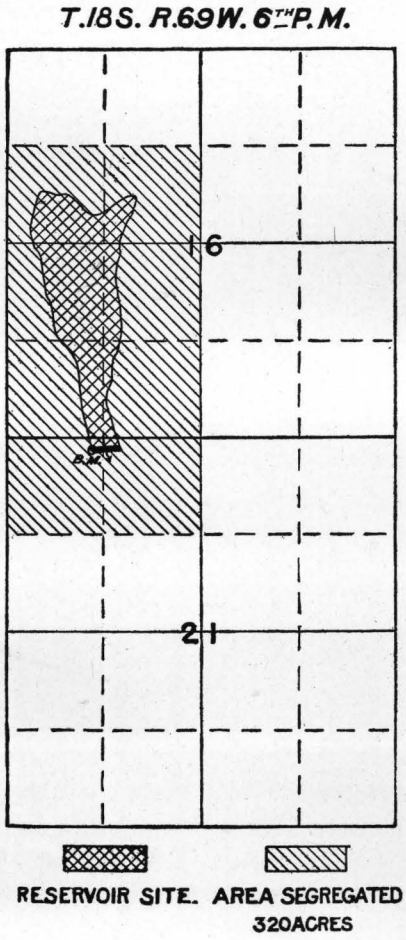


Fig. 124.—Reservoir Site No. 18, on Six Mile Creek.

Altitude above sea, approximately, 5,500 feet.

Area of reservoir site, approximately, 50 acres.

Capacity of reservoir, approximately, 3,100 acre-feet.

Spillway may be removed from dam a short distance by open cut across rock in place, or by short tunnel.

Material for dam construction at the site.
No cultivated land within the area of the site.
Irrigable lands between the foothills and the Arkansas River.

Lands segregated for reservoir.

				Acres.
S. ½ NW. ¼ Sec.	16,	T. 18 S.,	R. 69 W	80
SW. ¼	16	18	69	160
N. ½ NW. ¼	21	18	69	80
Area segregated				320

Action affecting titles to land segregated for Reservoir Site No. 18 has been taken as follows:

NE. ¼ NW. ¼ Sec. 21, T. 18 S., R. 69 W. (preemption December 17, 1879), 40 acres.

Reservoir Site No. 19.

Is situated in Fremont County, Colorado, on Eight Mile Creek, in foothills.
Drainage area about 50 square miles in high foothills. Upper portion lightly wooded. Stream intermittent.
Location of site, T. 18 S., R. 69 W., Secs. 10 and 15.
Location of dam, SW. ¼ of SE. ¼. Sec. 15.
Height of dam, 70 feet.

Bench mark cut on rock in place at eastern end of crest line of dam thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 5,500 feet.
Area of reservoir site, approximately, 210 acres.
Capacity of reservoir, approximately, 4,540 acre-feet.
Spillway at end of dam.
Material for dam construction at the site.
Cultivated land, about one-fifth of the site.
Irrigable lands lie to southward and southeastward; the dry mesas north of Arkansas River.

Lands segregated for reservoir.

				Acres.
N. ½ SE. ¼ Sec.	10,	T. 18 S.,	R. 69 W	80
W. ½ SE. ¼	10	18	69	40
SE. ¼ SW. ¼	10	18	69	40
NW. ¼	15	18	69	160
W. ½ NE. ¼	15	18	69	80
NE. ¼ SW. ¼	15	18	69	40
W. ½ SE. ¼	15	18	69	80
Area segregated				520

Action affecting titles to lands segregated for Reservoir Site No. 19 has been taken as follows:

					Acres.
NW. ¼ SE. ¼ Sec.	10,	T. 18 S.,	R. 69 W.	(timber, November 9, 1885)	40
SW. ¼ SE. ¼	10	18	69	(preemption, February 15, 1877)	40
SE. ¼ SW. ¼	10	18	69	(preemption, February 15, 1877)	40
NW. ¼	15	18	69	(preemption, January 15, 1880)	160
W. ½ NE. ¼	15	18	69	(filing, August 13, 1890)	80
SW. ¼ SE. ¼	15	18	69	(filing, October 15, 1889)	40
NW. ¼ SE. ¼	15	18	69	(filing, November 15, 1886)	40
					440

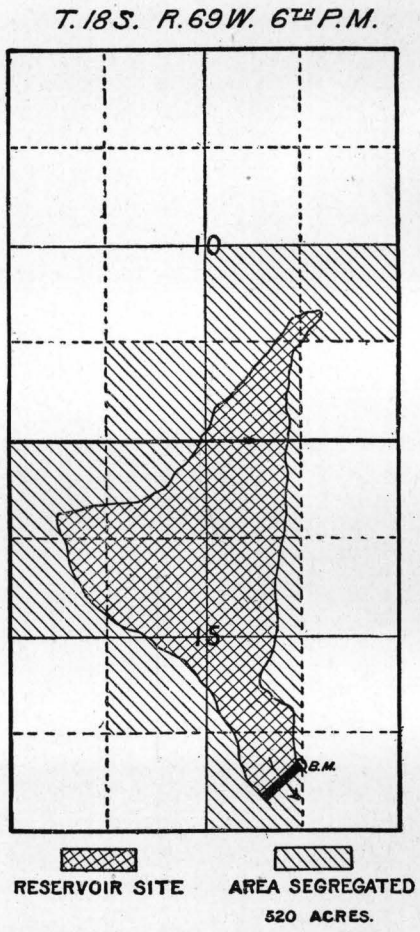


FIG. 125.—Reservoir Site, No. 19, on Eight-Mile Creek.

RESERVOIR SITE NO. 20.

Is situated in Fremont and Pueblo Counties, Colorado, on Beaver Creek, near its junction with the Arkansas River.

Drainage area of about 130 square miles, extending from Pikes Peak to the Arkansas River. For the upper 25 miles it receives tributaries from a mountainous and well timbered region. The main stream and several of its branches have continuous flow. After entering the plains region, and before reaching this reservoir site, all water is usually drawn off in the irrigation season.

Location of site T. 19 S., R. 68 W., Secs. 13 and 24, and T. 19 S., R. 67 W., Secs. 18 and 19.

Location of dam SW. ¼ of SE. ¼ Sec. 24, T. 19 S., R. 68 W.

Bench mark cut on bowlder at north end of dam crest, thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 5,100 feet.

Area of reservoir site, approximately, 215 acres.

Capacity of reservoir, approximately, 7,100 acre-feet.

Spillway at end of dam.

Material for dam construction near at hand.
Land cultivated over the greater part of the site.
Irrigable lands adjacent, to eastward.

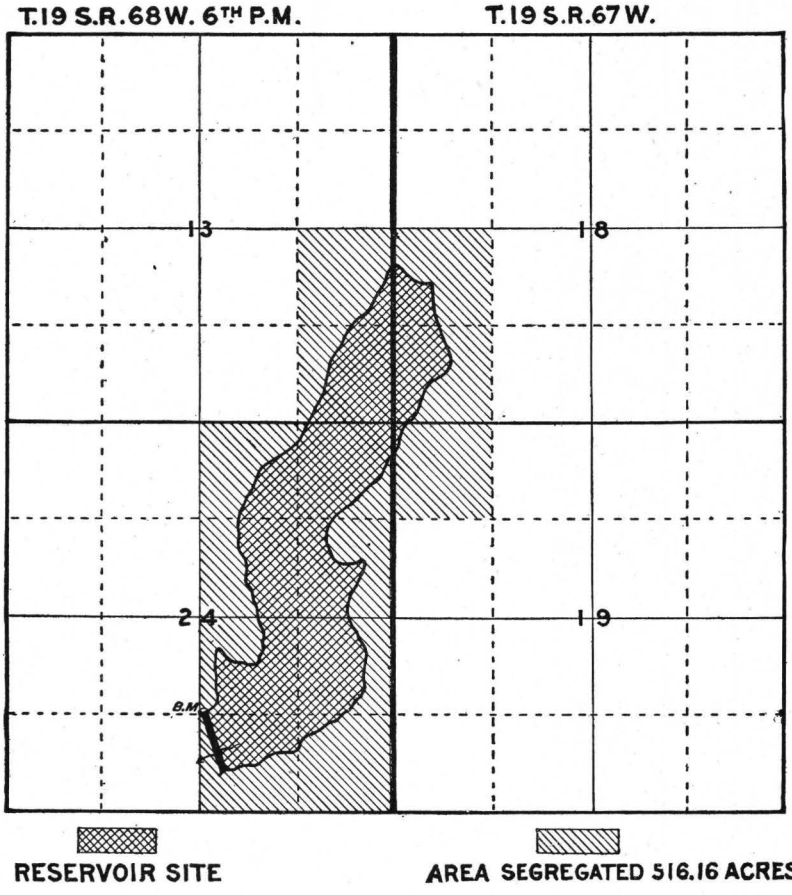


FIG. 126.—Reservoir Site No. 20, on Beaver Creek.

Lands segregated for reservoir.

					Acres.
E. ½ SE. ¼	Sec. 13,	T. 19 S.,	R. 68 W	.....	80·00
NE. ¼	24	19	68	.....	160·00
SE. ¼	24	19	68	.....	160·00
W. ½ SW. ¼	18	19	67	.....	77·50
NW. ¼ NW. ¼	19	19	67	.....	38·66
Area segregated				.....	516·16

Action affecting titles to lands segregated for Reservoir Site No. 20 has been taken as follows:

					Acres.
NE. ¼ SE. ¼	Sec. 13,	T. 19 S.,	R. 68 W	(homestead, August 22, 1876).....	40·00
SE. ¼ SE. ¼	13	19	68	(homestead, February 14, 1872).....	40·00
E. ½ NE. ¼	24	19	68	(homestead, February 14, 1872).....	80·00
SW. ¼ NE. ¼	24	19	68	(homestead, February 14, 1872).....	40·00
NW. ¼ NE. ¼	24	19	68	(private cash sale, June 8, 1887).....	40·00

						Acres.
SE. ¼ SE. ¼	Sec. 24,	T. 19 S.,	R. 68 W		(private cash sale, June 8, 1888)	40·00
N. ½ SE. ¼	24	19	68		(homestead, February 1, 1871)	80·00
SW. ¼ SE. ¼	24	19	68		(homestead, February 17, 1871)	40·00
W. ½ SW. ¼	18	19	67		(homestead, June 27, 1885)	77·50
NW. ¼ NW. ¼	19	19	68		(State school lands)	38·66
						516·16

RESERVOIR SITE NO. 21.

Is situated in Pueblo County, Colorado, on Turkey Creek, just outside of foothills, in a region of low mesas.

Drainage area of about 70 square miles, extending back to the higher ridges of the Pikes Peak group. The mountainous portion is well wooded. Turkey Creek at this point has a light continuous flow:

Location of site, T. 18 S., R. 66 W., Secs. 19, 20, 29, 30, and 31.

Location of dam, SE. ¼ of SW. ¼, Sec. 30, and NE. ¼ of NW. ¼, Sec. 31.

Height of dam, 80 feet.

Bench mark, none. Altitude of crest of dam above sea level, approximately, 5,400 feet.

Area of reservoir site, approximately, 520 acres.

Capacity of reservoir, approximately, 9,800 acre-feet.

Spillway over natural rock ¼-mile distant from dam.

Material for dam construction at the site.

No cultivated land within the reservoir area.

Irrigable lands to southward and southeastward, near at hand.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼	Sec. 19,	T. 18 S.,	R. 66 W		80
SE. ¼ SW. ¼	19	18	66		40
SW. ¼ SW. ¼	20	18	66		40
NW. ¼ NW. ¼	29	18	66		40
S. ½ NW. ¼	29	18	66		80
SW. ¼ SW. ¼	29	18	66		40
N. ½ SW. ¼	29	18	66		80
E. ½	30	18	66		320
E. ½ NW. ¼	30	18	66		80
E. ½ SW. ¼	30	18	66		80
N. ½ .NE ¼	31	18	66		80
NE. ¼ NW. ¼	31	18	66		40
Area segregated					1,000

Action affecting titles to lands segregated for Reservoir Site No. 21 has been taken as follows:

					Acres.
NE. ¼ NW. ¼	Sec. 31,	T. 18 S.,	R. 66 W.	(preemption, June 11, 1883)	40
SW. ¼ SE. ¼	19	18	66	(homestead, March 30, 1887)	40
SE. ¼ SW. ¼	19	18	66	(preemption, June 11, 1883)	40
SW. ¼ NW. ¼	29	18	66	(preemption, September 5, 1888)	40
W. ½ NE. ¼	30	18	66	(preemption, June 11, 1883)	80
E. ½ NE. ¼	30	18	66	(preemption, September 5, 1888)	80
W. ½ SE. ¼	30	18	66	(preemption, June 11, 1883)	80
NE. ¼ SE. ¼	30	18	66	(preemption, September 5, 1888)	40
NE. ¼ NW. ¼	30	18	66	(preemption, June 11, 1883)	40
SE. ¼ SW. ¼	30	18	66	(preemption, June 11, 1883)	40
NW. ¼ NE. ¼	31	18	66	(preemption, June 11, 1883)	40
					560

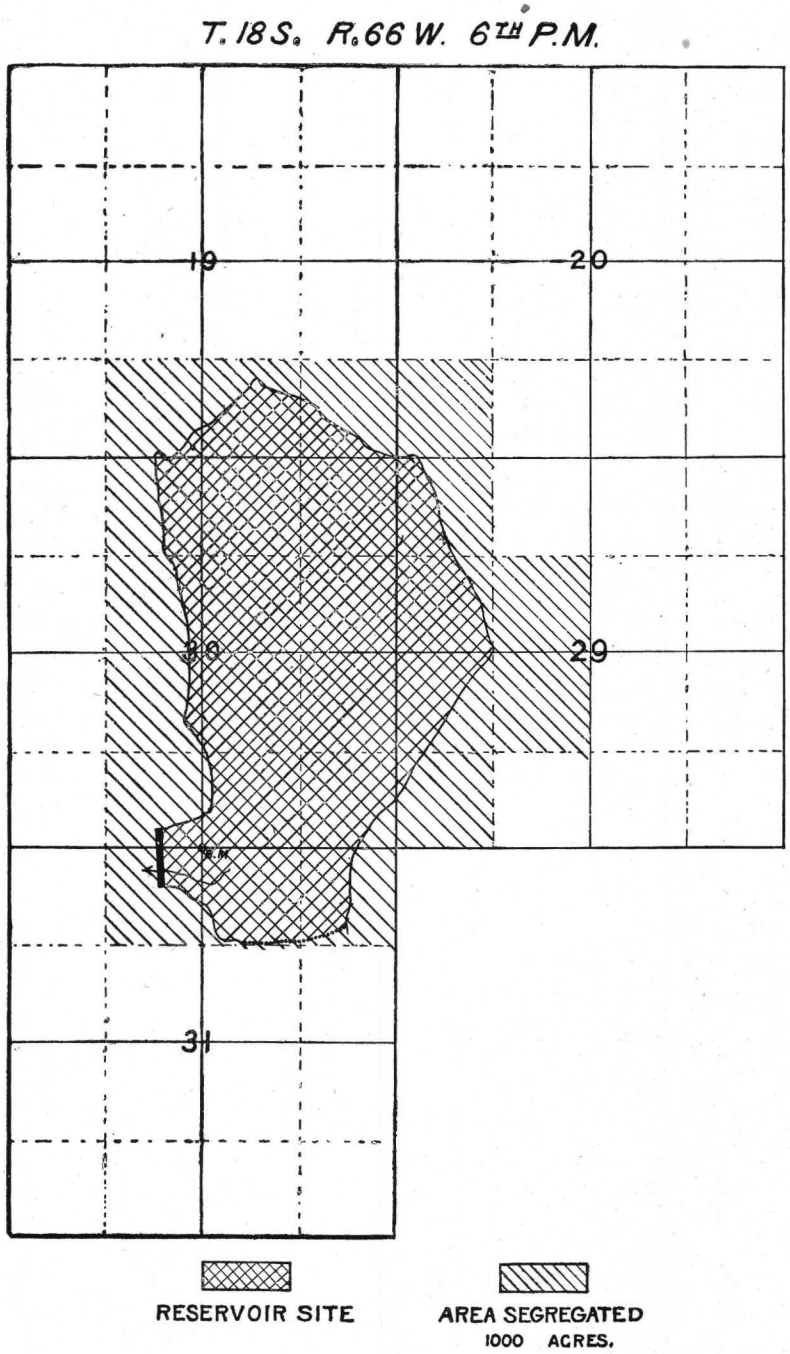


FIG. 127.—Reservoir Site No. 21, on Turkey Creek.

Reservoir Site No. 22.

Is situated in Pueblo County, Colorado, on Turkey Creek, just above junction with Arkansas River.

Drainage area of about 70 square miles, one half mountainous and one half plains. Mountainous portion lightly wooded. Streams have usually a continuous flow.

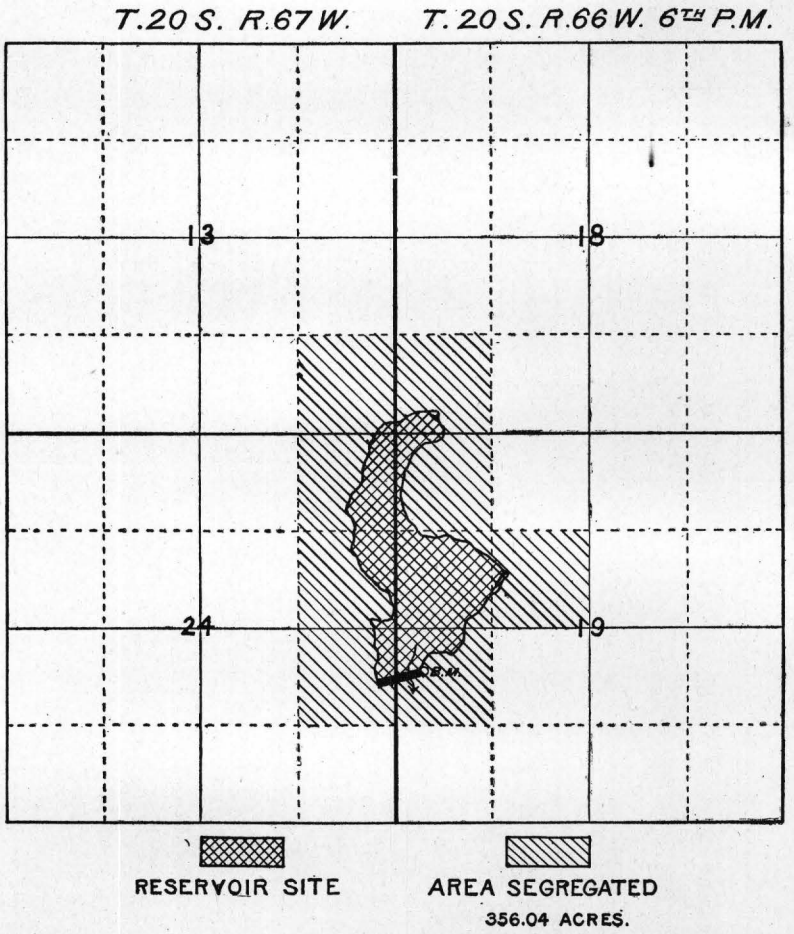


Fig. 128.—Reservoir Site No. 22, on Turkey Creek.

Location of site, T. 20 S., R. 67 W., Secs. 13 and 24; also T. 20 S., R. 66 W., Secs. 18 and 19.

Location of dam, NE. ¼ SE. ¼, Sec. 24, T. 20 S., R. 67 W., and NW. ¼ SW. ¼, Sec. 19 T. 20 S., R. 66 W.

Height of dam, 60 feet.

Bench mark cut on bowlder at eastern end of dam crest line, thus: B. M. U. S. G. S. 1890.

Altitude above sea level, approximately, 5,000 feet.

Area of reservoir site, approximately, 90 acres.

Capacity of reservoir, approximately, 1,920 acre-feet.

Spillway over dam.

Material for dam construction at the site.

Cultivated land, none.

Irrigable lands, none. The site can only be used as a feeder to the Arkansas River during low-water stages.

Lands segregated for reservoir.

					Acres.
SW. ¼ SW. ¼	Sec. 18,	T. 20 S.,	R. 66 W.		38·86
W. ½ NW. ¼	19	20	66		78·04
SE. ¼ NW. ¼	19	20	66		40·00
NW. ¼ SW. ¼	19	20	66		39·14
SE. ¼ SE. ¼	13	20	67		40·00
E. ½ NE. ¼	24	20	67		80·00
NE. ¼ SE. ¼	24	20	67		40·00
Area segregated					356·04

Action affecting titles to lands segregated for Reservoir Site No. 22 has been taken as follows:

					Acres.
SE. ¼ SE. ¼	Sec. 13,	T. 20 S.,	R. 67 W.	(private cash sale, October 8, 1885)	40·00
SE. ¼ NE. ¼	24	20	67	(military land warrant, May 4, 1880)	40·00
NE. ¼ NE. ¼	24	20	67	(private cash sale, August 31, 1885)	40·00
NE. ¼ SE. ¼	24	20	67	(preemption, April 10, 1871)	40·00
SW. ¼ SW. ¼	18	20	66	(private cash sale, February 7, 1883)	38·86
NW. ¼ NW. ¼	19	20	66	(preemption, January 28, 1871)	39·02
SW. ¼ NW. ¼	19	20	66	(preemption, May 28, 1873)	39·02
SE. ¼ NW. ¼	19	20	66	(private cash sale, August 28, 1885)	40·00
NW. ¼ SW. ¼	19	20	66	(preemption, May 28, 1873)	39·14
					316·04

Reservoir Site No. 23.

Is situated in Pueblo County, Colorado, on the Arkansas River, 8 miles west of Pueblo.

Drainage area, all the mountainous portion of the river basin directly tributary to the river. Mean annual flow about 900 second-feet.

Location of site, T. 20 S., R. 66 W., Secs. 19, 20, 25, 26, 28, 29, 30, 32, 33, 34, 35, and 36; and T. 21 S., R. 66 W., Secs. 1, 2, 3, and 4.

Location of dam W. ½ of NE. ¼, NW. ¼ of SE. ¼, and E. ½ of SW. ¼, Sec. 36, T. 20 S., R. 66 W. Height of dam, 90 feet.

Bench mark at southwest corner of flooring of iron bridge across river at Rocky Canyon, on the line of the proposed dam. Elevation above sea level 4,840 feet, and below reservoir flood level 60 feet.

Area of reservoir site, approximately, 1,920 acres.

Capacity of reservoir, approximately, 359,000 acre-feet.

Spillway may be provided for by light open cut across rock little to north of north end of dam.

Material for dam construction at either end of dam.

Cultivated land over the greater portion of the site.

Irrigable lands lie to the eastward.

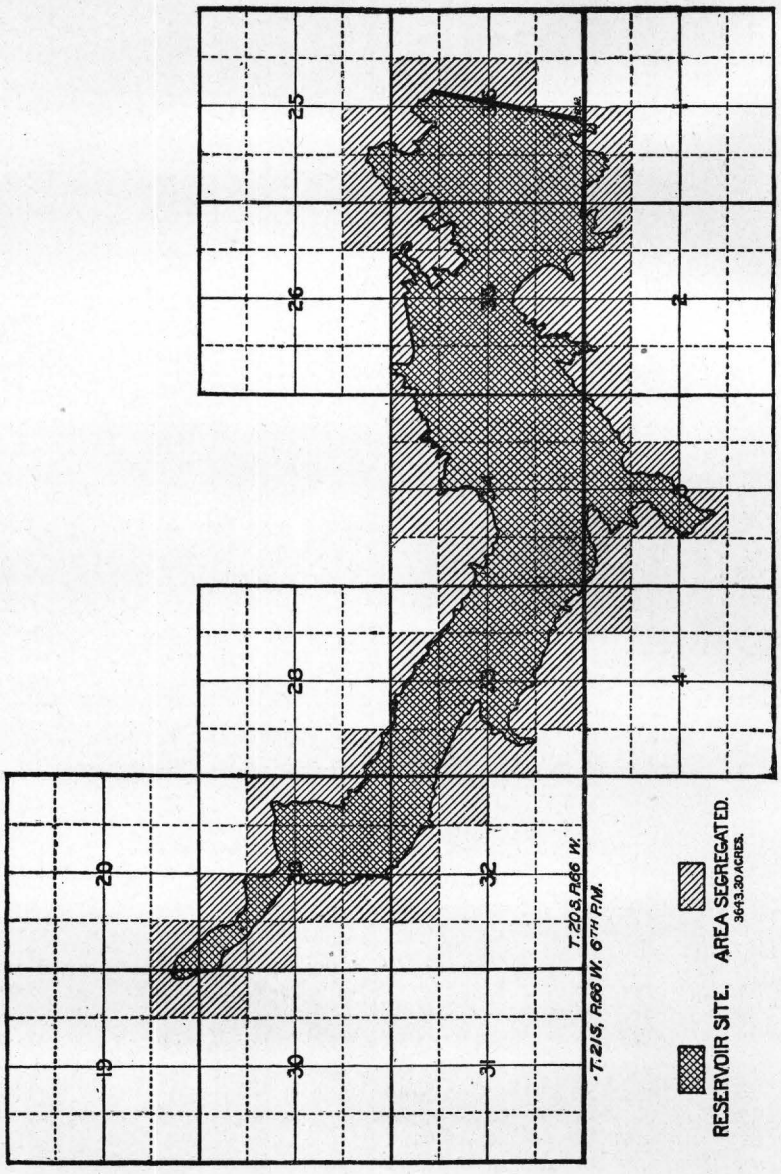


Fig. 129.—Reservoir Site No. 23, on Arkansas River.

Lands segregated for reservoir.

					Acres.
SE. ¼ SE. ¼	Sec. 19,	T. 20 S.,	R. 66 W	.....	40·00
SW. ¼ SW. ¼	20	20	66	.....	40·00
S. ½ SW. ¼	25	20	66	.....	80·00
SE. ¼ SE. ¼	26	20	66	.....	40·00
SW. ¼ SW. ¼	28	20	66	.....	40·00
S. ½ NE. ¼	29	20	66	.....	80·00
NW. ¼	29	20	66	.....	160·00
E. ½ SW. ¼	29	20	66	.....	80·00

				Acres.
SE. ¼ Sec.	29,	T. 20 S.,	R. 66 W	160·00
NE. ¼ NE. ¼	30	20	66	40·00
NE. ¼ NW. ¼	32	20	66	40·00
N. ½ NE. ¼	32	20	66	80·00
NW. ¼	33	20	66	160·00
W. ½ NE. ¼	33	20	66	80·00
SE. ¼ NE. ¼	33	20	66	40·00
N. ½ SW. ¼	33	20	66	80·00
SE. ¼ SW. ¼	33	20	66	40·00
SE. ¼	33	20	66	160·00
S. ½ NW. ¼	34	20	66	80·00
NE. ¼	34	20	66	160·00
S. ½	34	20	66	320·00
All	35	20	66	640·00
W. ½	36	20	66	320·00
W. ½ NE. ¼	36	20	66	80·00
NW. ¼ SE. ¼	36	20	66	40·00
N. ½ NW. ¼	1	21	66	78·03
N. ½ NE. ¼	2	21	66	82·06
N. ½ NW. ¼	2	21	66	83·00
N. ½ NE. ¼	3	21	66	81·82
SW. ¼ NE. ¼	3	21	66	40·00
E. ½ NW. ¼	3	21	66	79·84
NW. ¼ NW. ¼	3	21	66	39·12
NE. ¼ SW. ¼	3	21	66	40·00
NE. ¼ NE. ¼	4	21	66	38·62
Area segregated				3,643·30

Action affecting titles to lands segregated for Reservoir Site No. 23 has been taken as follows:

					Acres.
SE. ¼ SE. ¼ Sec.	19,	T. 20 S.,	R. 66 W.	(homestead, October 27, 1889)	40·00
SW. ¼ SW. ¼	20	20	66	(homestead, October 27, 1889)	40·00
S. ½ SW. ¼	25	20	66	(private sale, September 28, 1885)	80·00
SE. ¼ SE. ¼	26	20	66	(State school land)	40·00
SW. ¼ SW. ¼	28	20	66	(preemption, April 13, 1872)	40·00
SW. ¼ NE. ¼	29	20	66	(preemption, July 16, 1871)	40·00
SE. ¼ NE. ¼	29	20	66	(private sale, September 28, 1872)	40·00
E. ½ NW. ¼	29	20	66	(homestead, March 30, 1875)	80·00
W. ½ NW. ¼	29	20	66	(homestead, October 27, 1889)	80·00
E. ½ SW. ¼	29	20	66	(preemption, July 20, 1872)	80·00
S. ½ SE. ¼	29	20	66	(preemption, April 13, 1872)	80·00
NE. ¼ SE. ¼	29	20	66	(preemption, April 22, 1872)	40·00
NW. ¼ SE. ¼	29	20	66	(preemption, July 20, 1872)	40·00
NE. ¼ NE. ¼	30	20	66	(preemption by Mississippi agri. scrip January 13, 1872)	40·00
N. ½ NE. ¼	32	20	66	(preemption by Alabama agri. scrip November 20, 1871)	80·00
N. ½ NW. ¼	33	20	66	(preemption by Alabama agri. scrip November 20, 1871)	80·00
S. ½ NW. ¼	33	20	66	(preemption by Virginia agri. scrip September 14, 1872)	80·00
S. ½ NE. ¼	33	20	66	(preemption, January 17, 1871)	80·00
NW. ¼ NE. ¼	33	20	66	(preemption by Virginia agri. scrip September 14, 1872	40·00

					Acres.
N. ½ SW. ¼	Sec. 33,	T. 20 S.,	R. 66 W.	(preemption by Virginia agri. scrip September 14, 1872)	80·00
SE. ¼ SW. ¼	33	20	66	(private sale, October 18, 1876)	40·00
NE. ¼ SE. ¼	33	20	66	(preemption, January 17, 1871)	40·00
SE. ¼ SE. ¼	33	20	66		40·00
W. ½ SE. ¼	33	20	66	(homestead, November 23, 1871)	80·00
S. ½ NW. ¼	34	20	66	(preemption, April 13, 1872)	80·00
N. ½ NE. ¼	34	20	66	(filing, May 2, 1872)	80·00
S. ½ NE. ¼	34	20	66	(preemption, February 7, 1871)	80·00
NW. ¼ SE. ¼	34	20	66	(preemption, February 7, 1871)	40·00
S. ½ SE. ¼	34	20	66		80·00
NE. ¼ SE. ¼	34	20	66	(preemption, September 12, 1871)	40·00
E. ½ SW. ¼	34	20	66	(pre-emption, April 13, 1872)	80·00
SW. ¼ SW. ¼	34	20	66	(homestead, November 23, 1871)	40·00
NW. ¼ SW. ¼	34	20	66	(preemption, January 17, 1871)	40·00
N. ½ NW. ¼	35	20	66		80·00
SE. ¼ NW. ¼	35	20	66	(preemption, September 12, 1871)	40·00
SW. ¼ NW. ¼	35	20	66	(preemption, February 7, 1871)	40·00
SW. ¼ NE. ¼	35	20	66	(preemption. September 12, 1871)	40·00
N. ½ NE. ¼	35	20	66	(preemption, April 25, 1872)	80·00
SE. ¼ NE. ¼	35	20	66	(preemption, November 25, 1871)	40·00
NE. ¼ SW. ¼	35	20	66	(preemption, November 25, 1871)	40·00
S. ½ SW. ¼	35	20	66	(private sale, April 1, 1872)	80·00
NW. ¼ SW. ¼	35	20	66	(preemption, September 12, 1871)	40·00
N. ½ SE. ¼	35	20	66	(preemption, November 25, 1871)	80·00
S. ½ SE. ¼	35	20	66	(private sale, April 1, 1871)	80·00
W. ½	36	20	66	(State school land)	320·00
NW. ¼ NE. ¼	36	20	66	(State school land)	40·00
SW. ¼ NE. ¼	36	20	66		40·00
NW. ¼ SE. ¼	36	20	66		40·00

These two 40s are under the general law school land, but

The State has applied for indemnity, and has selected other lands in lieu of these 40s. The record division shows that the State has relinquished its right to them and that they are part of the public domain.

These claims for indemnity have not been approved as yet by the private claims division, and the records of this division show it to be school land.

N. ½ NW. ¼	Sec. 1,	T. 21 S.,	R. 66 W.	(preemption, July 24, 1889)	78·30
N. ½ NE. ¼	2	21	66	(originally filed as homestead, July 30, 1889, and commuted to preemption April, 1890	82·60
NW. ¼ NE. ¼	3	21	66	(preemption, February 25, 1890)	40·55
SW. ¼ NE. ¼	3	21	66	(preemption, February 27, 1888)	40·00
N. ½ NW. ¼	3	21	66	(preemption, February 25, 1890)	78·96
SE. ¼ NW. ¼	3	21	66	(preemption, February 27, 1888)	40·00
Total					3,360·41

Reservoir Site No. 24.

Is situated in Pueblo County, Colorado, on Rush Creek, on high broken plains, near the foothills.

Drainage area, 10 square miles on Rush Creek basin, and, by diversion, portions of the drainage of the Red Creek and Peck Creek basins, which extend back into the foothills and are subject annually to floods. Rush Creek has uncertain intermittent flow.

Location of site, T. 20 S., R. 67 W., Secs. 5, 6, 7, and 8.

Location of dam, E. ½ of SW. ¼, Sec. 5.

Height of dam, 50 feet.

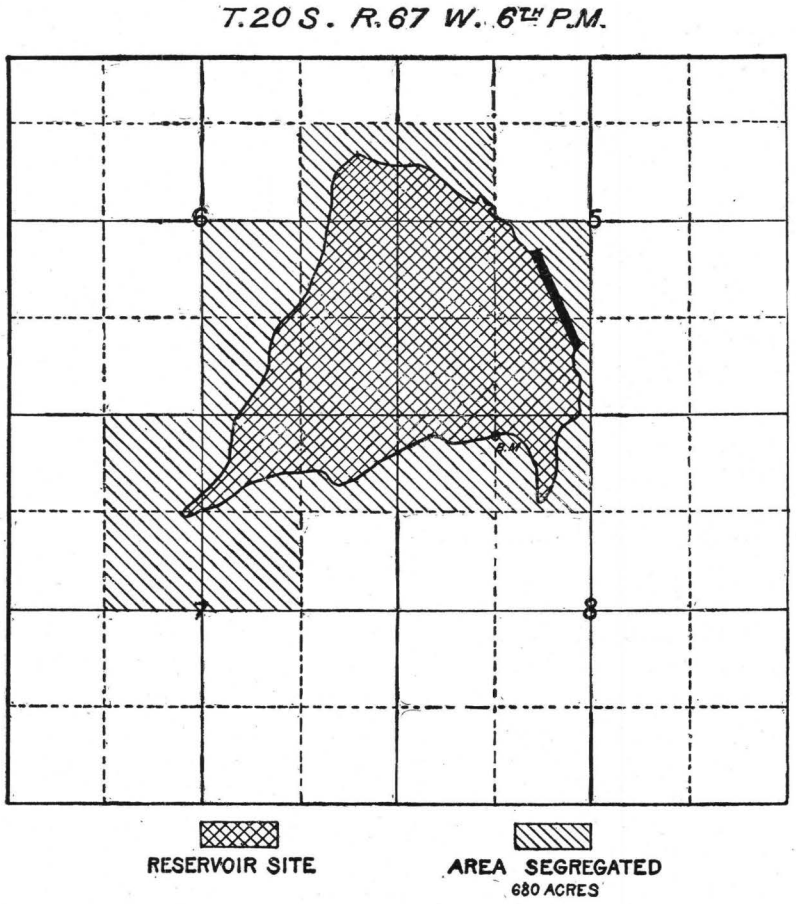


Fig. 130.—Reservoir Site No. 24, on Rush Creek.

Bench mark, none. Altitude above sea, approximately, 5,400 feet.

Area of reservoir site, approximately, 335 acres.

Capacity of reservoir, approximately, 2,100 acre-feet.

Spillway at end of dam, over rock in place.

Material for construction at the site.

No cultivated land on reservoir site.

Irrigable lands near, to eastward.

Lands segregated for reservoir.

					Acres.
SW. ¼ NW. ¼	Sec. 5,	T. 20 S.,	R. 67 W.		40
SW. ¼	5	20	67		160
SE. ¼ NE. ¼	6	20	67		40
SE. ¼	6	20	67		160
N. ½ NE. ¼	7	20	67		80
SW. ¼ NE. ¼	7	20	67		40
E. ½ NW. ¼	7	20	67		80
N. ½ NW. ¼	8	20	67		80
Area segregated					680

Action affecting titles to lands segregated for Reservoir Site No. 24 has been taken as follows:

					Acres.
SE. ¼ SW. ¼	Sec. 5,	T. 20 S.,	R. 67 W.	(preemption, November 13, 1885)	40
NE. ¼ SW. ¼	5	20	67	(private sale, October 24, 1885)	40
W. ½ SW. ¼	5	20	67	(filing, June 10, 1870)	80
SE. ¼ SE. ¼	6	20	67	(preemption, November 29, 1872)	40
N. ½ SE. ¼	6	20	67	(preemption, July 16, 1872)	80
SE. ¼ NE. ¼	6	20	67	(preemption, November 29, 1865)	40
					320

Reservoir Site No. 26.

Is situated in Pueblo County, Colorado, on St. Charles River, about midway from source to junction with Arkansas River, on the high plains.

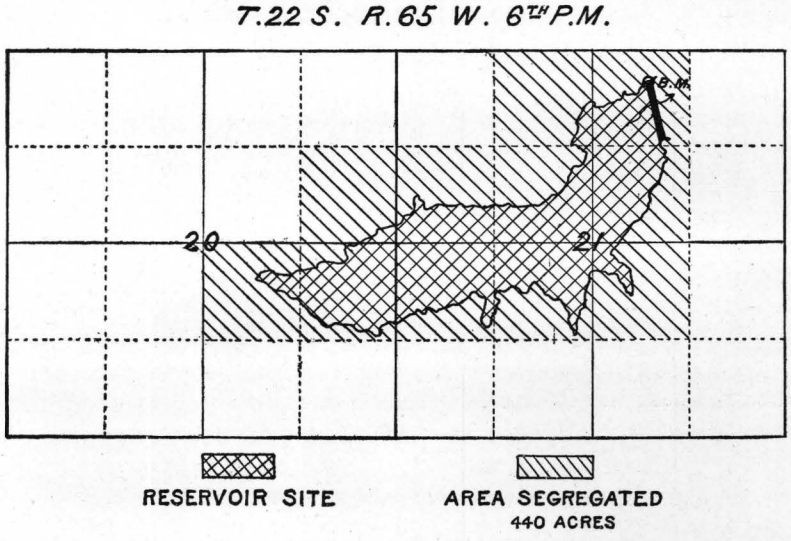


Fig. 131.—Reservoir Site No. 26, on St. Charles River.

Drainage area about 180 square miles, extending back 30 miles to the crest of the Greenhorn Range. Heavily timbered on mountain slopes, with small quantity of light wood in foothills. Stream has continuous flow.

Location of site, T. 22 S., R. 65 W., Secs. 20 and 21.

Location of dam, NW. ¼ of NE. ¼, Sec. 21.

Height of dam, 27 feet.

Bench mark at north end of dam crest, a stone marked thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 4,980 feet.
Area of reservoir site, approximately, 170 acres.
Capacity of reservoir, approximately, 2,640 acre-feet.
Spillway over dam.
Material for dam construction at the site.
Cultivated lands, with buildings, cover most of the site.
Irrigable lands near at hand to northeast.

Lands segregated for reservoir.

					Acres.
SE. ¼ NE. ¼	Sec. 20,	T. 22 S.,	R. 65 W		40
N. ½ SE. ¼	20	22	65		80
NE. ¼ NW. ¼	21	22	65		40
S. ½ NW. ¼	21	22	65		80
N. ½ SW. ¼	21	22	65		80
NW. ¼ SE. ¼	21	22	65		40
W. ½ NE. ¼	21	22	65		80
Area segregated					440

Action affecting titles to lands segregated for Reservoir Site No. 26 has been taken as follows:

					Acres.
N. ½ SE. ¼	Sec. 20,	T. 22 S.,	R. 65 W.	(preemption, January 4, 1872)	80
NE. ¼ NW. ¼	21	22	65	(embraced in Nolan grant; patented March 3, 1875)	40
SE. ¼ NW. ¼	21	22	65	(preemption, May 10, 1873)	40
SW. ¼ NW. ¼	21	22	65	(embraced in Nolan grant; patented March 3, 1875)	40
NE. ¼ SW. ¼	21	22	65	(preemption, January 4, 1872)	40
NW. ¼ SW. ¼	21	22	65	(preemption, January 4, 1872)	40
W. ½ NE. ¼	21	22	65	(preemption, May 10, 1873)	80
					360

Reservoir Site No. 27.

Is situated in Pueblo County, Colorado, on the St. Charles River, just behind the "Hogbacks," at the base of the Greenhorn Mountains.

Drainage area about 65 square miles, all on heavy mountain slopes, well wooded, and supplied with streams of continuous flow.

Location of site, T. 23 S., R. 68 W., Secs. 1, 2, and 11.

Location of dam, SE. ¼ of SE. ¼, Sec 2, and SW. ¼ of SW. ¼, Sec. 1.

Height of dam, 77 feet.

Bench mark at north end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 6,300 feet.
Area of reservoir site, approximately, 200 acres.
Capacity of reservoir, approximately, 3,340 acre-feet.
Spillway over dam.
Material for construction of dam at the site.
Cultivated lands, with buildings, cover the site.
Irrigable lands on the plains just outside the line of Hogbacks, behind which the basin lies.

Lands segregated for reservoir.

					Acres.
SW. ¼ SW. ¼	Sec. 1,	T. 23 S.,	R. 68 W.		40·00
SE. ¼ NE. ¼	2	23	68		40·00
W. ½ NE. ¼	2	23	68		89·70
E. ½ NW. ¼	2	23	63		89·90
SW. ¼ SW. ¼	2	23	68		40·00
E. ½ SW. ¼	2	23	68		80·00
SE. ¼	2	23	68		160·00
N. ½ NW. ¼	11	23	68		80·00
NW. ¼ NE. ¼	11	23	68		40·00
Area segregated					659·60

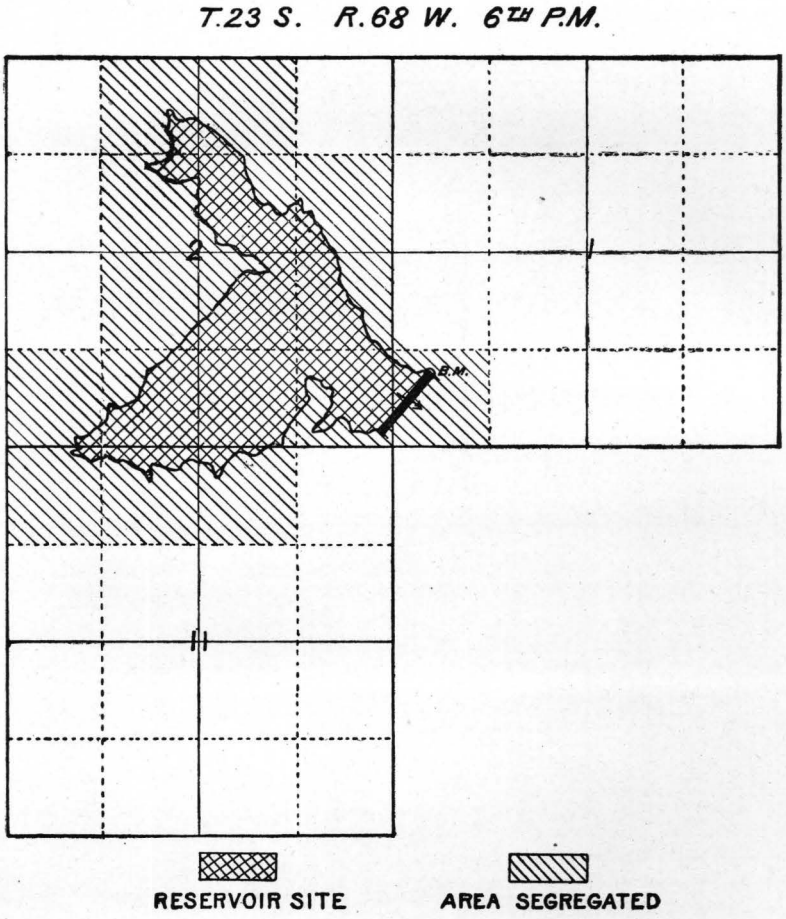


FIG. 132—Reservoir Site No. 27, on St. Charles River.

Action affecting titles to lands segregated for Reservoir Site No. 27 has been taken, as follows:

					Acres.
SW. ¼ SW. ¼	Sec. 1,	T. 23 S.,	R. 68 W.	(preemption, May 31, 1884)	40·00
NW. ¼ NE. ¼	2	23	68	(homestead, June 23, 1882)	49·70
SW. ¼ NE. ¼	2	23	68	(preemption, September 26, 1882)	40·00
SE. ¼ NW. ¼	2	23	68	(preemption, March 1, 1872)	40·00
NE. ¼ NW. ¼	2	23	68	(preemption, July 13, 1878)	49·90
SW. ¼ SW. ¼	2	23	68	(filing, August 1, 1880	40·00
E. ½ SW. ¼	2	23	68	(preemption, March 18, 1872)	80·00
SE. ¼ SE. ¼	2	23	68	(preemption, May 31, 1884)	40·00
W. ½ SE. ¼	2	23	68	(preemption, September 26, 1882	80·00
NE. ¼ NW. ¼	11	23	68	(preemption, March 18, 1872)	40·00
NW. ¼ NW. ¼	11	23	68	(preemption, January 25, 1873)	40·00
NW. ¼ NE. ¼	11	23	68	(preemption, September 26, 1882)	40·00
					579·60

Reservoir Site No. 28.

Is situated in Pueblo County, Colorado, on Graneros Creek, a mile above junction with Greenhorn Creek, and on high, broken plains near the foothills.

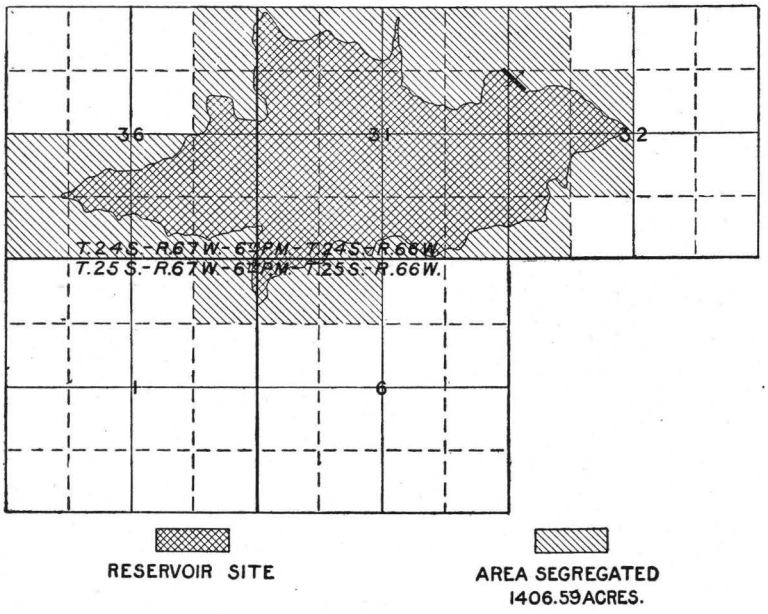


Fig. 153.—Reservoir Site No. 28, on Graneros Creek.

Drainage area of the Graneros is small, and furnishes an insignificant supply; Greenhorn Creek can be easily diverted into the basin, and will furnish a mean annual flow of perhaps 20 second-feet. Its drainage area is about 50 square miles, chiefly on the east front of Greenhorn Mountain. Slopes heavily timbered. The Huerfano River on the south may be diverted in part by an easily constructed canal 15 miles long.

Location of site T. 24 S., R. 66 W., Secs. 31 and 32; T. 24 S., R. 67 W., Sec. 36; T. 25 S., R. 67 W., Sec 1; and T. 25 S., R. 66 W., Sec. 6.

Location of dam SE. ¼ of NE. ¼, Sec. 31, and SW. ¼ of NW. ¼, Sec. 32, T. 24 S., R. 66 W.

Height of dam, 165 feet.

Bench mark, southeastern corner of foundation of a cabin near the center of Sec. 31.

Elevation above sea level 5,892 feet, and 110 feet below reservoir flood level.

Area of reservoir site, approximately, 760 acres.

Capacity of reservoir, 27,200 acre-feet, closely approximated from contour map on large scale.

Spillway over rock in place 100 feet to south of dam.

Material for dam construction at the site.

Cultivated land within the site, 20 acres.

Irrigable lands near at hand to eastward.

Lands segregated for reservoir.

				Acres.
All Sec. 31, T. 24 S. R. 66 W				645·20
W. ½ NW. ¼	32	24	66	80·00
SE. ¼ NW. ¼	32	24	66	40·00
W. ½ SW. ¼	32	24	66	80·00
NE. ¼ SW. ¼	32	24	66	40·00
E. ½ NE. ¼	36	24	67	80·00
S. ½	36	24	67	320·00
N. ½ NW. ¼	6	25	66	81·39
NE. ¼ NE. ¼	1	25	67	40·00
Area segregated				1,406·59

Action affecting titles to lands segregated for Reservoir Site No. 28 has been taken, as follows:

					Acres.
NE. ¼ NE. ¼	Sec. 31,	T. 24 S.	R. 66 W	(preemption August 17, 1886)	40·00
S. ½ NE. ¼	31	24	66	(preemption August 17, 1886)	80·00
NW. ¼ NE. ¼	31	24	66	(filing April 21, 1886)	40·00
N. ½ NW. ¼	31	24	66		80·60
S. ½ NW. ¼	31	24	66	(preemption October 1, 1883)	81·06
NW. ¼ SE. ¼	31	24	66	(preemption August 17, 1866	40·00
N. ½ SW. ¼	31	24	66	(preemption October 1, 1883)	81·54
					483·20

Reservoir Site No. 29.

Situated in Huerfano County, Colorado, on the Huerfano River, at a narrow gateway in the foothills where the Huerfano passes from a broad mountain valley to the plains.

Drainage area about 500 square miles, extending to high mountain crests around half its circumference of about 100 miles. Heavy timber on the higher mountain slopes and light wood on the foothills. The central portion of the basin is a mountain park, clear of timber. Streams have continuous flow and considerable volume.

Location of site, T. 27 S., R. 68 W., Secs. 5 and 6.

Location of dam, SW. ¼ of NE. ¼, Sec. 5.

Height of dam, 49 feet.

Bench mark at north end of dam crest cut on rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 6,895 feet.

Area of reservoir site, approximately, 115 acres.

Capacity of reservoir, approximately, 1,960 acre-feet.

Spillway over dam.

Material for dam construction at the site.

Cultivated lands with buildings over most of site.

Irrigable lands immediately below.

Recommended for segregation in letter dated February 27, 1891.

Lands segregated.

				Acres.
NW. ¼ Sec.	5,	T. 27 S.,	R. 68 W	160
SW. ¼ NE. ¼	5	27	68	40
NW. ¼ SE. ¼	5	27	68	40
N. ½ SW. ¼	5	27	68	80
E. ½ NE. ¼	6	27	68	80
Area segregated				400

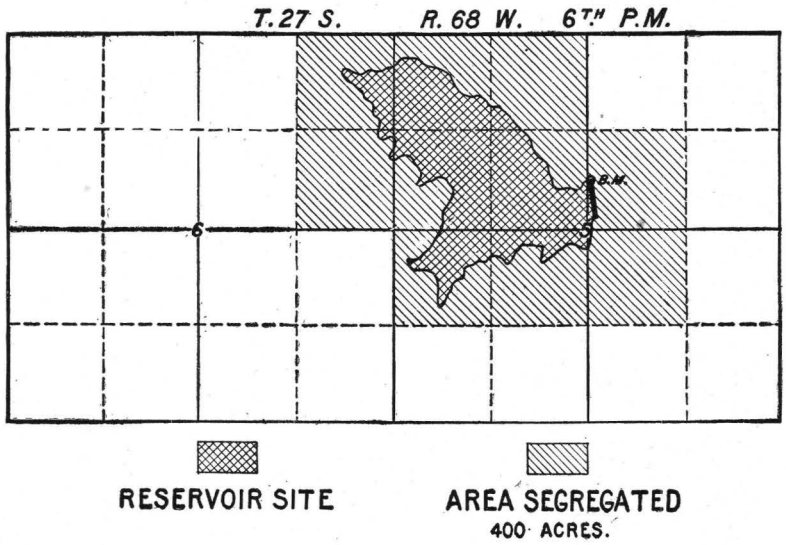


FIG. 134.—Reservoir Site No. 29, on Huerfano River.

Action affecting titles to lands segregated for Reservoir Site No. 29 has been taken, as follows:

					Acres.
N. ½ NW. ¼ Sec.	5,	T. 27 S.,	R. 68 W.	(homestead June 2, 1882)	80
SW. ¼ NW. ¼	5	27	68	(homestead June 2, 1882)	40
SE. ¼ NW. ¼	5	27	68	(homestead May 14, 1878)	40
SW. ¼ NE. ¼	5	27	68	(homestead May 14, 1878)	40
NW. ¼ SE. ¼	5	27	68	(homestead May 14, 1878)	40
NE. ¼ SW. ¼	5	27	68	(homestead May 14, 1875)	40
NE. ¼ NE. ¼	6	27	68	(preemption May 14, 1875)	40
SE. ¼ NE. ¼	6	27	68	(homestead June 2, 1882)	40
					360

RESERVOIR SITE NO. 30.

Is situated in Huerfano County, Colorado, on Cucharas River, in the foothills between the Spanish Peaks and the Culebra Range.

Draining area about 40 square miles, extending 6 or 8 miles back to the summits of the Culebra Range and the Spanish Peaks. Timber on the higher slopes, and light wood generally distributed. Streams have continuous flow.

Location of site, T. 30 S., R. 69 W., Secs. 24, 25, and 26.

Location of dam, NE. ¼ of NW. ¼, Sec. 25.

Height of dam, 132 feet.

Bench mark at north end of dam crest cut in stone thus: B. M. / U. S. G. S. / 1890.

Altitude above sea, approximately, 7,800 feet.

Area of reservoir site, approximately, 130 acres.
Capacity of reservoir, approximately, 4,125 acre-feet.
Spillway over dam.
Material for dam construction near at hand.
No cultivated land on the site.
Irrigable land to the northeast, about 15 miles, near La Veta.
Recommended for segregation in letter dated February 27, 1891

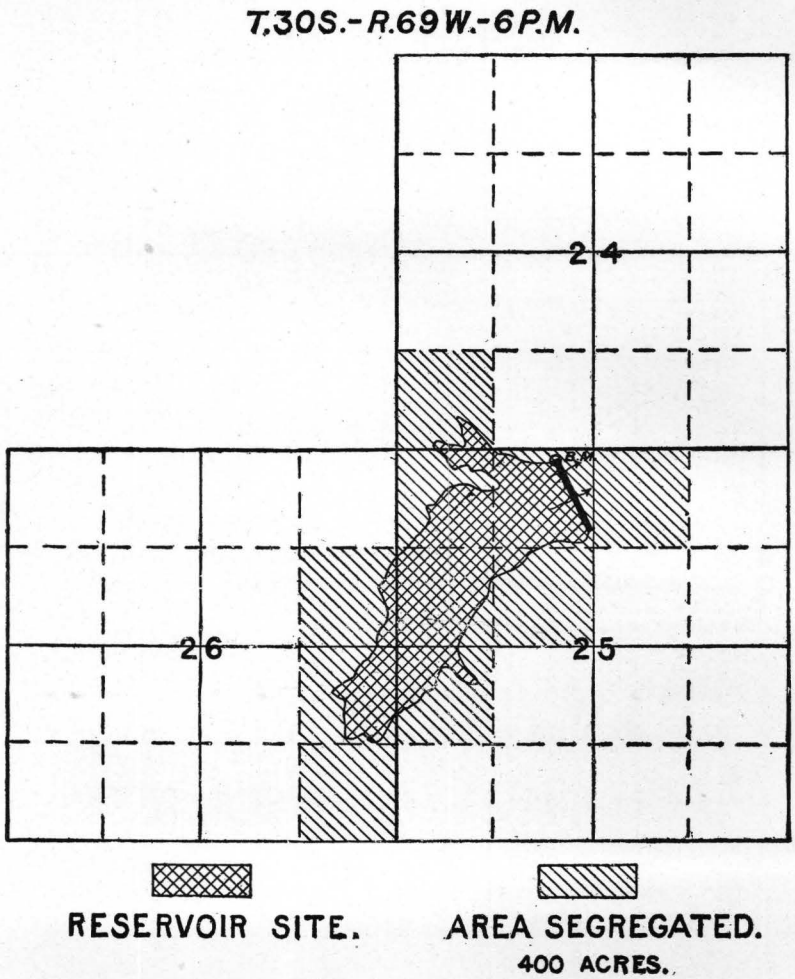


FIG. 135.—Reservoir Site No. 30, on Cucharas River.

Lands segregated for reservoir.

				Acres.
SW. ¼ SW. ¼ Sec.	24,	T. 30 S.,	R. 69 W	40
NW. ¼	25	30	69	160
NW. ¼ NE. ¼	25	30	69	40
NW. ¼ SW. ¼	25	30	69	40
SE. ¼ NE. ¼	26	30	69	40
E. ½ SE. ¼	26	30	69	80
Area segregated				400

Action affecting titles to lands segregated for Reservoir Site No. 30 has been taken as follows:

					Acres.
N. ½ NW. ¼	Sec. 25,	T. 30 S.,	R. 69 W.	(homestead, June 26, 1883)	80
SW. ¼ NW. ¼	25	30	69	(preemption, February 8, 1889)	40
NW. ¼ NE. ¼	25	30	69	(homestead, June 26, 1883)	40
NW. ¼ SW. ¼	25	30	69	(preemption, February 8, 1889)	40
E. ½ SE. ¼	26	30	69	(preemption, February 8, 1889)	80
					280

Reservoir Site No. 31.

Is situated in Huerfano County, Colorado, on Arapaho Creek, in foothills north of the Spanish Peaks.

Drainage area about 25 square miles, heading in the Spanish Peaks. A small amount of timber. Light continuous flow of streams.

Location of site, T. 29 S., R. 67 W., Secs. 21, 22, 23, 27, and 28.

Location of dam, NE. ¼ of SW. ¼ and NW. ¼ of SE. ¼, Sec. 22.

Height of dam, 139 feet.

Bench mark at west end of dam crest, cut on rock thus: $\frac{\text{B. M.}}{\text{U. S. G. S.}}$ $\frac{}{1890.}$ Altitude above sea, approximately, 7,200 feet.

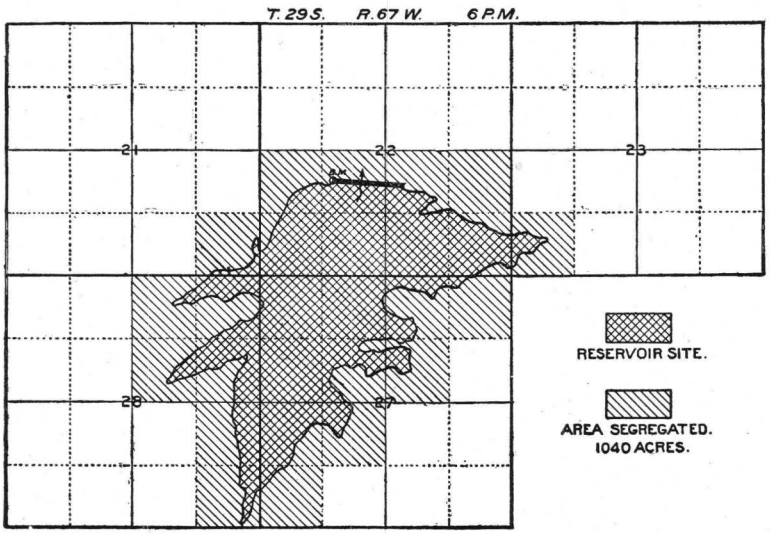


Fig. 136.—Reservoir Site No. 31, on Arapaho Creek.

Area of reservoir site, approximately, 450 acres.

Capacity of reservoir, approximately, 13,300 acre-feet

Spillway at end of dam.

Material for construction of dam on the site.

No cultivated land on the site.

Irrigable lands a few miles to north.

Lands segregated for reservoir.

					Acres.
SE. ¼ SE. ¼	Sec. 21,	T. 29 S.,	R. 67 W		40
S. ½	22	29	67		320
SW. ¼ SW. ¼	23	29	67		40
NW. ¼	27	29	67		160

					Acres.
N. ½ NE. ¼	27	29	67		80
SW. ¼ NE. ¼	27	29	67		40
N. ½ SW. ¼	27	29	67		80
SW. ¼ SW. ¼	27	29	67		40
NE. ¼	28	29	67		160
E. ½ SE. ¼	28	29	67		80
Area segregated					1,040

Action affecting titles to lands segregated for Reservoir Site No. 31 has been taken as follows:

					Acres.
NE. ¼ SE. ¼	22, T. 29 S., R. 67 W.			(preemption, December 8, 1882)	40
S. ½ SE. ¼	22	29	67	(preemption, December 8, 1882)	80
NW. ¼ SE. ¼	22	29	67	(filing, April 9, 1888)	40
N. ½ SW. ¼	22	29	67	(filing, April 9, 1889)	80
				(filing, April 17, 1889)	
SE. ¼ SW. ¼	22	29	67	(filing, April 17, 1889)	40
NW. ¼ NE. ¼	27	29	67	(preemption, December 8, 1882)	40
SW. ¼ NE. ¼	27	29	67	(preemption, January 28, 1883)	40
NE. ¼ SW. ¼	27	29	67	(preemption, January 28, 1883)	40
SW. ¼ SW. ¼	27	29	67	(preemption, May 28, 1884)	40
SE. ¼ SE. ¼	28	29	67	(preemption, July 5, 1889)	40
					480

RESERVOIR SITE NO. 32.

Is situated in Huerfano County, Colorado, on Santa Clara River, in the high mesas between the Spanish Peaks and the plains.

Drainage area of about 45 square miles, heading on the Spanish Peaks. Little timber, and light and continuous flow to streams.

Location of site, T. 29 S., R. 66 W., Secs. 34, 35, and T. 30 S., R. 66 W., Secs. 2, 3, and 10.

Location of dam, SW. ¼ of SE. ¼, Sec. 35, T. 29 S., R. 66 W., and NE. ¼ of NE. ¼, Sec. 2, T. 30 S., R. 66 W.

Height of dam, 142 feet.

Bench mark at north end of dam crest, cut on stone thus: U. S. G. S. B. M. 1890. Altitude above sea, approximately, 6,700 feet.

Area of reservoir site, approximately, 426 acres.

Capacity of reservoir, approximately, 10,150 acre feet.

Spillway at end of dam.

Material for dam construction on the site.

Little cultivated land within the site.

Irrigable lands in the valley of the Santa Clara a few miles below.

Lands segregated.

					Acres.
S. ½ SE. ¼ Sec.	34, T. 29 S., R. 66 W.				80·00
S. ½ SW. ¼	34	29	66		80·00
S. ½ SE. ¼	35	29	66		80·00
NE. ¼ SW. ¼	35	29	66		40·00
S. ½ SW. ¼	35	29	66		80·00
N. ½	2	30	66		320·48
SW. ¼	2	30	66		160·00
N. ½ SE. ¼	2	30	66		80·00
SW. ¼ SE. ¼	2	30	66		40·00

				Acres.
S. ½ SE. ¼	3	30	66	80·00
N. ½ NE. ¼	3	30	66	80·00
NE. ¼ NW. ¼	3	30	66	40·00
N. ½ NE. ¼	10	30	66	80·00
Area segregated				1,240·48

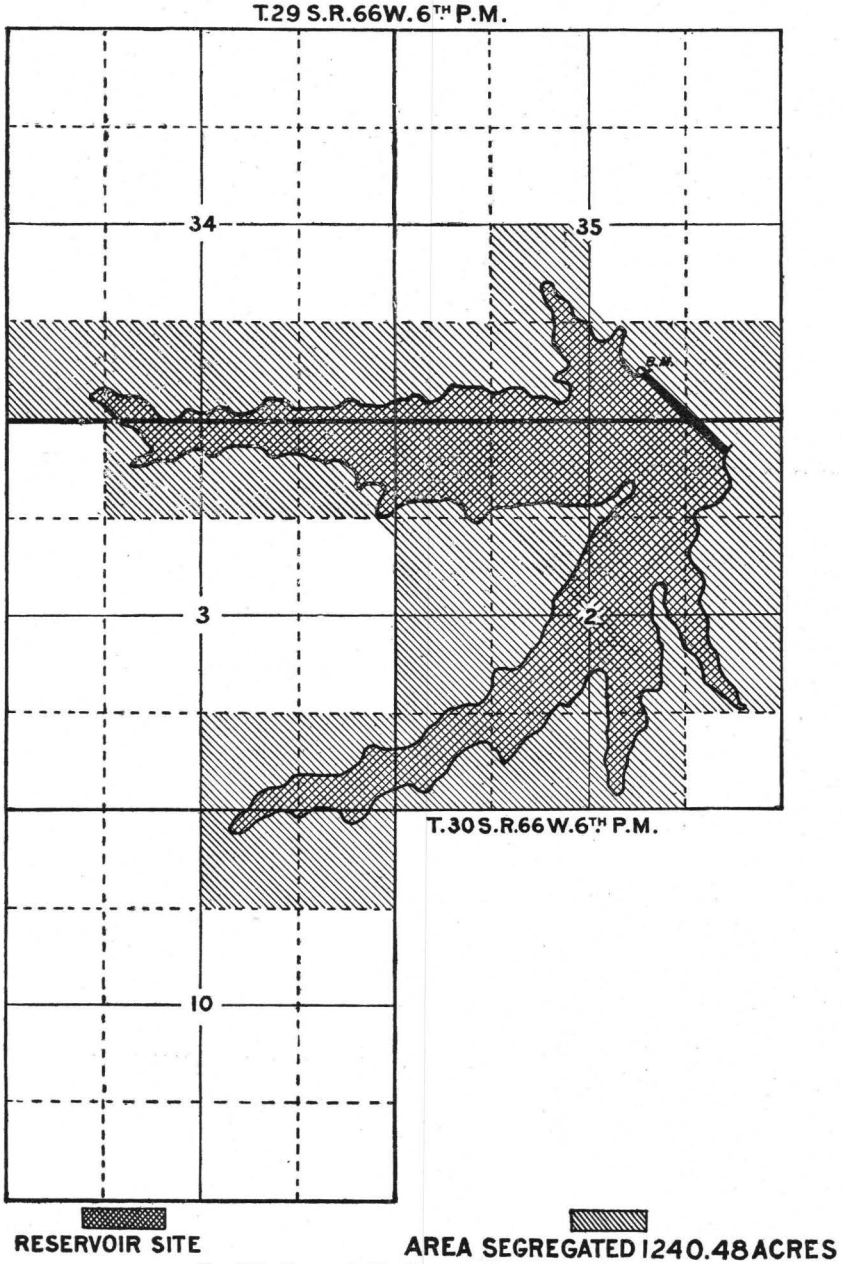


FIG. 137.—Reservoir Site No. 32, on Santa Clara River.

Action affecting titles to lands segregated for Reservoir Site No. 32 has been taken as follows:

						Acres.
SW. ¼	SE. ¼	Sec. 34	T. 29 S.,	R. 66 W.	(homestead, September 16, 1873)	40
S. ½	SW. ¼	34	29	66	(filing)	80
SW. ¼	SE. ¼	35	29	66	(school land)	40
SE. ¼	SE. ¼	35	29	66	(filing, July 9–11, 1890)	40
NE. ¼	SW. ¼	35	29	66	(timber, March 18, 1884)	40
S. ½	SW. ¼	35	29	66	(timber, March 18, 1884)	80
NW. ¼	SE. ¼	2	30	66	(preemption, December 17, 1873)	40
SW. ¼	SE. ¼	2	30	66	(filing, March 13, 1888)	40
W. ½	NE. ¼	2	30	66	(preemption, December 17, 1873)	80
SE. ¼	SW. ¼	2	30	66	(preemption, November 13, 1873)	40
SE. ¼	SE. ¼	3	30	66	(filing, July 29, 1889)	40
N. ½	NE. ¼	3	30	66	(homestead, September 16, 1873)	80
NE. ¼	NW. ¼	3	30	66	(homestead, September 16, 1873)	40
N. ½	NE. ¼	10	30	66	(homestead, August 2, 1875)	80
						760

Reservoir Site No. 33.

Is situated in Las Animas County, Colorado, on the Apishapa River, at the eastern edge of Park Plateau.

Drainage area of about 100 square miles extending westward to the southern slope of the Spanish Peaks. Little heavy timber, but general distribution of light wood. Continuous flow of streams.

Location of site, T. 31 S., R. 65 W., Secs. 7, 8, 17 and 18.

Location of dam, NE. ¼ of NW. ¼ and NW. ¼ of NE. ¼, Sec. 8.

Height of dam, 115 feet.

Bench mark at west end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 6,850 feet.

Area of reservoir site, approximately, 440 acres.

Capacity of reservoir, approximately, 12,790 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam.

Cultivated land, with buildings, over greater portion of site.

Irrigable lands immediately below.

Lands segregated for reservoir.

					Acres.
SE. ¼	NE. ¼	Sec. 7,	T. 31 S.,	R. 65 W.	40
E. ½	SE. ¼	7	31	65	80
W. ½		8	31	65	320
NE. ¼		8	31	65	160
W. ½	NW. ¼	17	31	65	80
W. ½	SW. ¼	17	31	65	80
E. ½	NE. ¼	18	31	65	80
E. ½	SE. ¼	18	31	65	80
Area segregated					920

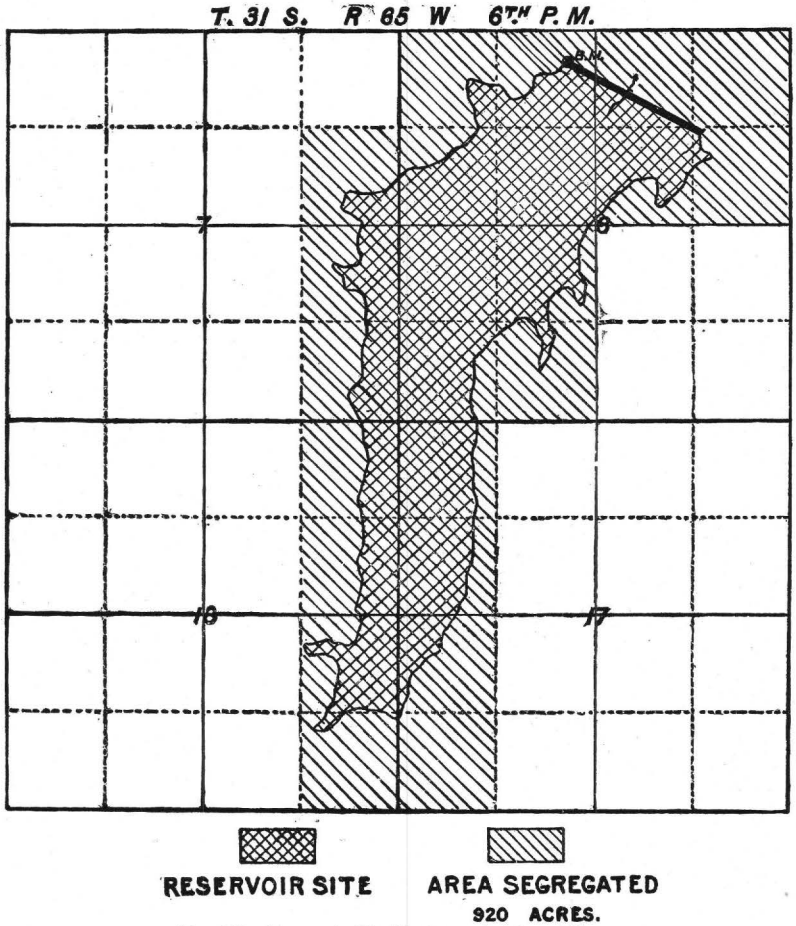


FIG. 138.—Reservoir Site No. 33, on Apishapa River.

Action affecting titles to lands segregated for Reservoir Site No. 33 has been taken as follows:

					Acres.
SE. ¼ NE. ¼ Sec.	7,	T. 31 S.,	R. 65 W.	(coal filing, February 1, 1890)	40
SE. ¼ SE. ¼	7	31	65	(homestead, July 11, 1882)	40
NE. ¼ SE. ¼	7	31	65	(coal filing, December 10, 1888)	40
W. ½ NW. ¼	8	31	65	(homestead, September 15, 1882)	80
SE. ¼ NW. ¼	8	31	65	(homestead, September 15, 1882)	40
NE. ¼ NW. ¼	8	31	65	(preemption, December 9, 1874)	40
W. ½ SW. ¼	8	31	65	(homestead, July 11, 1882)	80
NE. ¼ SW. ¼	8	31	65	(homestead, July 11, 1882)	40
SE. ¼ SW. ¼	8	31	65	(coal land, May 16, 1888)	40
NE. ¼ NE. ¼	8	31	65	(coal land)	40
SW. ¼ NE. ¼	8	31	65	(homestead, September 15, 1882)	40
NW. ¼ NE. ¼	8	31	65	(preemption, December 9, 1874)	40
SE. ¼ NE. ¼	8	31	65	(coal land, July 22, 1887)	40
W. ½ NW. ¼	17	31	65	(homestead, June 11, 1887)	80
W. ½ SW. ¼	17	31	65	(coal filing, March 14, 1888)	80
E. ½ NE. ¼	18	31	65	(homestead, June 11, 1887)	80
E. ½ SE. ¼	18	31	65	(homestead, May 8, 1880)	80
					920

Reservoir Site No. 34.

Is situated in Las Animas County, Colorado, on the Purgatoire River at the junction with South Fork.

Drainage area about 320 square miles, extending back to the crest of the Culebra Range. The basin includes the Stonewall Valley and several other settled areas of small size, but its greater portion is heavily timbered. Streams are numerous and have continuous flow.

Location of site, T. 33 S., R. 67 W., Secs. 25, 26, 27, 34, 35, 36, and T. 34 S., R. 67 W., Sec. 2.

Location of dam, W. ½ of NW. ¼, Sec. 36, T. 33 S., R. 67 W.

Height of dam, 120 feet.

Bench mark at north end of dam crest cut on rock, thus: B. M. U. S. G. S. 1890.

Altitude above sea approximately 6,620 feet.

Area of reservoir site approximately 450 acres.

Capacity of reservoir approximately 6,200 acre-feet.

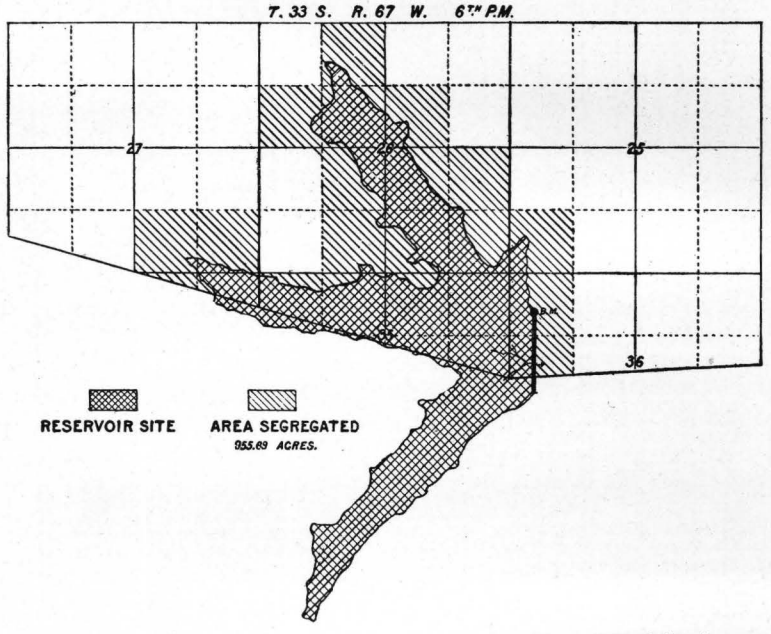


Fig. 139.—Reservoir Site No. 34, on Purgatoire River, on Maxwell Land Grant.

Spillway over dam.

Material for dam construction near at hand.

Cultivated land with buildings over a portion of the site.

Irrigable lands beyond the mesas, 30 miles eastward.

Lands segregated for reservoir.

					Acres.
SW. ¼ SW. ¼	Sec. 25,	T. 33 S.,	R. 67 W		40·00
SW. ¼ NE. ¼	26	33	67		40·00
SE. ¼	26	33	67		160·00
E. ½ NW. ¼	26	26	67		80·00
SW. ¼ NW. ¼	26	33	67		40·00
E. ½ SW. ¼	26	33	67		80·00

					Acres.
S. ½	SE. ¼	Sec. 27,	T. 33 S.,	R. 67 W	80·00
	Lot 1	34	33	67	16·61
	Lot 2	34	33	67	4·72
N. ½	NE. ¼	35	33	67	80·00
	Lot 3	35	33	67	39·25
	Lot 4	35	33	67	28·81
	Lot 5	35	33	67	22·70
	Lot 6	35	33	67	15·64
NW. ¼	NW. ¼	36	33	67	40·00
	Lot 8	36	33	67	25·96
Area segregated					793·69
Area of reservoir on land grant					162·00
Total					955·69

Action affecting titles to lands segregated for Reservoir Site No. 34 has been taken as follows:

						Acres.
SW. ¼	SW. ¼	Sec. 25,	T. 33 S.,	R. 67 W.	(filing, June 18, 1888)	40·00
SW. ¼	NE. ¼	26	33	67	(cash sale coal land, December 1, 1887)	40·00
	SE. ¼	26	33	67	(patented homestead, November 17, 1886)	160·00
E. ½	NW. ¼	26	33	67	(coal filing, November 14, 1889)	80·00
SW. ¼	NW. ¼	26	33	67	(cash sale coal land, December 1, 1887)	40·00
SE. ¼	SW. ¼	26	33	67	(coal filing, January 21, 1888)	40·00
NE. ¼	SW. ¼	26	33	67	(cash filing, September 10, 1888)	40·00
S. ½	SE. ¼	27	33	67	(homestead, April 13, 1887)	80·00
NE. ¼	NE. ¼	Lot 1, Sec. 34,	T. 33 S.,	R. 67 W.	(homestead, May 18, 1883)	16·61
NW. ¼	NE. ¼	2	33	67	(homestead, May 18, 1883)	4·72
NE. ¼	NW. ¼	3	35	33	67 (homestead, May 18, 1883)	39·25
NW. ¼	NW. ¼	4	35	33	67 (homestead, May 18, 1883)	28·81
Lots 5 and 6 (townsite of Weston), Sec. 35, T. 33 S., R. 67 W. (preemption, Sept. 7, 1888)						38·34
N. ½	NE. ¼	Sec. 35,	T. 33 S.,	R. 67 W.	(homestead, July 25, 1883)	80·00
NW. ¼	NW. ¼	36	33	67	(coal filing, January 5, 1889)	40·00
						767·73

RESERVOIR SITE NO. 35.

Is situated in Las Animas County, Colorado, in Stonewall Valley, at the eastern base of the Culebra Range.

Drainage area of about 50 square miles, all heavily wooded, with a considerable portion of heavy timber. Streams all have strong continuous flow.

Location of site, T. 33S., R. 69 W., Secs. 24, 25, and T. 33 S., R. 68 W., Secs. 19 and 30.

Location of dam, SE. ¼ of SW. ¼, Sec. 19, T. 33 S., R. 68 W.

Height of dam, 135 feet.

Bench mark at south end of dam crest. cut in rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 8,300 feet.

Area of reservoir site, approximately, 240 acres.

Capacity of reservoir, approximately, 11,200 acre-feet.

Spillway at end of dam.

Material for dam construction at either end of dam site.

Cultivated land, with buildings, over one-half the site.

Irrigable lands on the plains beyond Trinidad, 50 miles eastward.

Located by rejected survey in Secs. 19 and 30, T. 33 S., R. 68 W., and Secs. 24 and 25, T. 33 S., R. 69 W.

Area of reservoir, 222 acres.

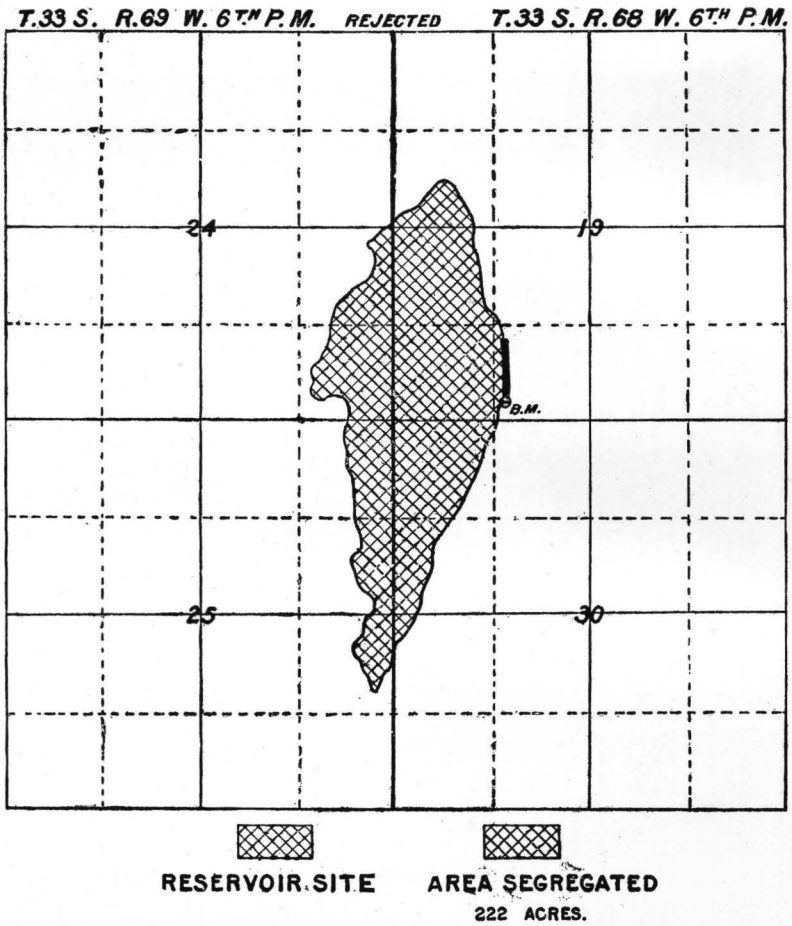


FIG. 140.—Reservoir Site No. 35, on Middle Fork, Purgatoire River, in Stonewall Valley, on Maxwell Land Grant.

RESERVOIR SITE NO. 36.

Is situated in Las Animas County, Colorado, on the Purgatoire River in Stonewall Valley, at the eastern base of the Culebra Range.

Drainage area about 65 square miles, nearly all heavily wooded. Streams have continuous flow.

Location of site, T. 33 S., R. 68 W., Secs. 19, 20, 29, 30, and 31.

Location of dam, W. ½ of NW. ¼, Sec. 29.

Height of dam, 142 feet.

Bench mark at south end of dam crest, cut in rock, thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 8,200 feet.

Area of reservoir site, approximately, 760 acres.

Capacity of reservoir, approximately, 22,700 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam site.
Cultivated land over about one-third of site.
Irrigable land on the plains beyond Trinidad, 50 miles eastward.

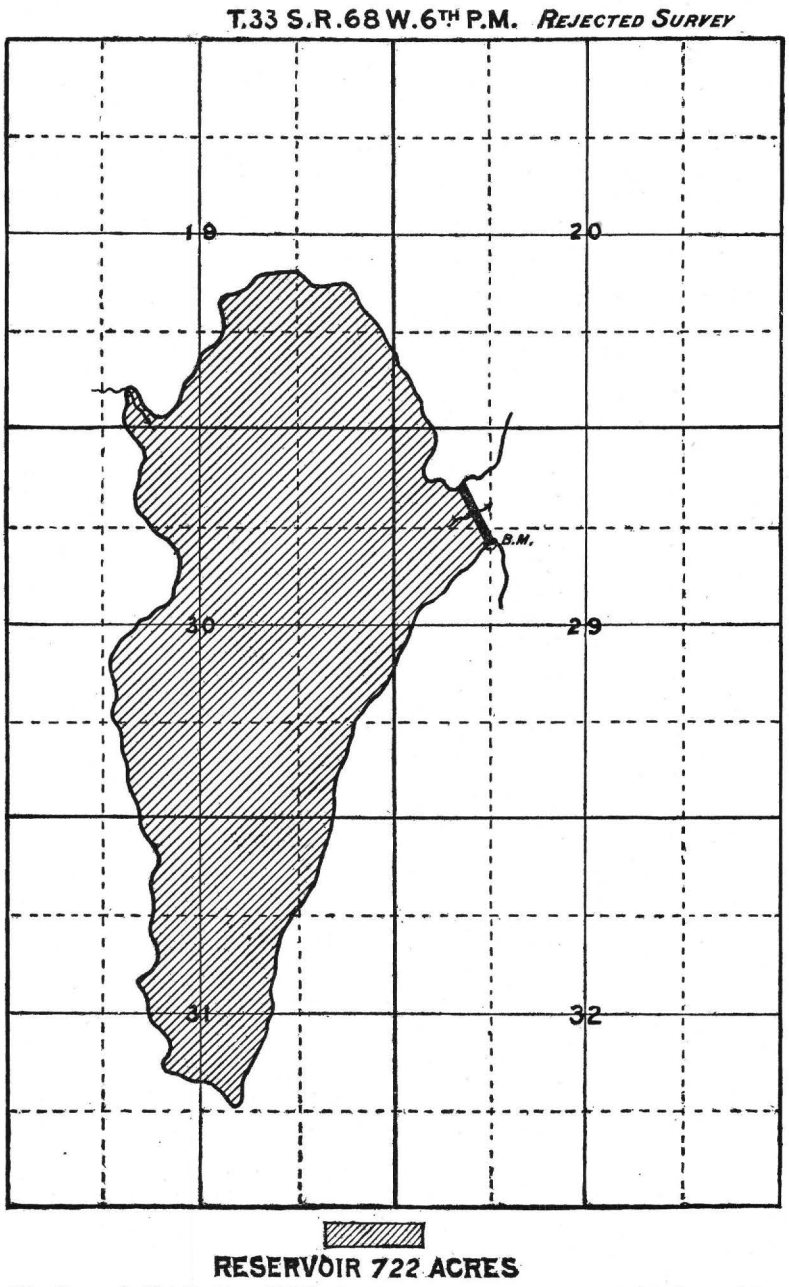


FIG. 141.—Reservoir Site No. 36, on Middle Fork, Purgatoire River, in Stonewall Valley, on Maxwell Land Grant.

Located by rejected survey in Secs. 19, 20, 29, 30, and 31.
Area of reservoir, 722 acres.

Reservoir Site No. 37.

Is situated in Las Animas County, Colorado, on the Apishapa River, 40 miles east of the mountains.

Drainage area about 420 square miles from the Spanish Peaks eastward. Bare of timber excepting in the extreme western portion. Light continuous flow, usually; in exceptionally dry years, intermittent flow.

Location of site, T. 28 S., R. 61 W., Secs. 19, 20, 29, and 30.

Location of dam, SW. ¼ of NW. ¼, Sec. 20.

Height of dam, 31 feet.

Bench mark at north end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890.

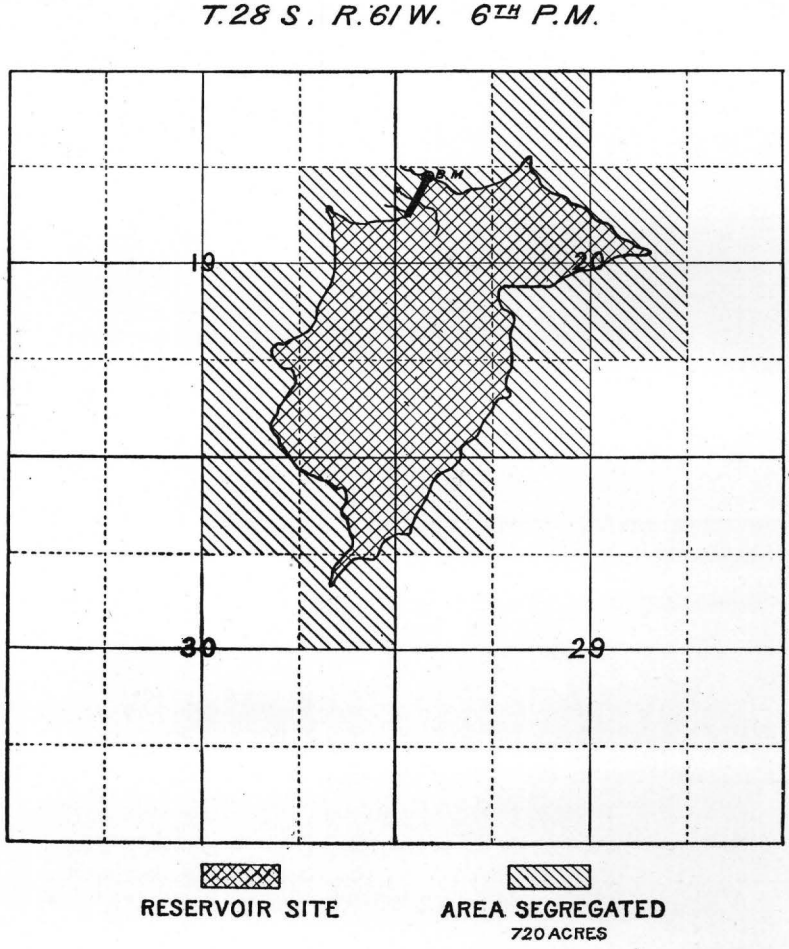


Fig. 142.—Reservoir Site No. 37, on Apishapa River.

Altitude above sea, approximately, 5,600 feet.

Area of reservoir site, approximately, 250 acres.

Capacity of reservoir, 3,840 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam site.

No cultivated land on site.

Irrigable lands lie below along the Arkansas River Valley.

Lands segregated for reservoir.

				Acres.
SE. ¼ NE. ¼ Sec.	19,	T. 28 S.,	R. 61 W.	40
SE. ¼	19	28	61	160
NE. ¼ NW. ¼	20	28	61	40
S. ½ NW. ¼	20	28	61	80
SW. ¼	20	28	61	160
NW. ¼ SE. ¼	20	28	61	40
SW. ¼ NE. ¼	20	28	61	40
NW. ¼ NW. ¼	29	28	61	40
N. ½ NE. ¼	30	28	61	80
SE. ¼ NE. ½	30	28	61	40
Area segregated				720

Action affecting titles to lands segregated for Reservoir Site No. 37 has been taken as follows:

					Acres.
NW. ¼ SE. ¼ Sec.	20,	T. 28 S.,	R. 61 W.	(homestead November 22, 1880)	40
SW. ¼ NE. ¼	20	28	61	(homestead November 22, 1880)	40
					80

Reservoir Site No. 40.

Is situated in Las Animas County, Col., on Smith Canyon Creek, 15 miles south of its junction with the Purgatoire River.

Drainage area of about 220 square miles on high, partly wooded plateaus. Main stream has intermittent flow through site.

Location of site, T. 28 S., R. 54 W., Secs. 25, 26, 34, 35, and 36; T. 29 S., R. 54 W., Secs. 1, 2, 3, 10, 11, 12, and 13.

Location of dam, SE. ¼ of SE. ¼, Sec. 27, and S. ½ of SW. ¼ Sec. 26, T. 28 S., R. 54 W.

Height of dam, 98 feet.

Bench mark at west end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 4,700 feet.

Area of reservoir site, approximately, 1,400 acres.

Capacity of reservoir, approximately, 34,230 acre-feet.

Spillway over natural rock a little beyond west end of dam.

Material for dam construction at either end of dam.

No cultivated land on site.

Irrigable lands lie along the valley below.

Lands segregated for reservoir.

				Acres.
SE. ¼ SE. ¼ Sec.	27,	T. 28 S.,	R. 54 W.	40·00
S. ½ SW. ¼	26	28	54	80·00
E. ½ NE. ¼	34	28	54	80·00
E. ½ SE. ¼	34	28	54	80·00
N. ½	35	28	54	320·00
SW. ¼	35	28	54	160·00
N. ½ SE. ¼	35	28	54	80·00
SW. ¼ SE. ¼	35	28	54	40·00
SW. ¼ NW. ¼	36	28	54	40·00
NW. ¼ SW. ¼	36	28	54	40·00
W. ½ NW. ¼	1	29	54	80·00
NW. ¼ SW. ½	1	29	54	40·00
All	2	29	54	641·53
E. ½	3	29	54	321·49
E. ½ SW. ½	3	29	54	80·00
NE. ¼ NW. ¼	10	29	54	40·00
W. ½ NE. ¼	10	29	54	80·00
N. ½ NW. ¼	11	29	54	80·00

				Acres.
SE. ¼ NW. ¼ Sec.	11,	T. 29 S.,	R. 54W	40·00
NE. ¼	11	29	54	160·00
N. ½ SE. ¼	11	29	54	80·00
SE. ¼ SE. ¼	11	29	54	40·00
SW. ¼ NW. ¼	12	29	54	40·00
SW. ¼	12	29	54	160·00
NW. ¼	13	29	54	160·00
Area segregated				3,003·02

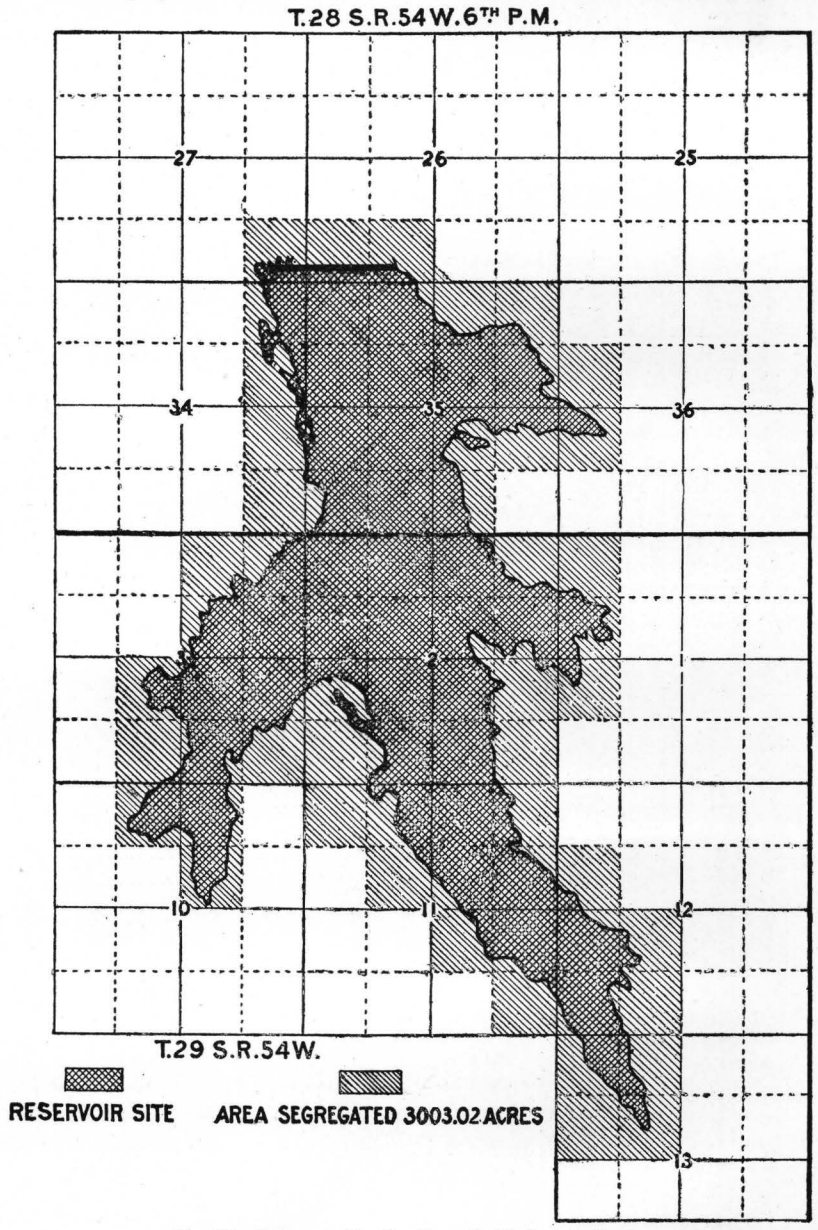


FIG. 143.—Reservoir Site No. 40, on Smith Canyon Creek.

Action affecting titles to lands segregated for Reservoir Site No. 40 has been taken as follows:

						Acres.
SW. ¼ NW. ¼	Sec.	36,	T. 28 S.,	R. 54 W.	(school land)	40·00
NW. ¼ SW. ¼		36	28	54	(school land)	40·00
E. ½ SE. ¼		2	29	54	(preemption, September 10, 1883)	80·00
W. ½ NE. ¼		2	29	54	(filing, February 17, 1885)	80·27
E. ½ NW. ¼		2	29	54	(duplicate filings. Filing, February 17, 1885)	80·45
E. ½ NW. ¼		2	29	54	(duplicate filings. Filing May 1, 1885)	
N. ½ NE. ¼		2	29	54	(filing, May 1, 1885)	80·36
N. ½ NE. ¼		11	29	54	(preemption, September 10, 1883)	80·00
						481·08
NW. ¼ NE. ¼		2	29	54	(less, duplicated)	40·27
						440·81

Reservoir Site No. 41.

Is situated in Bent County, Colorado, on Rule Creek, midway of its length.

Drainage area of about 140 square miles. No heavy timber and very little light-wood growth. Stream flow, intermittent.

Location of site, T. 26 S., R. 52 W., Secs. 2, 3, 10, 11, 14, 15, and 22.

Location of dam, W. ½ and SE. ¼ of NE. ¼, and NE. ¼ of SE. ¼, Sec. 2.

Height of dam, 68 feet.

Bench mark at west end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 4,250 feet.

Area of reservoir site, approximately, 1,560 acres.

Capacity of reservoir, approximately, 32,780 acre-feet.

Spillway at end of dam.

Material for construction at either end of dam.

No cultivated land on the site.

Irrigable lands in the valley of Rule Creek, below.

Lands segregated.

					Acres.
W. ½	Lot 6, Sec.	2, T. 26 S.,	R. 52 W		40
	Lot 7	2	26	52	80
E. ½	Lot 5	2	26	52	40
	Lot 8	2	26	52	80
	S. ½	2	26	52	320
E. ½	SE. ¼	3	26	52	80
	E. ½	10	26	52	320
	W. ½	11	26	52	320
N. ½	NE. ¼	11	26	52	80
SW. ¼	NE. ¼	11	26	52	40
NW. ¼	SE. ¼	11	26	52	40
	W. ½	14	26	52	320
	E. ½	15	26	52	320
E. ½	NW. ¼	15	26	52	80
E. ½	SW. ¼	15	26	52	80
NE. ¼	NE. ¼	22	26	52	40
N. ½	NW. ¼	22	26	52	80
Area segregated					2,360

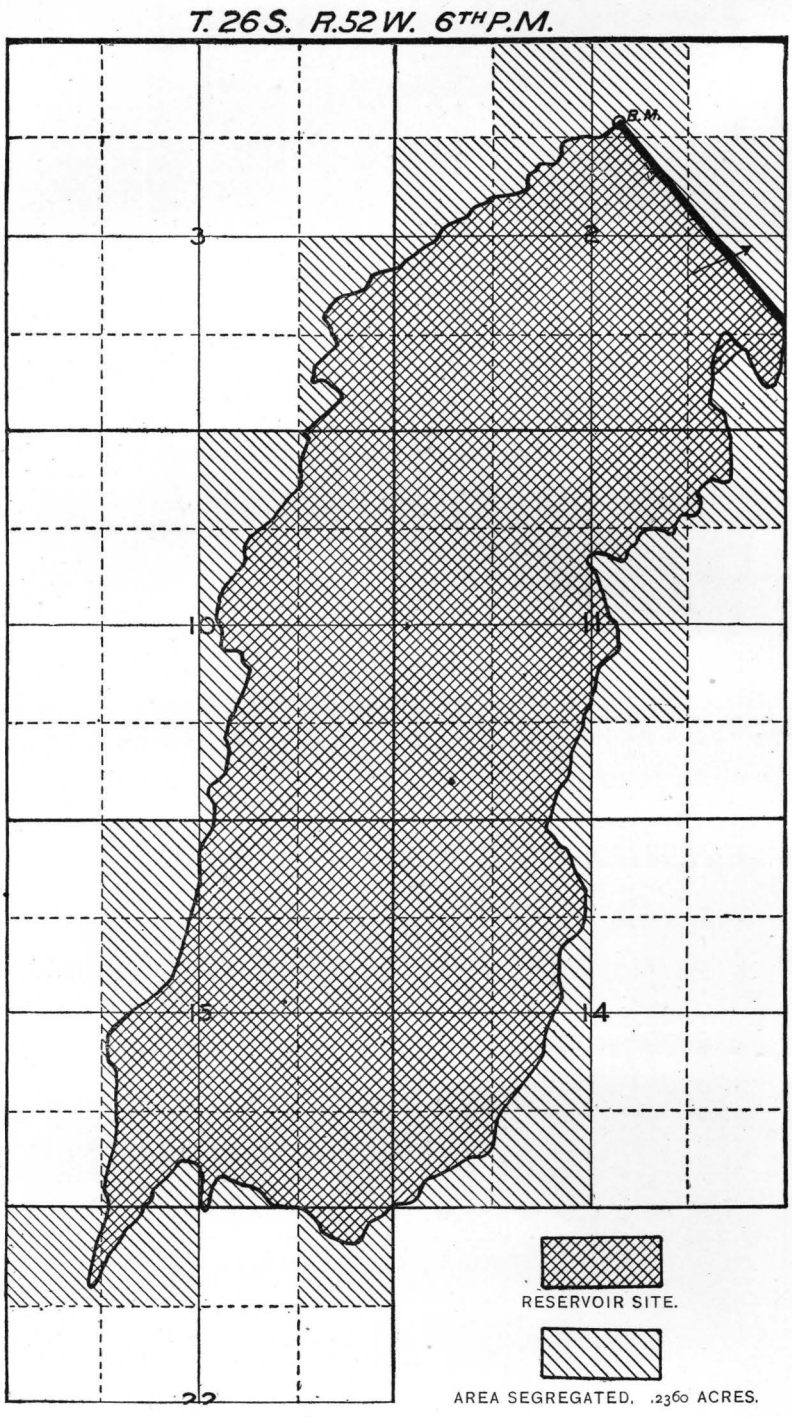


FIG. 144.—Reservoir Site No. 41, on Rule Creek.

Action affecting the titles to lands segregated for Reservoir Site No. 41 has been taken as follows:

						Acres.
S. ½	NW. ¼	Sec. 11,	T. 26 S.,	R. 52 W	(timber culture, March 27, 1888).....	80
NE. ¼	NW. ¼	11	26	52	(timber culture, March 27, 1888).....	40
NW. ¼	SW. ¼	11	26	52	(timber culture, March 27, 1888).....	40
						160

Reservoir Site No. 42.

Is situated in Bent County, Colorado, on Cottonwood Creek, 4 miles above junction with Rule Creek.

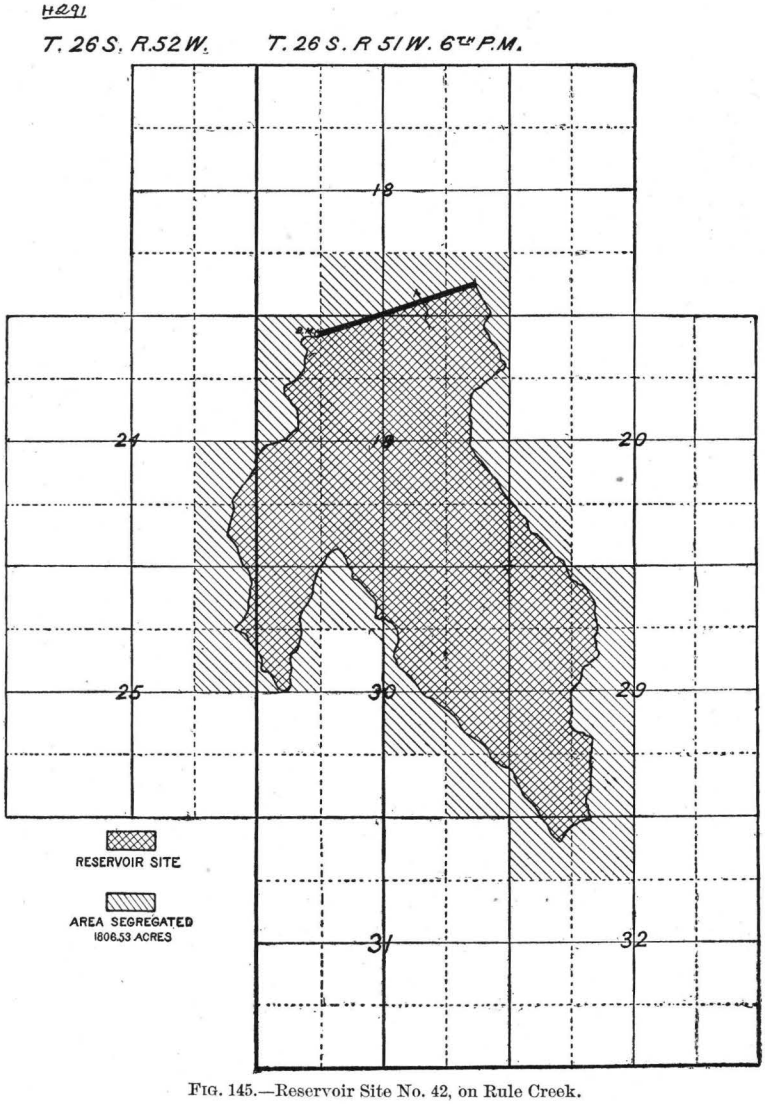


Fig. 145.—Reservoir Site No. 42, on Rule Creek.

Drainage area of about 110 square miles, among low mesas. Occasional light tree growth on mesas. Stream has occasional light flow and annual floods.

Location of site, T. 26 S., R. 52 W., Secs. 24 and 25; T. 26 S., R. 51 W., Secs. 18, 19, 20, 29, 30, and 32.

Location of dam, NW. ¼, Sec. 19, and S. ½ of SE. ¼, Sec. 18, T. 26 S., R. 51 W.

Height of dam, 58 feet.

Bench mark at west end of dam, cut on rock thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 4,300 feet.

Area of reservoir site, approximately, 1,000 acres.

Capacity of reservoir, approximately, 25,680 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam.

No cultivated land on the site.

Irrigable land to north along valley of Rule Creek.

Lands segregated.

					Acres.
S. ½ SE. ¼	Sec. 18,	T. 26 S.,	R. 51 W.		80·00
SE. ¼ SW. ¼	18	26	51		40·00
All	19	26	51		644·32
W. ½ SW. ¼	20	26	51		80·00
W. ½	29	26	51		320·00
E. ½ SE. ¼	30	26	51		80·00
NW. ¼ SE. ¼	30	26	51		40·00
NE. ¼	30	26	51		160·00
N. ½ NW. ¼	30	26	51		81·16
SW. ¼ NW. ¼	30	26	51		41·05
N. ½ NW. ¼	32	26	51		80·00
E. ½ SE. ¼	24	26	52		80·00
E. ½ NE. ¼	25	26	52		80·00
Area segregated					1,806·53

Action affecting titles to lands segregated for Reservoir Site No. 42 has been taken as follows:

					Acres.
S. ½ SE. ¼	Sec. 18,	T. 26 S.,	R. 51 W.	(timber culture, February 18, 1885)	80
N. ½ NW. ¼	32	26	51	(preemption, June 20, 1888)	80
					160

Reservoir Site No. 43.

Is situated in Las Animas and Baca counties, Colorado, on Two Butte Creek, at the point where the mesas end in plains.

Drainage area of about 250 square miles, in a region of low mesas, rising to a maximum elevation of 5,500 feet above sea level. Light pine growth along mesa edges. Intermittent flow on stream branches, but continuous flow through reservoir site.

Location of site, T. 29 S., R. 50 W., Secs. 7, 8, 16, 17, and 18.

Location of dam, W. ½ of NW. ¼, Sec. 16.

Height of dam, 50 feet.

Bench mark at north end of dam crest, cut in rock thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 4,500 feet.

Area of reservoir site, approximately, 480 acres.

Capacity of reservoir, approximately, 5,900 acre-feet.

Spillway over dam.

Material for dam construction at either end of dam.

No cultivated land on site.

Irrigable lands lie east, several miles, along the valley of Butte Creek.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼	Sec.	7,	T. 29 S.,	R. 50 W	80
SE. ¼ SW. ¼		7	29	50	40
SW. ¼		8	29	50	160
SE. ¼		8	29	50	160
E. ½ NE. ¼		17	29	50	80
NW. ¼ NE. ¼		17	29	50	40
N. ½ NW. ¼		17	29	50	80
NE. ¼		18	29	50	160
NE. ¼ NW. ¼		18	29	50	40
N. ½ SE. ¼		18	29	50	80
W. ½ NW. ¼		16	29	50	80
Area segregated					1,000

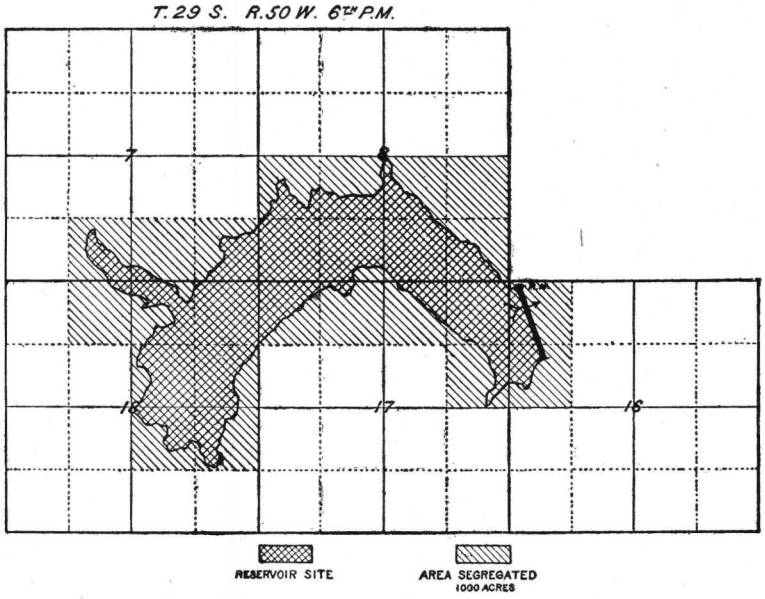


FIG. 146.—Reservoir Site No. 43, on Two Butte Creek.

Action affecting titles to lands segregated for Reservoir Site No. 43 has been taken as follows:

	Acres.
N. ½ NW. ¼, Sec. 17, T. 29 S., R. 50 W. (timber culture, date of sale May 23, 1887, no patent)	80

RESERVOIR SITE NO. 44.

Situated in Otero County, Colorado, in a depression on the open plains, about 6 miles east of Rocky Ford. Depth increased by low dam.

No drainage area; to be supplied by ditch from the Arkansas River.

Location of site, T. 23 S., R. 55 W., Secs. 5, 6, 7, and 8, and T. 23 S., R. 56 W., Secs. 1 and 12.

Location of dam, E. ½ of SE. ¼, Sec. 7, and SW. ¼ of NW. ¼, Sec. 8.

Height of dam, 20 feet.

No bench mark.

Area of reservoir about 700 acres.
Capacity of reservoir, approximately, 14,720 acre-feet.
Capacity, approximately, 10,200 acre-feet.
Spillway over dam.
Material for dam construction at the site.
No cultivated land on the site.
Irrigable lands immediately adjacent.

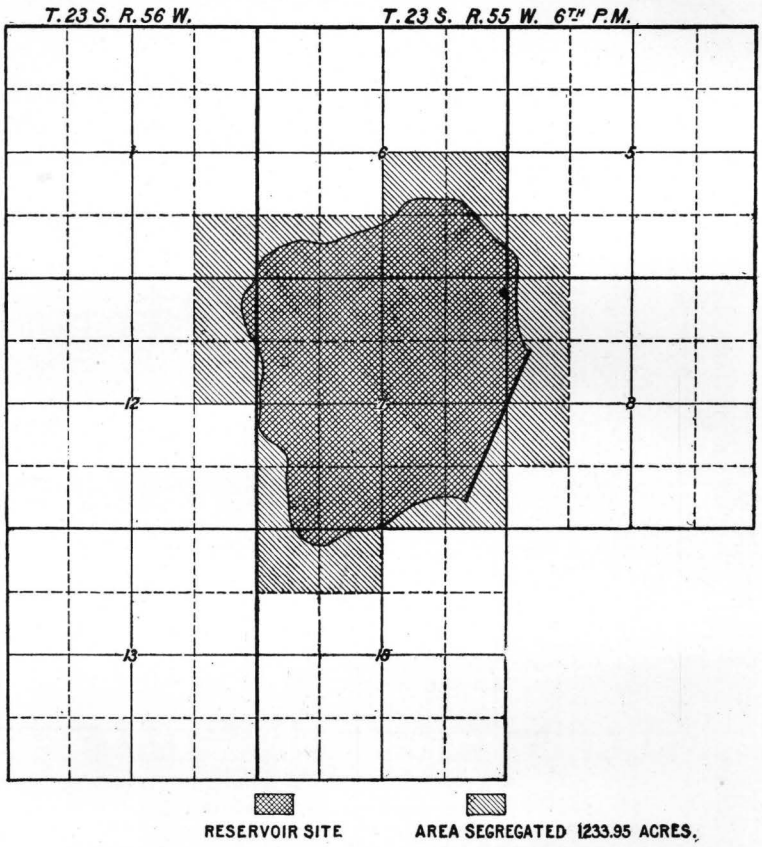


FIG. 147.—Reservoir Site No. 44. Six miles east of Rocky Ford, Colorado.

Lands segregated.

					Acres.
SW. ¼ SW. ¼	Sec.	5,	T. 23 S.,	R. 55 W	40·00
SE. ¼		6	23	55	160·00
S. ½ SW. ¼		6	23	55	78·77
All		7	23	55	636·00
W. ½ NW. ¼		8	23	55	80·00
NW. ¼ SW. ¼		8	23	55	40·00
N. ½ NW. ¼		18	23	55	79·18
SE. ¼ SE. ¼		1	23	56	40·00
E. ½ NE. ¼		12	23	56	80·00
Area segregated					1,233·95

Action affecting titles to lands segregated for Reservoir Site No. 44 has been taken as follows:

					Acres.
SE. ¼	Sec. 6,	T. 23 S.,	R. 55 W.	(school land)	160·00
SE. ¼ SW. ¼	6	23	55	(school land)	40·00
NW. ¼	7	23	55	(timber, April 22, 1887)	157·80
Lots 3 and 4	7	23	55	(state school)	78·20
NE. ¼	7	23	55	(state school)	160·00
E. ½ SW. ¼	7	23	55	(state school)	80·00
SE. ¼	7	23	55	(state school)	160·00
W. ½ NW. ¼	8	23	55	(timber, April 16, 1890)	80·00
NW. ¼ SW. ¼	8	23	55	(state school)	40·00
NE. ¼ NW. ¼	18	23	55	(school land)	40·00
Lot (NW. ¼ NW.) ¼	18	23	55	(school land)	39·18
SE. ¼ SE. ¼	1	23	56	(preemption, Jan. 18, 1889)	40·00
					1,075·18

Reservoir Site No. 45.

Is situated in Bent and Otero Counties, Colorado, in a depression on the open plains, about 3 miles west of Adobe Creek and north of Horse Creek, and 8 miles south or Kilburn, on the Missouri Pacific Railroad.

No drainage area of importance. To be supplied by ditch from the Arkansas River.

Location of site, T. 21 S., R. 54 W., Secs. 25 and 36; T. 21 S., R. 53 W., Secs. 30 and 31; T. 22 S., R. 54 W., Secs. 1 and 12; T. 22 S., R. 53 W., Sec. 6.

No dam; it is proposed to empty the basin to a depth of 20 feet only, by an open cut.

No bench mark.

Area of reservoir, about 1,680 acres.

Capacity of reservoir, about 21,470 acre-feet.

Capacity to depth of 20 feet, 15,820 acre-feet.

No cultivated land.

Irrigable land adjoining below.

Lands segregated.

					Acres.
All except SE. ¼ SE. ¼	Sec. 30,	T. 21 S.,	R. 53 W.		623·04
SW. ¼	31	21	53		149·09
NW. ¼ NW. ¼	31	21	53		34·92
S. ½ NW. ¼	31	21	53		74·77
SE. ¼ NE. ¼	25	21	54		40·00
SE. ¼	25	21	54		160·00
E. ½	36	21	54		320·00
SE. ¼ NW. ¼	36	21	54		40·00
E. ½ SW. ¼	36	21	54		80·00
W. ½	6	22	53		297·81
E.. ½	1	22	54		320·81
E. ½ NW. ¼	1	22	54		81·01
E. ½ SW. ¼	1	22	54		80·00
NE. ¼ NW. ¼	12	22	54		40·00
N. ½ NE. ¼	12	22	54		80·00
Area segregated					2,421·45

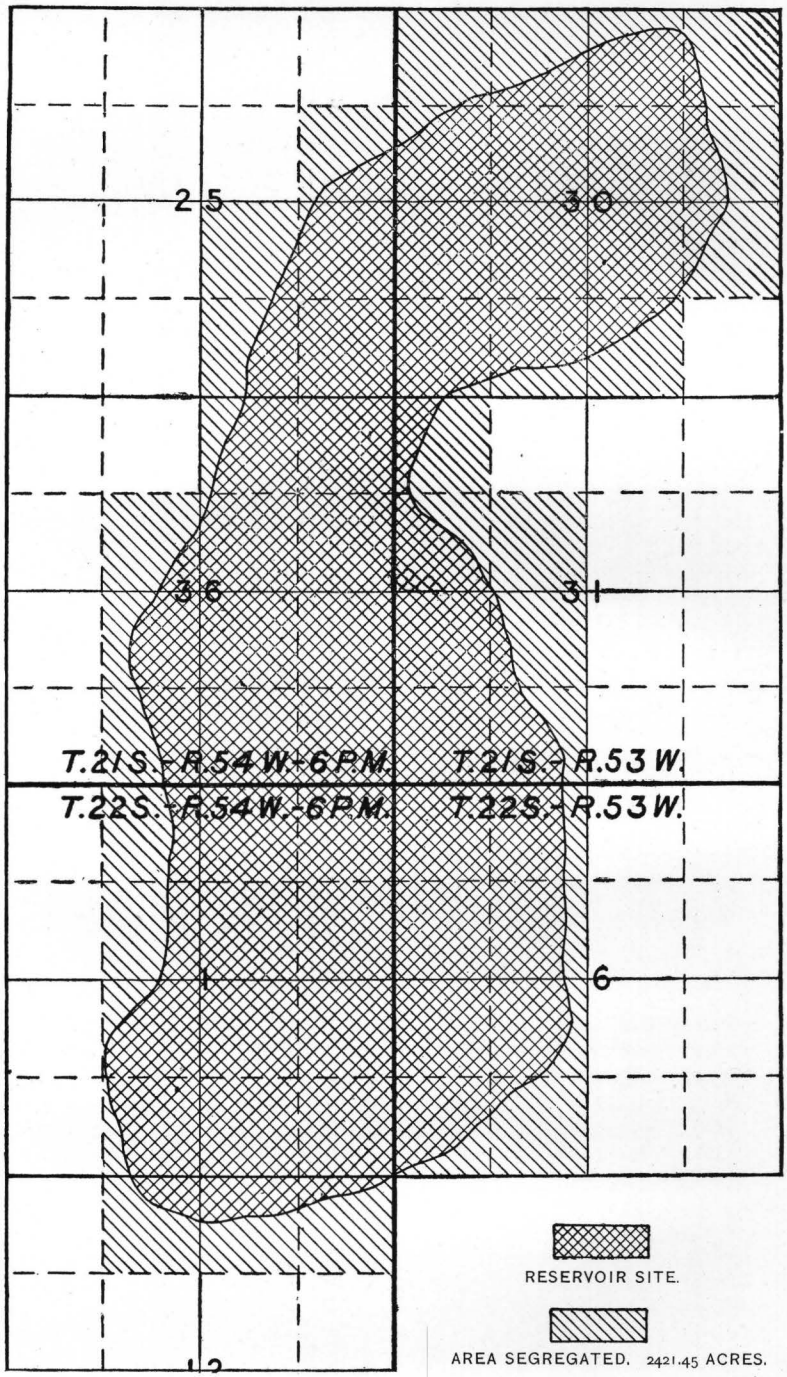


FIG. 148.—Reservoir Site No. 45, 12 miles northwest of La Junta, Colorado.

Action affecting titles to lands segregated for Reservoir Site No. 45 has been taken as follows:

					Acres.
N. ½ SE. ¼	Sec. 30,	T. 21 S.,	R. 53 W.	(timber, April 15, 1887)	80·00
SW. ¼ SE. ¼	30,	21	53	(timber, April 15, 1887)	40·00
SW. ¼	31	21	53	(timber, April 13, 1887)	149·09
SE. ¼ NE. ¼	25	21	54	(filing, June 21, 1887)	40·00
SE. ¼	25	21	54	(filing, May 30, 1887)	160·00
NW. ¼	6	22	53	(timber, March 29, 1887)	148·86
SW. ¼	6	22	53	(filing, June 2, 1887)	148·95
NE. ¼	1	22	54	(timber, April 2, 1882)	160·81
SE. ¼	1	22	54	(preemption, September 6, 1888)	160·00
E. ½ NW. ¼	1	22	54	(filing, June 21, 1887)	81·01
E. ½ SW. ¼	1	22	54	(preemption, September 21, 1888)	80·00
NE. ¼ NW. ¼	12	22	54	(timber, March 30, 1887)	40·00
N. ½ NE. ¼	12	22	54	(preemption, July 27, 1888)	80·00
					1,368·72

Reservoir Site No. 46.

Is situated in Kiowa and Bent Counties, Colorada, in a depression on the plains, just east of Adobe Creek, and 10 miles southeast from Arlington on the Missouri Pacific Railroad.

No drainage area of importance. To be supplied by ditch from the Arkansas River.

Location of site, T. 20 S., R. 52 W., Secs. 27, 28, 29, 31, 32, 33, and 34; T. 21 S., R. 52 W., Secs. 3, 4, 5, 7, 8, 9, 17.

No dam. It is proposed to empty the basin to a depth of 20 feet by an open cut.

No bench mark.

Area of reservoir site, approximately, 4,160 acres.

Capacity of reservoir, approximately, 73,300 acre-feet.

Capacity to depth of 20 feet, 43,300 acre-feet.

No cultivated land in the basin.

Irrigable land immediately below.

Lands segregated for reservoir.

				Acres.
SE. ¼ SE. ¼	Sec. 27, T. 20 S.,	R. 52 W.		40·00
W. ½ SE. ¼	27	20	52	80·00
NE. ¼ SW. ¼	27	20	52	40·00
S. ½ SW. ¼	27	20	52	80·00
S. ½	28	20	52	320·00
SE. ¼	29	20	52	160·00
E. ½ SW. ¼	29	20	52	80·00
E. ½ SE. ¼	31	20	52	80·00
All	32	20	52	640·00
All	33	20	52	640·00
W. ½	34	20	52	320·00
W. ½ NE. ¼	34	20	52	80·00
NW. ¼ SE. ¼	34	20	52	40·00
Lot 2	3	21	52	28·55
W. ½ Lot 6	3	21	52	40·00
Lot 3	3	21	52	28·65
Lot 4	3	21	52	28·75
Lot 5	3	21	52	80·00

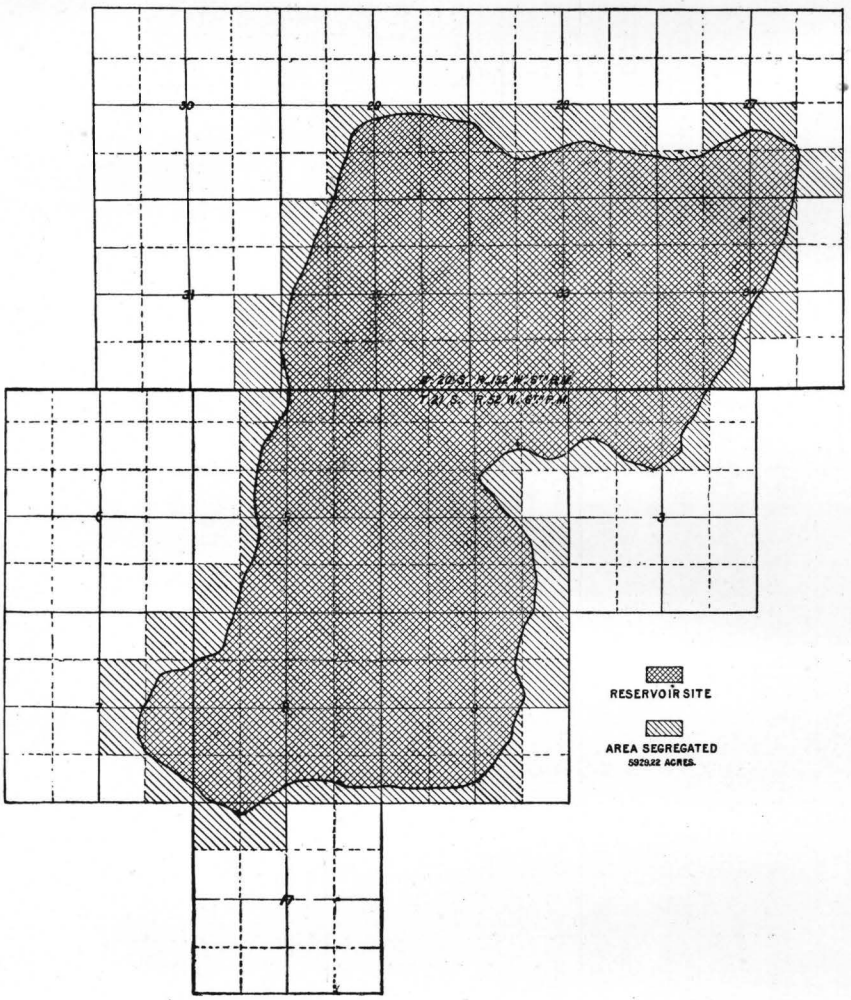


FIG. 149.—Reservoir Site No. 46, twelve miles north of Las Animas.

					Acres.
Lot	1	Sec. 4,	T. 21 S.,	R. 52 W.	29·12
Lot	2	4	21	52	29·13
Lot	3	4	21	52	29·13
Lot	4	4	21	52	29·14
Lot	5	4	21	52	80·00
Lot	6	4	21	52	80·00
Lot	7	4	21	52	80·00
Lot	8	4	21	52	80·00
Lot	9	4	21	52	80·00
W. ½ Lot	10	4	21	52	40·00
S. ½		4	21	52	320·00
Lot	1	5	21	52	29·01
Lot	2	5	21	52	28·92
Lot	6	5	21	52	80·00
Lot	7	5	21	52	80·00

					Acres.
Lot 10	Sec. 5	T. 21 S.,	R. 52		80·00
SE. ¼	5	21	52		160·00
NE. ¼ SW. ¼	5	21	52		40·00
Lot 3	5	21	52		28·82
E. ½ Lot 5	5	21	52		40·00
E. ½ Lot 8	5	21	52		40·00
E. ½ Lot 9	5	21	52		40·00
S. ½ SW. ¼	5	21	52		80·00
NE. ¼ NE. ¼	7	21	52		40·00
S. ½ NE. ¼	7	21	52		80·00
N. ½ SE. ¼	7	21	52		80·00
SE. ¼ SE. ¼	7	21	52		40·00
All	8	21	52		640·00
N. ½	9	21	52		320·00
W. ½ SE. ¼	9	21	52		80·00
SW. ¼	9	21	52		160·00
N. ½ NW. ¼	17	21	52		80·00
Area segregated					5,929·22

Action affecting titles to lands segregated for Reservoir Site No. 46 has been taken as follows:

					Acres.
E. ½ SW. ¼	Sec. 29,	T. 20 S.,	R. 52 W.	(timber, September 19, 1887)	80·00
E. ½ SE. ¼	31	20	52	(timber, September 16, 1887)	80·00
SE. ¼	32	20	52	(timber, November 5, 1887)	160·00
SW. ¼	33	20	52	(timber, August 8, 1887)	160·00
SW. ¼	34	20	52	(timber, August 6, 1887)	160·00
Lots 2, 3, 4, 5, and W. ½ of 6, Sec. 3, T. 21 S., R. 52 W. (State school land)					205·95
Lots 1, 2, 3, 4, 5, 6, 7, 8, 9, and W. ½ of 10, Sec. 4, T. 21 S., R. 52 W. (State school land)					396·52
Lots 1, 2, 3, 6, 7, 10; E. ½ of 5; E. ½ of 8; E. ½ of 9; Sec. 5, T. 21 S., R. 52 W. (State school land)					446·75
SE. ¼	Sec. 5,	T. 21 S.	R. 52 W.	(State school land)	160·00
NE. ¼ SW. ¼	5	21	52	(timber, March 28, 1890)	40·00
S. ½ SW. ¼	5	21	52	(timber, March 28, 1890)	80·00
NE. ¼ NE. ¼	7	21	52	(State school land)	40·00
E. ½	8	21	52	(State school land)	320·00
NW. ¼	8	21	52	(State school land)	160·00
					1,549·22

RESERVOIR SITE NO. 47.

Is situated in Lake County, Colorado, on the Northwest Branch of the Tennessee Fork of the Arkansas River.

Drainage area about 20 square miles, on the east slope of the main range. Heavily timbered. Streams have continuous flow.

Location of site, T. 8 S., R. 80 W., Secs. 17, 18, 19, 20.

Location of dam, SW. ¼ of SW. ¼, Sec. 17, and NW. ¼ of NW. ¼, Sec. 20.

Height of dam, 50 feet.

Bench mark at the north end of dam, cut in the rock thus: $\frac{\text{B. M.}}{\text{U. S. G. S.}}$ Altitude above sea level, approximately, 10,600 feet.

Area of reservoir site, approximately, 420 acres.

Capacity of reservoir, approximately, 9,600 acre-feet.

Spillway to southwest of dam about 300 feet, over rock.

Material for dam construction near at hand.
No cultivated land on the site.
Irrigable land down the Arkansas Valley.

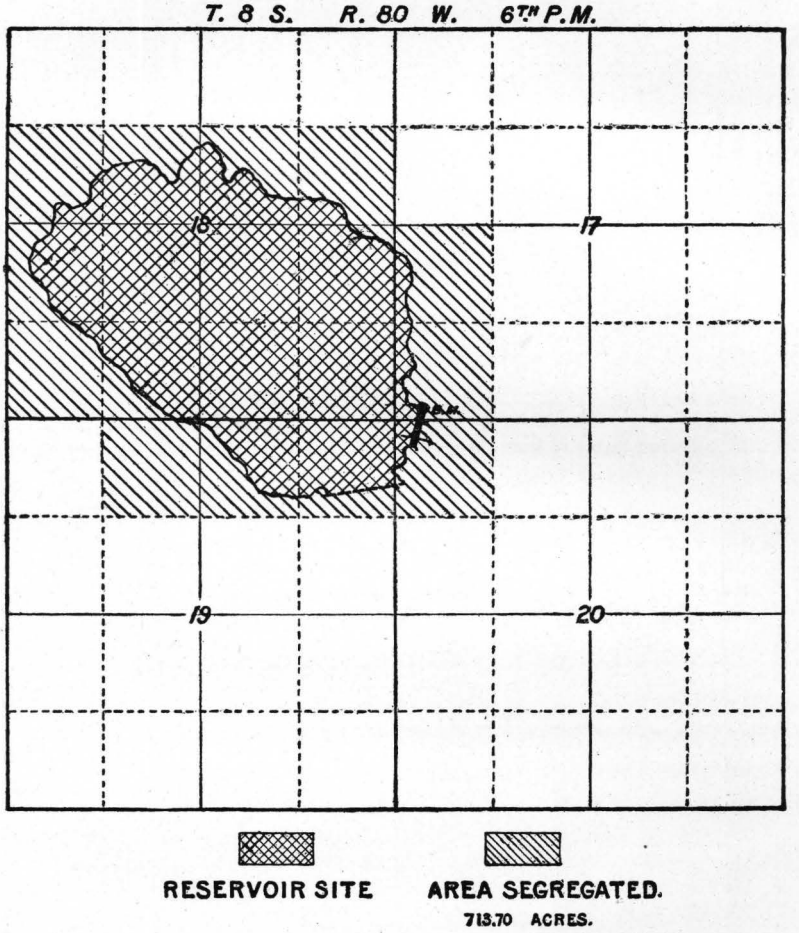


FIG. 150—Reservoir Site No. 47, on West Branch Tennessee Fork of Arkansas River.

Lands segregated for reservoir.

				Acres.
W. ½ SW. ¼ Sec.	17,	T. 8 S.,	R. 80 W	80·00
SE. ¼	18	8	80	160·00
E. ½ SW. ¼	18	8	80	80·00
NW. ¼ SW. ¼	18	8	80	37·86
SW. ¼ SW. ¼	18	8	80	37·89
S. ½ NE. ¼	18	8	80	80·00
SE. ¼ NW. ¼	18	8	80	40·00
SW. ¼ NW. ¼	18	8	80	37·95
N. ½ NE. ¼	19	8	80	80·00
NE. ¼ NW. ¼	19	8	80	40·00
NW. ¼ NW. ¼	20	8	80	40·00
Area segregated				713·70

Action affecting titles to lands segregated for Reservoir Site No. 47 has been taken as follows:

Sections 17, 18, 19, and 20 are designated as mineral lands, but no claims can be identified.

RESERVOIR SITE NO. 48.

Situated in Lake County, Colorado, on the East Fork of the Arkansas River, near the junction.

Drainage area of about 30 square miles; cleared of timber; continuous flow of streams.

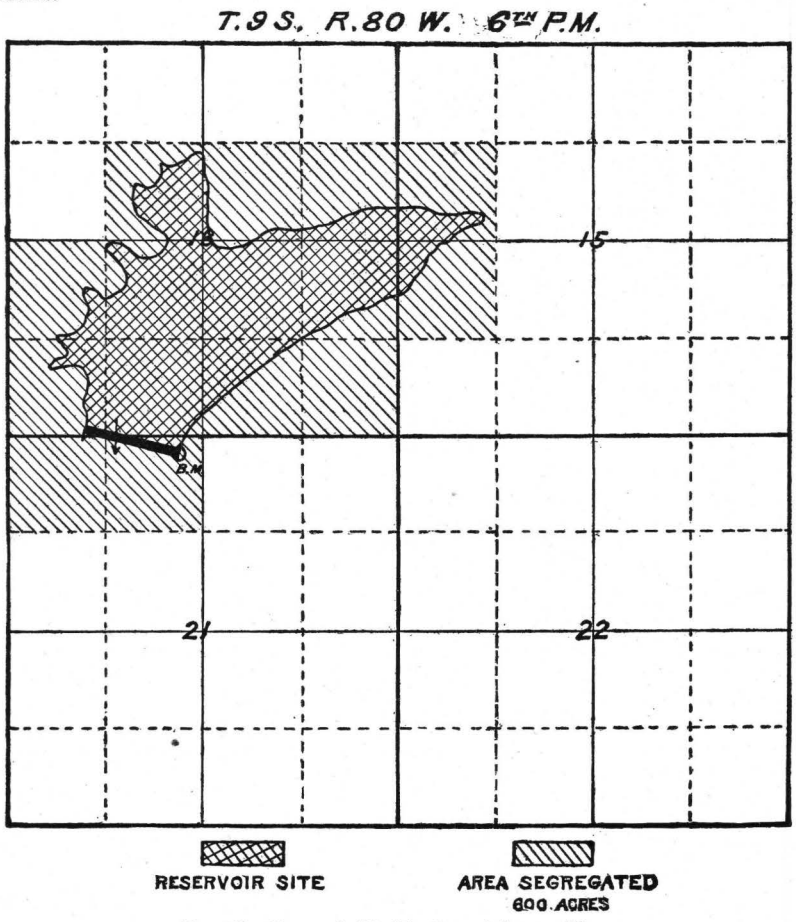


FIG. 151.—Reservoir Site No. 48, on Arkansas River.

Location of site, T. 9 S., R. 80 W., Secs. 15, 16, 21, and 22.

Location of dam, SW. ¼ of SW., Sec. 16, and NE. ¼ of NW. ¼, Sec. 21.

Height of dam, 45 feet.

Bench mark at the east end of the dam crest, cut on rock thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 10,100 feet.

Area of reservoir site, approximately, 250 acres.

Capacity of reservoir, approximately, 4,100 acre-feet.

Spillway over dam.

Material for dam construction at the site.
The greater portion of land on the site is improved.
Irrigable lands immediately below, in the Arkansas River Valley.

Lands segregated for reservoir.

				Acres.
SW. ¼ NW. ¼ Sec.	15,	T. 9 S.,	R. 80 W.	40
NW. ¼ SW. ¼	15	9	80	40
S. ½ NE. ¼	16	9	80	80
SE. ¼ NW. ¼	16	9	80	40
SE. ¼	16	9	80	160
SW. ¼	16	9	80	160
N. ½ NW. ¼	21	9	80	80
Area segregated				600

Action affecting titles to lands segregated for Reservoir Site No. 48 has been taken as follows:

					Acres.
SW. ¼ NW. ¼ Sec.	15,	T. 9 S.,	R. 80 W.	(homestead, January 29, 1889)	40
NW. ¼ SW. ¼	15	9	80	(Leadville mineral applications Nos. 541 and 532)	40
S. ½ NE. ¼	16	9	80	(homestead, August 26, 1880)	80
SE. ¼ NW. ¼	16	9	80	(homestead, August 26, 1880)	40
NE. ¼ SE. ¼	16	9	80	(homestead, August 26, 1880)	40
SE. ¼ SE. ¼	16	9	80	(homestead, September 6, 1881)	40
NW. ¼ SE. ¼	16	9	80	(homestead, August 26, 1880. Leadville mineral entry No. 3360)	40
W. ½ SW. ¼ SE. ¼	16	9	80	(homestead, August 26, 1880. Leadville mineral entry No. 3360)	20
E. ½ SW. ¼	16	9	80	(homestead, August 26, 1880. Leadville mineral entry No. 3340)	80
					380

Reservoir Site No. 49.

Is situated in Chaffee County, Colorado, on Pine Creek, 5 miles west of the Arkansas River.

Drainage area, about 20 square miles; partly wooded; stream has continuous flow.

Location of site, T. 12 S., R. 79 W., Secs. 33 and 34 and T. 13 S., R. 79 W., Secs. 3 and 4.

Location of dam, SE. ¼ of SE. ¼, Sec. 33, T. 12 S., R. 79 W.

Height of dam, 60 feet.

Bench mark at north end of dam, cut on stone thus: $\frac{\text{B. M.}}{\text{U. S. G. S. 1890.}}$ Altitude above sea level, approximately, 8,545 feet.

Area of reservoir site, approximately, 130 acres.

Capacity of reservoir, approximately, 2,500 acre-feet.

Spillway to southeast of dam 200 feet, over rock.

Material for dam construction near at hand.

No cultivated land on the site.

Irrigable land southward about 5 miles, in the Arkansas River basin.

Recommended for segregation in letter dated February 27, 1891.

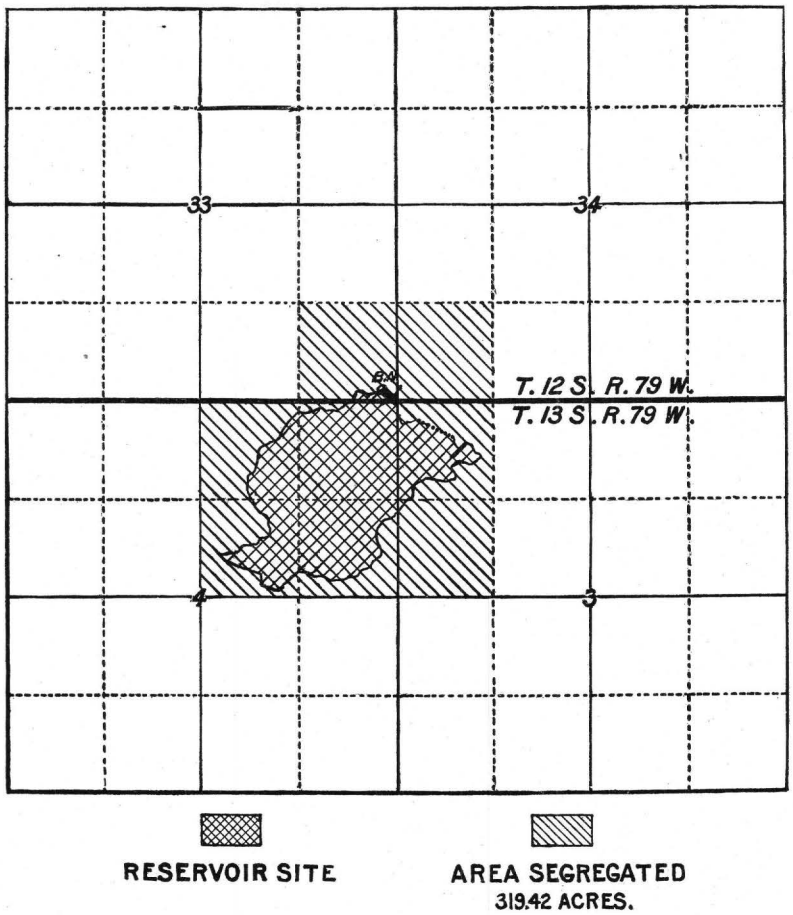


FIG. 152.—Reservoir Site No. 49, on Pine Creek.

Lands segregated for reservoir.

				Acres.
SW. ¼ SW. ¼ Sec.	34,	T. 12 S.,	R. 79 W	40·00
SE. ¼ SE. ¼	33	12	79	40·00
NW. ¼ NW. ¼	3	13	79	39·82
SW. ¼ NW. ¼	3	13	79	40·00
NE. ¼ NE. ¼	4	13	79	39·82
NW. ¼ NE. ¼	4	13	79	39·78
S. ½ NE. ¼	4	13	79	80·00
Area segregated				319·42

Land Office records show area segregated to be all public lands.

RESERVOIR SITE NO. 50.

Is situated in Chaffee County, Colorado, on Pine Creek, about 3 miles above its junction with the Arkansas River.

Drainage area about 25 square miles. Partly wooded. Stream has continuous flow.

Location of site, T. 12 S., R. 79 W., Secs. 26, 27, 34, and 35.

Location of dam, SW. ¼ of SW. ¼, Sec. 26.

Height of dam, 70 feet.

Bench mark at south end of dam, cut on rock thus: U. B. M. S. G. S. 1890. Altitude above sea, approximately, 8,600 feet.

Area of reservoir site, approximately, 90 acres.

Capacity of reservoir, approximately, 1,500 acre-feet.

Spillway over dam.

Material for dam construction on the site.

No cultivated land in the site.

Irrigable lands lie in the valley of the Arkansas River eastward and southeastward.

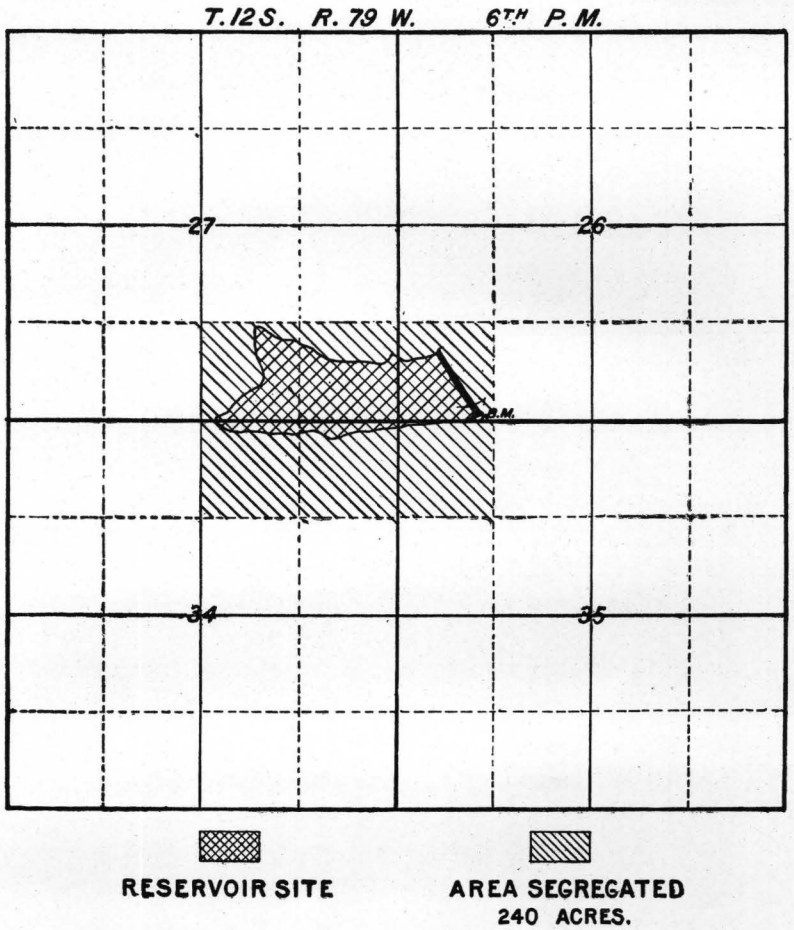


FIG. 153.—Reservoir Site No. 50, on Pine Creek.

Recommended for segregation in letter dated February 27, 1891.

Lands segregated for reservoir.

					Acres.
SW. ¼ SW. ¼	Sec. 26,	T. 12 S.,	R. 79 W		40
S. ½ SE. ¼	27	12	79		80
N. ½ NE. ¼	34	12	79		80
NW. ¼ NW. ¼	35	12	79		40
Area segregated					240

Action affecting titles to lands segregated for Reservoir Site No. 50 has been taken as follows:

					Acres.
NW. ¼ NE. ¼	Sec. 34,	T. 12 S.,	R. 79 W.	(homestead, March 6, 1886)	40
NW. ¼ NW. ¼	35	12	79	(homestead, January 30, 1882)	40
					80

Mineral protest, 1883, No. 3236.

Reservoir Site No. 51.

Is situated in Chaffee County, Colorado, on the Arkansas River, at junction with Seven Mile Creek.

Drainage area of about 600 square miles, extending back to mountain crests on the east and west; heavily timbered on the western mountain slopes, lightly timbered on the eastern slopes and bare in the valley. Continuous flow of all streams.

Location of site, T. 13 S., R. 79 W., Secs. 25, and T. 13 S., R. 78 W., Secs. 30, 31, and 32, and T. 14 S., R. 78 W., Secs. 5 and 6.

Location of dam, N. ½ of NW. ¼, Sec. 5, T. 14 S., R. 78 W.

Height of dam, 120 feet.

Bench mark, at west end of dam, cut in the rock thus: U. S. G. S. B. M. 1890. Altitude above sea, approximately, 8,000 feet.

Area of reservoir site, approximately, 420 acres.

Capacity of reservoir, approximately, 11,940 acre-feet.

Spillway northwest of dam about 600 feet and over rock.

Material for dam construction on the dam site.

Greater portion of the site is improved.

Irrigable lands lie below in the Arkansas River Valley.

Lands segregated for reservoir.

				Acres.
SW. ¼ NE. ¼	Sec. 30,	T. 13 S.,	R. 78 W.	40·00
S. ½ NW. ¼	30	13	78	82·92
SW. ¼	30	13	78	166·10
W. ½ SE. ¼	30	13	78	80·00
NE. ¼ NW. ¼	31	13	78	40·00
W. ½ NE. ¼	31	13	78	80·00
SE. ¼ NE. ¼	31	13	78	40·00
SE. ¼	31	13	78	160·00
SE. ¼ NW. ¼	32	13	78	40·00
SW. ¼	32	13	78	160·00
SW. ¼ SE. ¼	32	13	78	40·00
N. ½ SE. ¼	25	13	79	80·00
SE. ¼ SE. ¼	25	13	79	40·00
NW. ¼ NE. ¼	5	14	78	38·15
N. ½ NW. ¼	5	14	78	76·60
NE. ¼ NE. ¼	6	14	78	38·60
Area segregated				1,202·37

Action affecting titles to lands segregated for Reservoir Site No. 51 has been taken as follows:

NW. ¼ SE. ¼	Sec. 25,	T. 13 S.,	R. 79 W.	(preemption July 5, 1889)	40·00
NE. ¼ SE. ¼	25	13	79	(filing, July 26, 1887)	40·00
SE. ¼ SE. ¼	25	13	79	(preemption, July 15, 1889)	40·00
SW. ¼ NE. ¼	30	13	78	(filing, July 5, 1881; filing, March 21, 1882	40·00

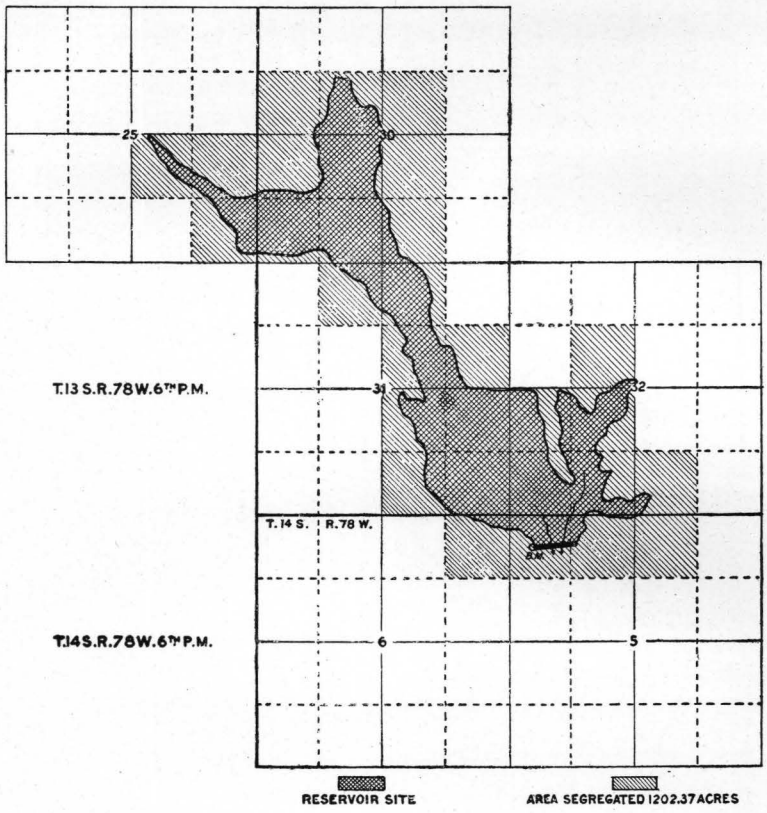


FIG. 154.—Reservoir Site No. 51, on Arkansas River.

					Acres.
SW. ¼ NW. ¼	Sec. 30,	T. 13 S.,	R. 78 W	(preemption, January 18, 1883)	42·92
SW. ¼ SW. ¼	30	13	78	(preemption, July 15, 1889; filing, August 6, 1886)	43·09
E. ½ SW. ¼	30	13	78	(filing, August 5, 1886)	80·00
NW. ¼ SW. ¼	30	13	78	(filing, August 5, 1886)	43·01
NE. ¼ NW. ¼	31	13	78	(filing, June 18, 1890)	40·00
W. ½ NE. ¼	31	13	78	(filing, June 18, 1890)	80·00
N. ½ SE. ¼	31	13	78	(preemption, September 15, 1890)	80·00
S. ½ SE. ¼	31	13	78	(filing, June 17, 1890)	80·00
SE. ¼ NW. ¼	32	13	78	(filing, August 15, 1881)	40·00
E. ½ SW. ¼	32	13	78	(preemption, May 14, 1884)	80·00
W. ½ SW. ¼	32	13	78	(filing, July 5, 1887)	80·00
SW. ¼ SE. ¼	32	13	78	(preemption, May 14, 1884)	40·00
NW. ¼ NE. ¼	5	14	78	(filing, July 20, 1881)	40·00
SE. ¼ NE. ¼	5	14	78	(preemption, September 16, 1890)	40·00
					969·02

RESERVOIR SITE NO. 52.

Is situated in Fremont County, Colorado, on Oak Grove Creek, half a mile south of Cotopaxi and three-fourths of a mile above the junction of Oak Grove Creek with the Arkansas River.

Drainage area of about 30 square miles on the foothill slopes of the west mountain range. Lightly wooded. Oak Grove Creek has a light continuous flow.

Location of site, T. 48 N., R. 12 E. (N. M. meridian), Sec. 31, and T. 47 N., R. 12 E., Sec. 6.

Height of dam, 84 feet.

Bench mark cut on rock in place at east end of dam crest, thus: B. M. U. S. G. S. 1890. Altitude above sea, approximately, 6,425 feet.

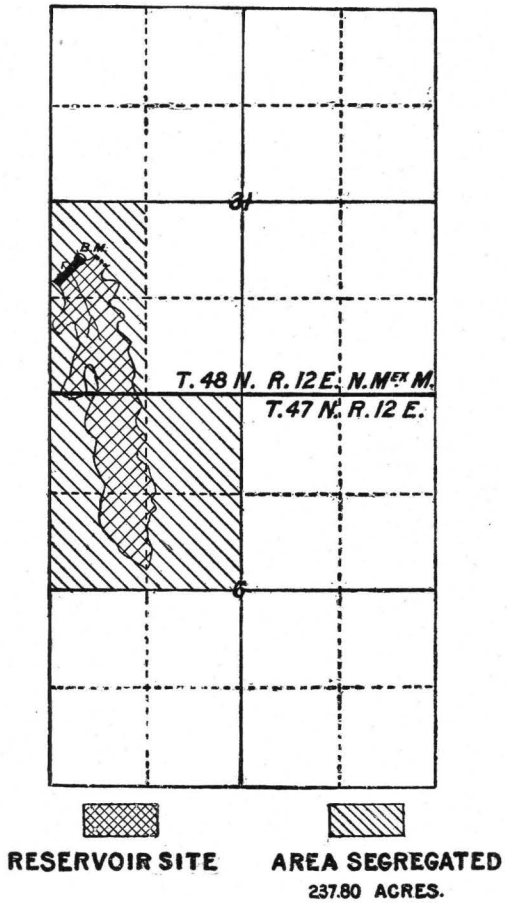


FIG. 155.—Reservoir Site No. 52, on Oak Grove Creek.

Area of reservoir site, approximately, 80 acres.
Capacity of reservoir, approximately, 1,310 acre-feet.
Spillway at east end of dam.
Material for dam construction on the site.
No cultivated land on the site.
Irrigable lands down the Arkansas River Valley to eastward.
Recommended for segregation in letter dated February 27, 1891.

Lands segregated for reservoir.

	Acres.
W. ½ SW. ¼ Sec. 31, T. 48 N., R. 12 E	76·95
NW. ¼ 6 47 12	160·85
Area segregated	237·80

RESERVOIR SITE NO. 53.

Is situated in Pueblo County, Colorado, on Rock Creek, 8 miles above its junction with the Arkansas River.

Drainage area of about 30 square miles, running back to low foothills. Not wooded. Usually dry, but subject to floods.

Location of site T. 21 S., R. 66 W., Secs. 19, 20, 29, 30, and 31.

Location of dam, SE. ¼ of NE. ¼, Sec. 20.

Height of dam 70 feet.

Bench mark cut in natural rock near the southwest corner of Sec. 20, thus: B. M. U. S. G. S. 1890.

Altitude above sea, approximately, 5,200 feet.

Area of reservoir site, approximately, 300 acres.

Capacity of reservoir, approximately, 6,600 acre-feet.

Spillway just beyond western end of dam over natural rock.

Material for dam construction near at hand.

No cultivated land on the site.

No irrigable land near at hand. The reservoir could best be used as a feeder to the Arkansas River at low-water stages.

Lands segregated for reservoir.

					Acres.
SE. ¼ SE. ¼	Sec. 19,	T. 21 S.,	R. 66 W		40
S. ½ NE. ¼	20	21	66		80
SE. ¼ NW. ¼	20	21	66		40
N. ½ SE. ¼	20	21	66		80
SW. ¼	20	21	66		160
SW. ¼ SE. ¼	20	21	66		40
N. ½ NW. ¼	29	21	66		80
SW. ¼ NW. ¼	29	21	66		40
NW. ¼ SW. ¼	29	21	66		40
SE. ¼ NW. ¼	29	21	66		40
SW. ¼ SW. ¼	29	21	66		40
NE. ¼	30	21	66		160
E. ½ SE. ¼	30	21	66		80
NE. ¼ NE. ¼	31	21	66		40
Area segregated					960

Action affecting titles to lands segregated for Reservoir Site No. 53 has been taken as follows:

					Acres.
S. ½ NE. ¼	Sec. 20,	T. 21 S.,	R. 66 W.	(homestead, November 6, 1889)	80
SE. ¼ NW. ¼	20	21	66	(preemption, August 10, 1888)	40
N. ½ SE. ¼	20	21	66	(preemption, August 21, 1888)	80
SE. ¼ SW. ¼	20	21	66	(homestead, July 19, 1887)	40
N. ½ SW. ¼	20	21	66	(filing, May 15, 1888)	80
SW. ¼ SE. ¼	20	21	66	(preemption, August 12, 1889)	40
NE. ¼ NW. ¼	29	21	66	(homestead, August 12, 1889)	40
NW. ¼ NW. ¼	29	21	66	(preemption, January 31, 1889)	40
SW. ¼ NW. ¼	29	21	66	(preemption, August 23, 1879)	40
NW. ¼ SW. ¼	29	21	66	(preemption, August 23, 1879)	40
SE. ¼ NW. ¼	29	21	66	(preemption, August 12, 1889)	40
SW. ¼ SW. ¼	29	21	66	(preemption, August 23, 1879)	40
NW. ¼ NE. ¼	Sec. 30,	T. 21 S.,	R. 66 W.	(preemption, May 31, 1889)	40
NE. ¼ NE. ¼	30	21	66	(preemption, January 3, 1889)	40
SE. ¼ NE. ¼	30	21	66	(filing, July 5, 1876)	40
NE. ¼ SE. ¼	30	21	66	(timber, February 21, 1884)	40
					760

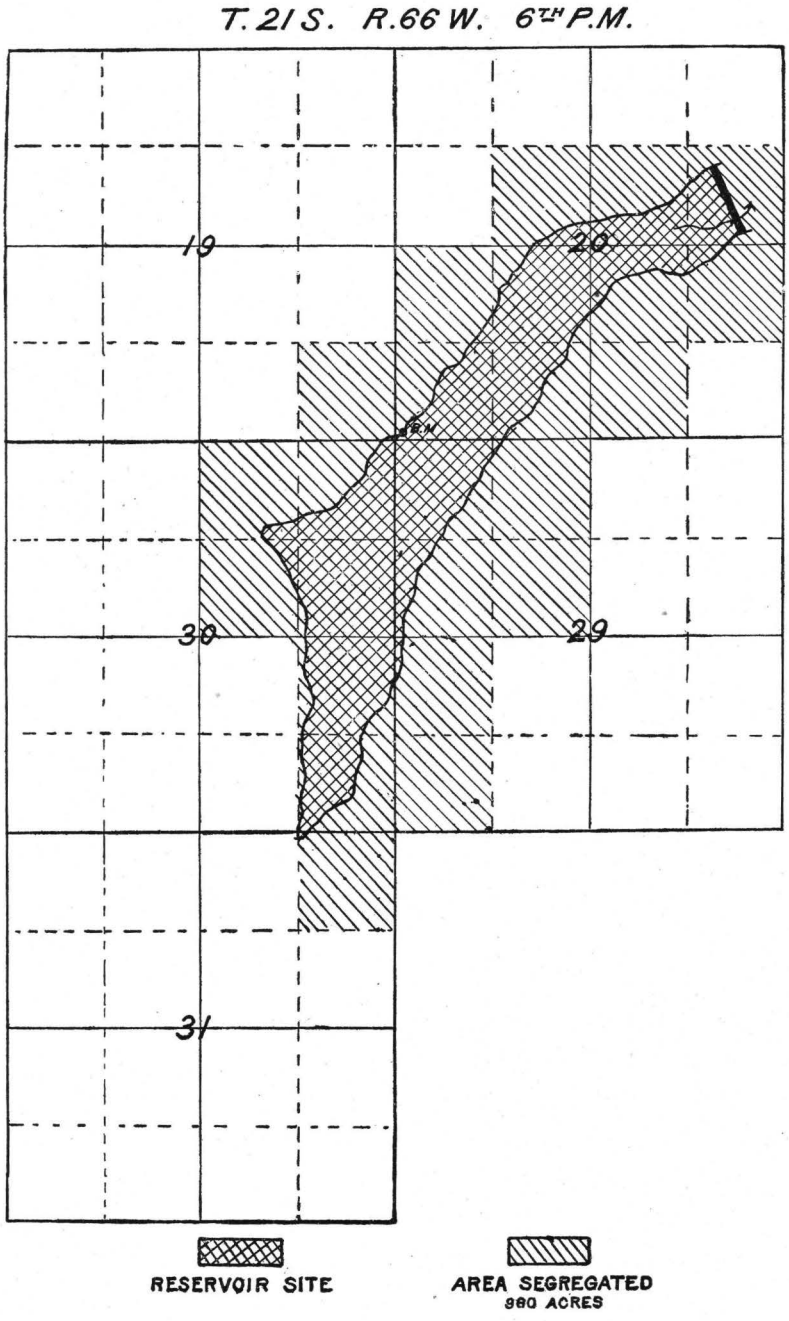


FIG. 156.—Reservoir Site No. 53, on Rock Creek.

Reservoir Site No. 54.

Is situated in Otero and Las Animas counties, Colorado, on Timpas Creek, near its head.

Drainage area of about 75 square miles, among low, lightly wooded mesas. Creek has intermittent flow.

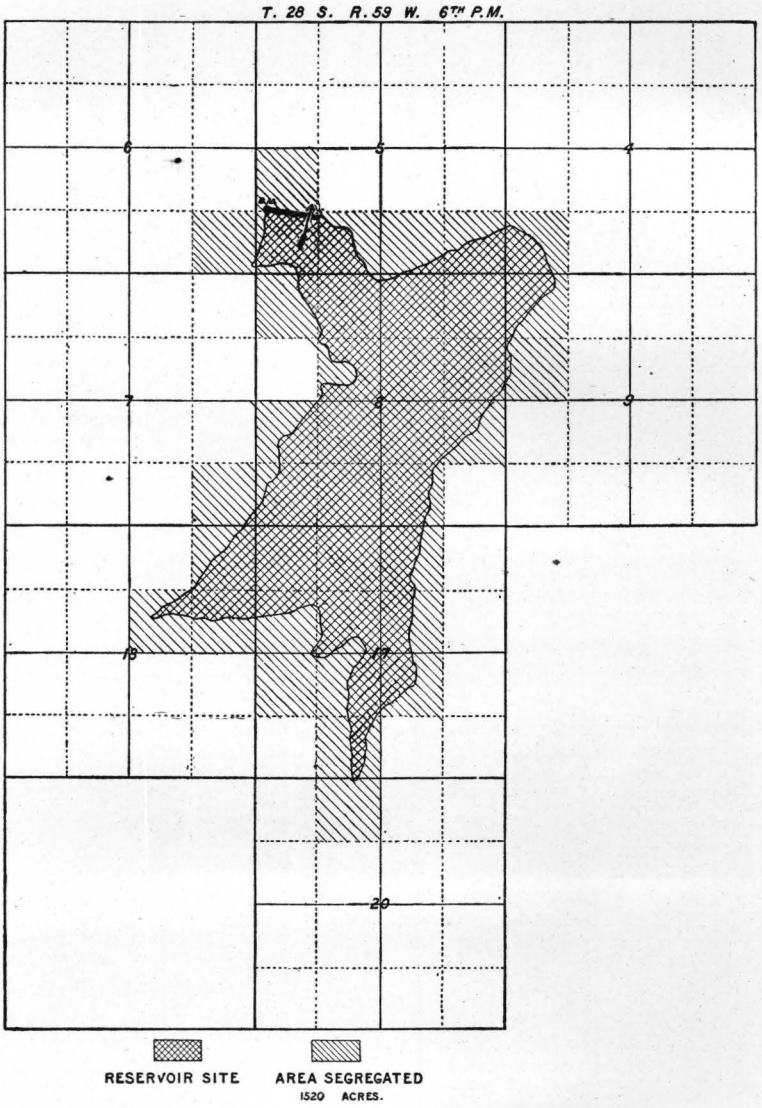


Fig. 157.—Reservoir site No. 54, on Timpas Creek.

Location of site, T. 28 S., R. 59 W., Secs. 4, 5, 6, 7, 8, 9, 17, 18, and 20.
Location of dam, S. ½ of SW. ¼, Sec. 5.
Height of dam, 88 feet.

Bench mark at west end of dam, cut in rock thus: B. M. U. S. G. S. 1890.
Altitude above the sea, approximately, 4,950 feet.
Area of reservoir site, approximately, 840 acres.
Capacity of reservoir, approximately, 13,640 acre-feet.
Spillway half mile to east of dam.
Material for dam construction at the site.
No cultivated land.
Irrigable lands lie downstream, a few miles to northeast.

Lands segregated.

					Acres.
SW. ¼ SW. ¼	Sec. 4,	T. 28 S.	R. 59 W.		40
S. ½ SE. ¼	5	28	59		80
S. ½ SW. ¼	5	28	59		80
NW. ¼ SW. ¼	5	28	59		40
SE. ¼ SE. ¼	6	28	59		40
SE. ¼ SE. ¼	7	28	59		40
NE. ¼	8	28	59		160
N. ½ NW. ¼	8	28	59		80
SE. ¼ NW. ¼	8	28	59		40
SW. ¼	8	28	59		160
N. ½ SE. ¼	8	28	59		80
SW. ¼ SE. ¼	8	28	59		40
W. ½ NW. ¼	9	28	59		80
W. ½ NE. ¼	17	28	59		80
NW. ¼	17	28	59		160
N. ½ SW. ¼	17	28	59		80
SE. ¼ SW. ¼	17	28	59		40
NW. ¼ SE. ¼	17	28	59		40
E. ½ NE. ¼	18	28	59		80
SW. ¼ NE. ¼	18	28	59		40
NE. ¼ NW. ¼	20	28	59		40
Area segregated					1,520

Action affecting titles to lands segregated for Reservoir Site No. 54 has been taken as follows:

	Acres.
NW. ¼ SW. ¼ Sec. 5, T. 28 S., R. 59 W. (preemption September 6, 1884)	40

Reservoir Site No. 55.

Is situated in Las Animas County, Colorado, on the Las Animas River, at its junction with the Chaquaque.

Drainage area about 2,400 square miles, extending westward to the Culebra Range and southward to the Raton and Chicora Mesas and Mesa de Maya. Along the eastern slope of the Culebra Range there is a large slope well timbered; eastward to Trinidad there is a scattering of light trees. Eastward of Trinidad trees line the mesa slope occasionally. The Purgatoire and Chaquaque have a continuous flow.

Location of sight, T. 28 S., R. 56 W., Secs. 25, 35, and 36, and T. 29 S., R. 56 W., Secs. 1, 2, 3, 10, 11, 12, and 15, and T. 29 S., R. 55 W., Secs. 6 and 7.

Location of dam, SE. ¼ of SW. ¼, and SW. ¼ of SE. ¼, Sec. 25, and N. ½ of NW. ¼, Sec. 36, T. 28 S., R. 56 W.

Height of dam, 108 feet.

Bench-mark at northwest end of dam, cut in rock thus: B. M. U. S. G. S. 1890.

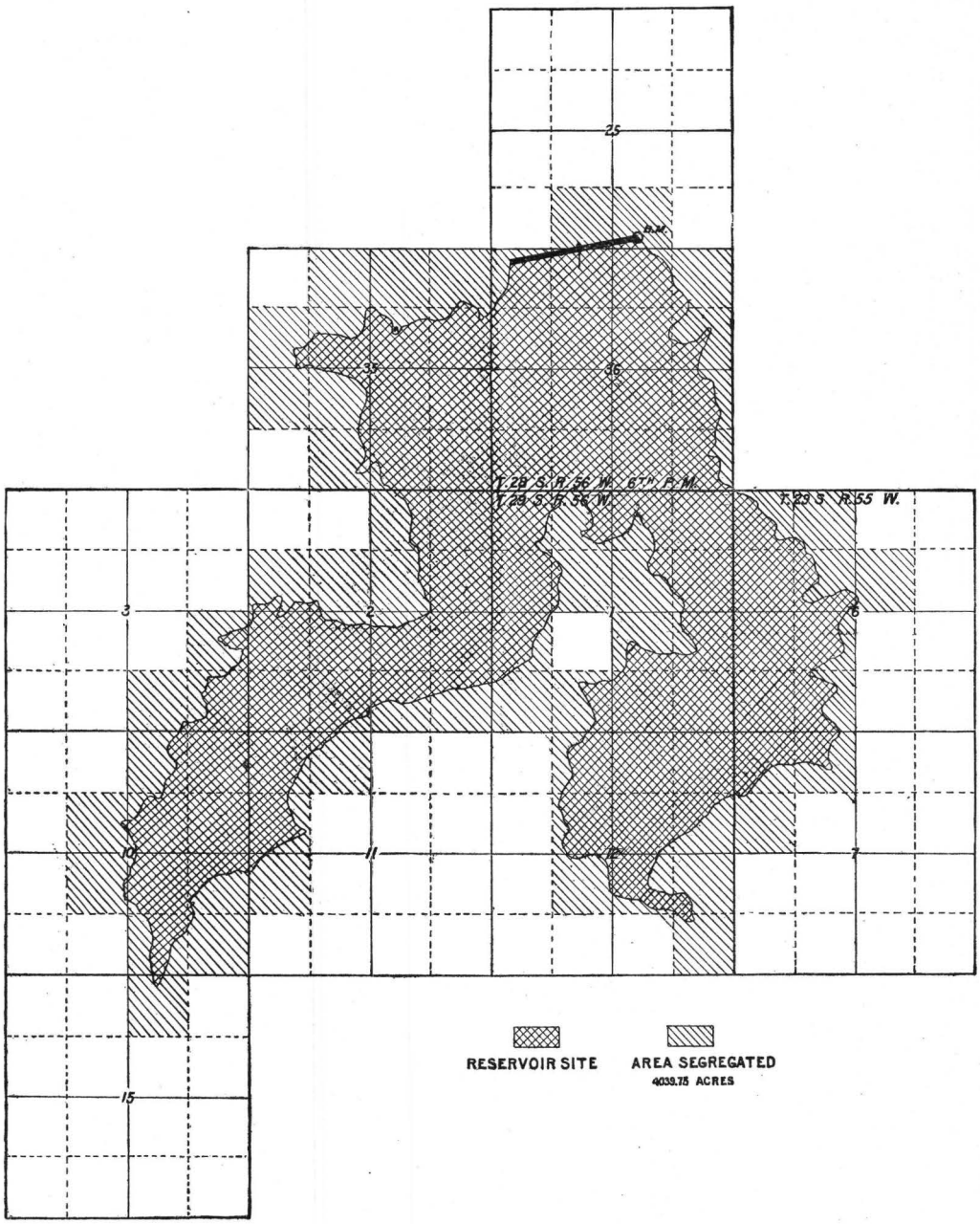
Altitude above sea, approximately, 4,450 feet.
Area of reservoir site, approximately, 2,360 acres.
Capacity of reservoir, approximately, 43,330 acre-feet.
Spillway over dam.
Material for construction at either end of dam.
A small proportion of improved land on site.
Irrigable lands along the Arkansas Valley 50 miles northeast.

Lands segregated for reservoir (*See* Pl. LV).

					Acres.
SW. ¼ SE. ¼	Sec. 25,	T. 28 S.,	R. 56 W		40·00
SE. ¼ SW. ¼	25	28	56		40·00
E. ½	35	28	56		320·00
NE. ¼ NW. ¼	35	28	56		40·00
S. ½ NW. ¼	35	28	56		80·00
N. ½ SW. ¼	35	28	56		80·00
SE. ¼ SW. ¼	35	28	56		40·00
All	36	28	56		640·00
W. ½	6	29	55		319·33
SW. ¼ NE. ¼	6	29	55		40·00
N. ½ NW. ¼	7	29	55		79·75
SW. ¼ NW. ¼	7	29	55		39·79
N. ½	1	29	56		320·38
SE. ¼	1	29	56		160·00
S. ½ SW. ¼	1	29	56		80·00
NW. ¼ SW. ¼	1	29	56		40·00
E. ½	2	29	56		320·49
S. ½ NW. ¼	2	29	56		80·00
SW. ¼	2	29	56		160·00
E. ½ SE. ¼	3	29	56		80·00
SW. ¼ SE. ¼	3	29	56		40·00
E. ½	10	29	56		320·00
SE. ¼ NW. ¼	10	29	56		40·00
NE. ¼ SW. ¼	10	29	56		40·00
N. ½ NW. ¼	11	29	56		80·00
SW. ¼ NW. ¼	11	29	56		40·00
NW. ¼ SW. ¼	11	29	56		40·00
NE. ¼	12	29	56		160·00
E. ½ NW. ¼	12	29	56		80·00
NE. ¼ SW. ¼	12	29	56		40·00
N. ½ SE. ¼	12	29	56		80·00
SE. ¼ SE. ¼	12	29	56		40·00
NW. ¼ NE. ¼	15	29	56		40·00
Area segregated					4,039·74

Action affecting titles to lands segregated for Reservoir Site No. 55 has been taken as follows:

					Acres.
N. ½ NE. ¼	Sec. 35,	T. 28 S.,	R. 56 W.	(homestead, July 19, 1880)	80·00
S. ½ SE. ¼	35	28	56	(homestead, June 4, 1883)	80·00
SE. ¼ SW. ¼	35	28	56	(deeded January 16, 1885)	40·00
	36	28	56	(school section)	640·00
NW. ¼ SE. ¼	1	29	56	(preemption, December 26, 1873)	40·00
E. ½ NW. ¼	1	29	56	(preemption, December 26, 1873)	80·12
W. ½ NW. ¼	1	29	56	(homestead, December 8, 1883)	80·17
E. ½ NE. ¼	2	29	56	(homestead, December 8, 1883)	80·22



RESERVOIR SITE, COLORADO, NO. 55.

					Acres.
N. ½ SW. ¼, SE. ¼ SW. ¼, and SW. ¼ SE. ¼, Sec. 2, T. 29 S., R. 56 W. (preemption February 10, 1886)					160·00
SE. ¼ NW. ¼ and W. ½ NE. ¼, Sec. 2, T. 29 S., R. 56 W. (filing January 16, 1885)					120·59
W. ½ SE. ¼ and S. ½ SW. ¼, Sec. 2, T. 29 S., R. 56 W. (filing December 23, 1867)					160·00
SE. ¼ Sec.	3,	T. 29 S.,	R. 56 W.	(homestead, October 6, 1883)	160·00
NW. ¼ NE. ¼	10	29	56	(homestead, October 16, 1883)	40·00
SW. ¼ SE. ¼	10	29	56	(homestead, January 2, 1887)	40·00
E. ½ SE. ¼	10	29	56	(homestead, March 13, 1880)	80·00
SE. ¼ NW. ¼	10	29	56	(homestead, October 16, 1883)	40·00
					1,751·10

MONTANA.

RESERVOIR SITES NUMBERED FROM 11 TO 38, INCLUSIVE.

Recommended for segregation in letter to Secretary of the Interior dated Feb. 27, 1891.

RESERVOIR SITE NO. 11.

Two miles above Martinsdale, on flat one-fourth mile south of Copperopolis road in Meagher County, Montana.

The drainage basin tributary to this reservoir includes about 10 square miles, mostly rolling prairie. The average elevation is 5,500 feet. There is but little running water in this area and no well defined stream at any time of the year. The timber is very sparsely distributed and of no commercial value.

Site located in T. 8 and 9 N., R. 11 E., principal meridian of Montana. It comprises parts of Sec. 33, T. 9 N., R. 11 E., and Secs. 3 and 4, T. 8 N., R. 11 E.

Dam located in SE. ¼ of SE. ¼, Sec. 33, T. 9 N., R. 11 E.

Height of dam, 15 feet.

Bench mark is a mound of dirt at water line at west end of dam. Altitude about 5,000 feet.

Elevation of top contour, 5,015 feet.

Area inclosed by top contour, 30 acres.

Capacity of reservoir, 160 acre-feet.

No stone in immediate vicinity, but easily obtainable.

Site not settled.

Irrigable lands adjacent to reservoir.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼ Sec.	33,	T. 9 N.,	R. 11 E.		80·0
Lot 4	3	8	11		43·2
Lot 3	3	8	11		43·0
Lot 1	4	8	11		43·6
Area segregated					209·8

Action affecting the titles to lands segregated for Reservoir Site No. 11 has been taken as follows:

					Acres.
S. ½ SE. ¼ Sec.	33,	T. 9 N.,	R. 11 E.		80·0
Lot 1	4	8	11		43·6
Lot 4	3	8	11		43·2
Lot 3	3	8	11		43·0
					209·8

Selected by Northern Pacific Railroad, February 26, 1885. Act of July 2, 1864. Resolution, May 31, 1870.

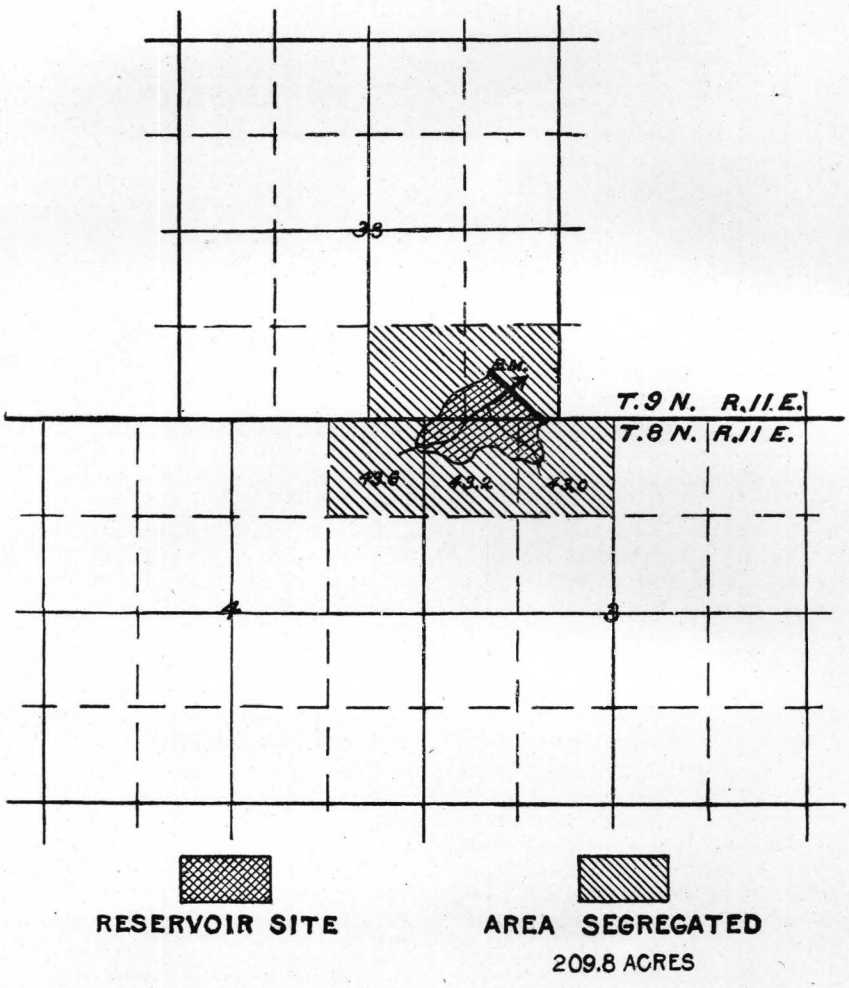


FIG. 158.—Reservoir Site No. 11, 2 miles above Martinsdale, on flat one-half mile south of Copperopolis road.

RESERVOIR SITE NO. 12.

Site 3½ miles above Martinsdale, one-half mile south of North Fork of Musselshell River, in Meagher County, Montana.

Altitude of drainage basin, from 4,900 to 7,600 feet; character of topography, mountainous.

Site located in T. 9 N., R. 11 E., Sec. 29.

Dam located in E. ½ of SE. ¼ Sec. 29.

Height of dam, 40 feet.

Bench mark, two rocks on top contour at north end of dam. Approximate altitude, 4,900 feet.

Altitude of top contour 4,900 feet.

Area of reservoir, 40 acres.

Approximate content of reservoir, 800 acre-feet.

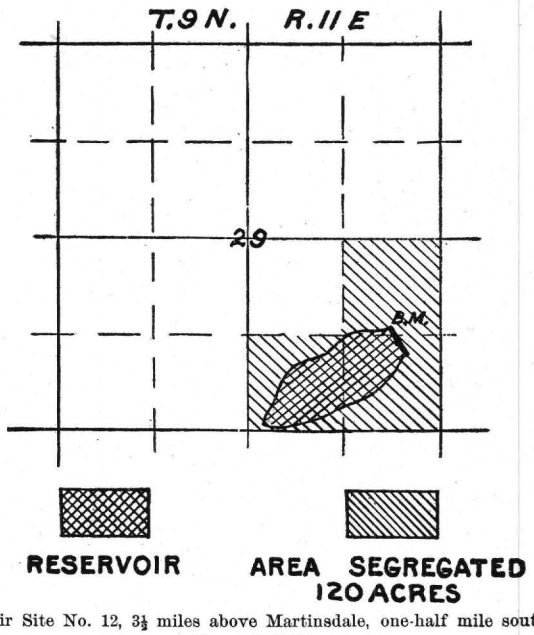


FIG. 159.—Reservoir Site No. 12, 3½ miles above Martinsdale, one-half mile south of North Fork Musselshell River.

Lands segregated for reservoir.

	Acres.
S. ½ SE. ¼ Sec. 29, T. 9 N., R. 11 E	80
NE. ¼ SE. ¼ 29 9 11	40
Area segregated	120

Action affecting the title of lands segregated for Reservoir Site No. 12 has been taken as follows:

E. ½ SE. ¼ Sec. 29 T. 9 N., R. 11 E (homestead, July 3, 1890)	80
SW. ¼ SE. ¼ 29 9 11	40
	120

Selected by Northern Pacific Railroad, February 26, 1885. Act of July 2, 1864. Resolution of May 31, 1870. Section 29. Reserved by order of Secretary of Interior, March 13, 1880.

RESERVOIR SITE NO. 13.

On Daisy Dean Creek, 2½ miles north of Oka road in Meagher County, Montana.

Drainage basin, about 40 square miles, varying in elevation from 5,000 to 8,000 feet. Daisy Dean Creek runs in spring only. Timber scattering and on higher hills only.

Site includes parts of Secs. 32 and 33, T. 9 N., R. 12 E., principal meridian of Montana.

Dam located in SW. ¼ of NW. ¼ and NW. ¼ of SW. ¼, Sec. 33.

Height of dam, 15 feet.

Bench mark, rock at water line at south end of dam. Altitude of bench mark about 5,000 feet.

Incloses 20 acres.
Capacity of reservoir, 105 acre-feet.
Abundant stone available for construction.
Partly settled.
Irrigable lands immediately below site.

Lands segregated for reservoir.

					Acres.
SE. ¼ NE.¼	Sec. 32,	T. 9 N.,	R. 12 E		40
NE. ¼ SE.¼	32	9	12		40
SW. ¼ NW.¼	33	9	12		40
NW. ¼ SW.¼	33	9	12		40
Area segregated					160

Action affecting the titles to lands segregated for Reservoir Site No. 13 has been taken as follows:

					Acres.
SE. ¼ NE.¼	Sec. 32,	T. 9 N.,	R. 12 E		40
NE. ¼ SE.¼	32	9	12		40
Reserved by order of Secretary, March 13, 1890.					
SW. ¼ NW.¼	33	9	12		40
NW. ¼ SW.¼	33	9	12		40
					160

Selected by Northern Pacific Railroad, February 26, 1885. Act of July 2, 1864. Resolution May 31, 1870.

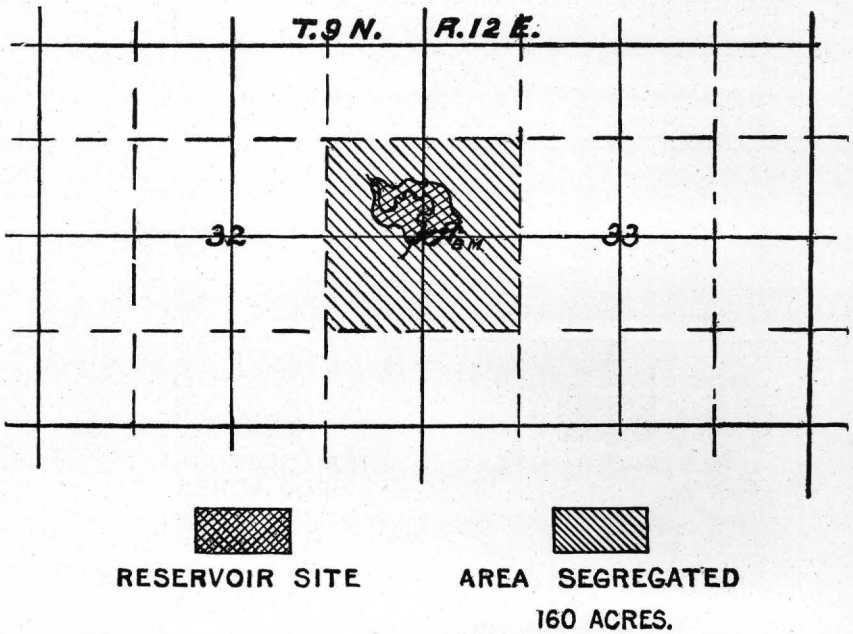


FIG. 160.—Reservoir Site No. 13, on Daisy Dean Creek, 2½ miles north of Oka Road.

Reservoir Site No. 14.

On east branch of Daisy Dean Creek, 1¼ miles north of Oka road, in Meagher County, Montana.

Drainage basin about 18 square miles. Altitude from 4,800 to 8,000 feet. Scattering timber on slopes of highest hills. No running water ordinarily.

Reservoir includes parts of Secs. 26, 34, and 35, T. 9 N., R. 12 E. prin. mer., Montana.

Dam located in SE. ¼ of NE. ¼, Sec. 34.

Height of dam, 35 feet.

Bench mark is rock monument at water line at east end of dam.

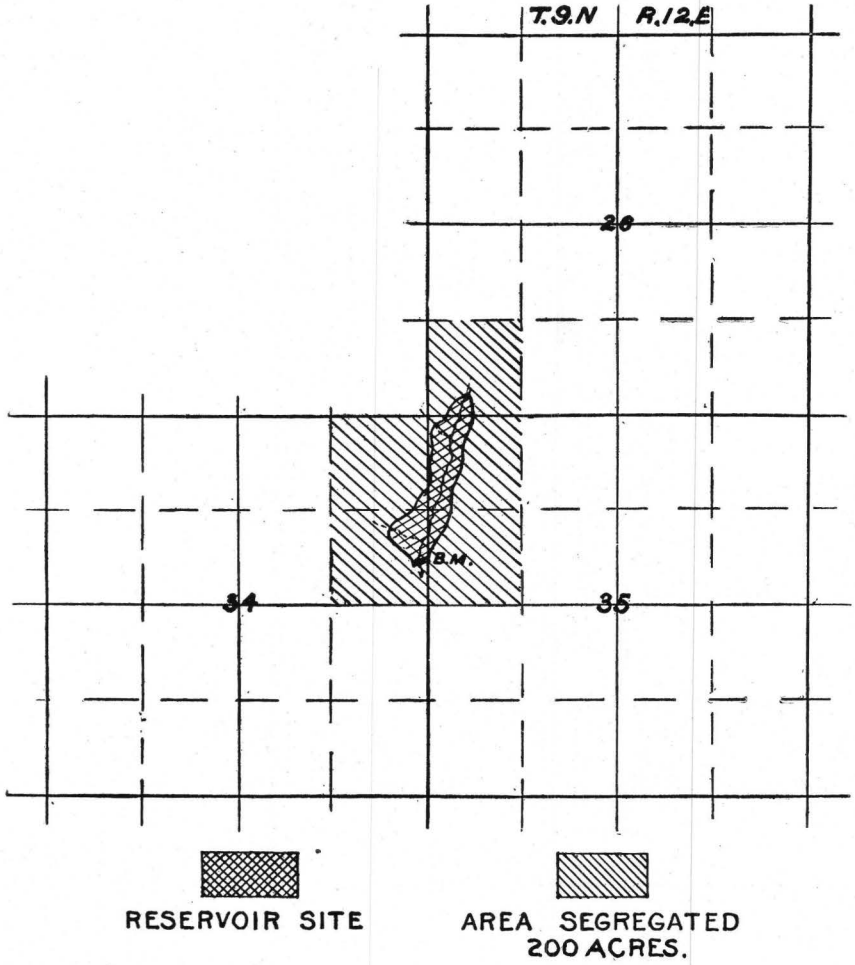


Fig. 161.—Reservoir Site No. 14, on east branch of Daisy Dean Creek, 1¼ miles east of Oka road.

Altitude, 4,830 feet.
Top contour, 4,830 feet in altitude.
Area of reservoir, 30 acres.
Capacity, 390 acre-feet.
Stone easily obtainable.
Partly settled.
Irrigable lands immediately below dam.

Lands segregated for reservoir.

				Acres.
E. ½ NE. ¼ Sec.	34,	T. 9 N.,	R. 12 E.	80
W. ½ NW. ¼	35	9	12	80
SW. ¼ SW. ¼	26	9	12	40
Area segregated				200

Action affecting the titles to lands segregated for Reservoir Site No. 14 has been taken as follows:

				Acres.
SW. ¼ SW. ¼ Sec.	26,	T. 9 N.,	R. 12 E.	40
E. ½ NE. ¼	34	9	12	80
Reserved by order of Secretary, March 13, 1890.				
W. ½ NW. ¼	35	9	12	80
				200

Selected by Northern Pacific Railroad, February 26, 1885. Act of July 2, 1864. Resolution of May 31, 1870.

RESERVOIR SITE NO. 15.

On North Fork of Musselshell River, ½ mile below James Nagues's ranch, in Meagher County, Montana.

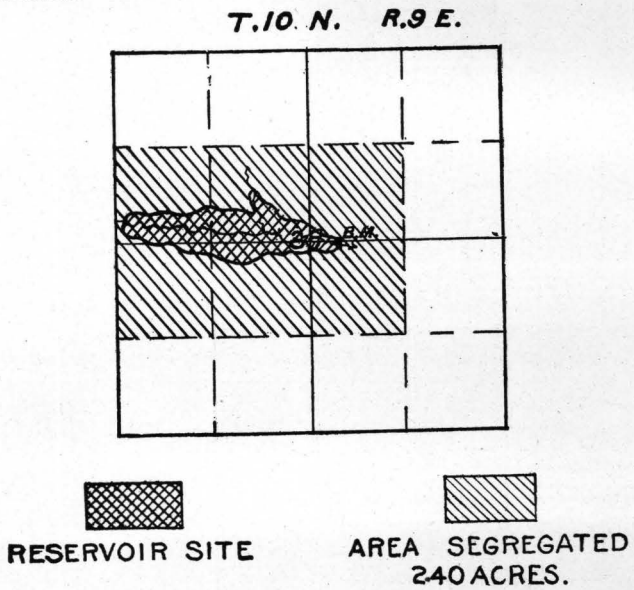


FIG. 162.—Reservoir Site No. 15, on North Fork of Musselshell River, ½ mile below James Nagues's ranch.

Drainage basin about 60 square miles. Altitude of basin, from 5,400 to 8,000 feet. Abundant water running throughout the year. Heavy pine timber on slopes of hills.

Reservoir includes parts of following section: Sec. 35, T. 10 N., R. 9 E. prin. mer., Montana.

Dam in SW. ¼ of NE. ¼ and NW. ¼ of SE. ¼, Sec. 35.

Height of dam, 35 feet.

Bench mark is pile of rocks at water line at north end of dam.

Top contour, 5,435 feet in altitude.

Area inclosed, 40 acres.

Capacity, about 520 acre-feet.
Timber and stone abundant in vicinity.
Partly settled.

Lands segregated for reservoir.

				Acres.
S. ½ NW. ¼ Sec.	35,	T. 10 N.,	R. 9 E	80
SW. ¼ NE. ¼	35	10	9	40
NW. ¼ SE. ¼	35	10	9	40
N. ½ SW. ¼	35	10	9	80
Area segregated				240

Action affecting the titles of lands segregated for Reservoir Site No. 15 has been taken as follows:

Sec. 35, T. 10 N., R. 9 E. Selected by Northern Pacific Railroad, February 26, 1885. Act of July 2, 1864. Resolution of May 31, 1870.

Reservoir Site No. 16.

On South Fork of Musselshell River, 13 miles above Martinsdale, at fork of stream (mouth Castle Creek), in Meagher County, Montana.

Altitude of drainage basin from 5,000 to 8,500 feet; area of basin, 95 square miles.
Site is located in T. 8 N., R. 9 E., Secs. 35 and 36.
Dam is located in W. ½ of NW. ¼, Sec. 36.
Height of dam, 55 feet.
Bench mark, rock monument on top contour at north end of dam.
Approximate altitude 5,000 feet.
Altitude of top contour, 5,000 feet.
Area inclosed by top contour, 100 acres.

Lands segregated for reservoir.

				Acres.
W. ½ NW. ¼ Sec.	36,	T. 8 N.,	R. 9 E	80
NW. ¼ SW. ¼	36	8	9	40
E. ½ NE. ¼	35	8	9	80
NW. ¼ NE. ¼	35	8	9	40
E. ½ SE. ¼	35	8	9	80
Area segregated				320

Action affecting the titles to lands segregated for Reservoir Site No. 16 has been taken as follows:

				Acres.
N. ½ NE. ¼ Sec.	35,	T. 8 N.,	R. 9 E	80
SE. ¼ NE. ¼	35	8	9	40
E. ½ SE. ¼	35	8	9	80
				200

Selected by Northern Pacific Railroad October 22, 1887. Act of July 2, 1864.

Reservoir Site No. 17.

On South Fork of Musselshell River, 14 miles above Martinsdale and 1 mile above the mouth of Castle Creek, in Meagher County, Montana.

Drainage basin from 5,100 to 8,500 feet in altitude; character of topography, mountainous.

Site located in T. 8 N., R. 9 E., Sec. 35.

Dam located in NW. ¼ of SE. ¼, Sec. 35.
Height of dam, 20 feet.
Bench mark, rock monument on top contour at south end of dam.
Approximate altitude, 5,100 feet.
Altitude of top contour, 5,100 feet.
Area inclosed by top contour, 25 acres.

Lands segregated for reservoir.

	Acres.
E. ½ SW. ¼ Sec. 35, T. 8 N., R. 9 E	80
NW. ¼ SE. ¼ 35 8 9	40
Area segregated	120

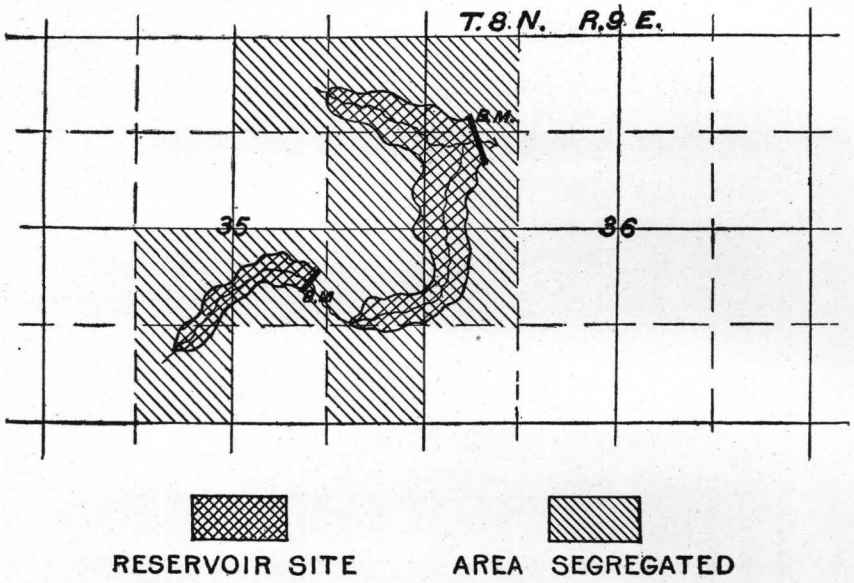


FIG. 163.—Reservoir Sites Nos. 16 and 17, on South Fork of Musselshell River, 14 miles above Martinsdale and 1 mile above mouth of Castle Creek.

Action affecting the titles to lands segregated for Reservoir Site No. 17 has been taken as follows:

	Acres.
E. ½ SW. ¼ Sec. 35, T. 8 N., R. 9 E	80
NW. ¼ SE. ¼ 35 8 9	40
	120

Selected by Northern Pacific Railroad October 22, 1887. Act of July 2, 1864.

RESERVOIR SITE NO. 18.

On Sixteen-Mile Creek, at Lincoln's ranch, in Meagher County, Montana.

Drainage basin about 90 square miles, varying in elevation from 5,500 to 7,000 feet. Abundant running water. Very little scattering timber.

Reservoir located on following sections: Sec. 32, T. 7 N., R. 8 E., and Secs. 4, 5, 8, 9, 10, 15, 16, 17, 21, and 22, T. 6 N., R. 8 E.

Dam in E. ½ of SE. ¼, Sec. 8.

Height of dam, 50 feet.

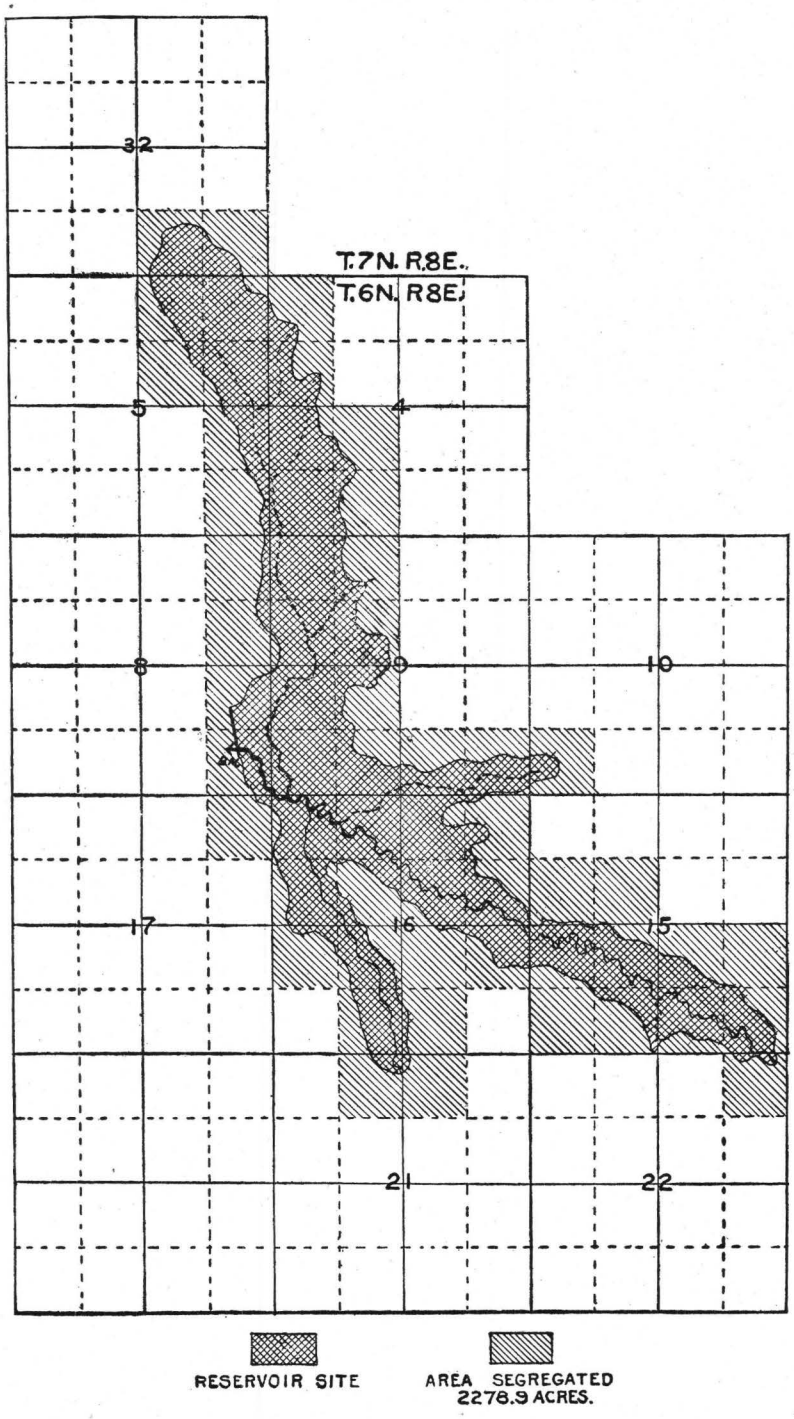


FIG. 164.—Reservoir site No. 18, on Sixteen-Mile Creek at Lincoln's Ranch.

Bench mark is stake at water line at south end of dam.
Altitude of top contour, about 5,550 feet.
Area in reservoir, about 1,055 acres.
Capacity, 19,781 acre-feet.
Stone obtainable but no timber.
Partly settled.
Irrigable lands in small areas along Sixteen-Mile Creek clear to its mouth.
Recommended for segregation in letter of January 8, 1890.

Lands segregated for reservoir.

				Acres.
S. ½ SE. ¼ Sec.	32,	T. 7 N.,	R. 8 E.	80·0
S. ½ NE. ¼	5	6	8	80·0
Lots 1 and 2	5	6	8	79·3
E. ½ SE. ¼	5	6	8	80·0
SW. ¼ NW. ¼	4	6	8	40·0
Lot 4	4	6	8	39·6
SW. ¼	4	6	8	160·0
NW. ¼	9	6	8	160·0
SW. ¼	9	6	8	160·0
S. ½ SE. ¼	9	6	8	80·0
SW. ¼ SW. ¼	10	6	8	40·0
E. ½ NE. ¼	8	6	8	80·0
E. ½ SE. ¼	8	6	8	80·0
NE. ¼ NE. ¼	17	6	8	40·0
NW. ¼	16	6	8	160·0
NE. ¼	16	6	8	160·0
NW. ¼ SW. ¼	16	6	8	40·0
E. ½ SW. ¼	16	6	8	80·0
W. ½ SE. ¼	16	6	8	80·0
NE. ¼ SE. ¼	16	6	8	40·0
S. ½ NW. ¼	15	6	8	80·0
SW. ¼	15	6	8	160·0
SE. ¼	15	6	8	160·0
NE. ¼ NE. ¼	22	6	8	40·0
NW. ¼ NE. ¼	21	6	8	40·0
NE. ¼ NW. ¼	21	6	8	40·0
Area segregated				2,278·9

Action affecting the titles of lands segregated for Reservoir Site No. 18 has been taken as follows:

T. 7 N., R. 8 E.

		Acres.
S. ½ SE. ¼ Sec.	32 (reserved per Secretary's order, March 13, 1890)	80·00

T. 6 N., R. 8 E.

		Acres.
S. ½ NE. ¼ Sec.	5 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	80·00
Lots 1 and 2	5 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	79·30
E. ½ SE. ¼	5 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	80·00
Lot 4	4 (reserved per Secretary's order of March 13, 1890)	39·60
SW. ¼ NW. ¼	4 (reserved per Secretary's order of March 13, 1890)	40·00
SW. ¼	4 (reserved per Secretary's order of March 13, 1890)	160·00
SE. ¼ SE. ¼	8 (timber culture January 18, 1889)	40·00
NE. ¼ SE. ¼	8 (reserved per Secretary's order of March 13, 1890)	40·00

		Acres.
E. ½ NE. ¼	Sec. 8 (reserved per Secretary's order of March 13, 1890)	80·00
SW. ¼ SW. ¼	10 (reserved per Secretary's order of March 13, 1890)	40·00
NW. ¼	9 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	160·00
SW. ¼	9 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	160·00
S. ½ SE. ¼	9 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	80·00
W. ½ NE. ¼	16 (homestead March 15, 1886)	80·00
SE. ¼ NE. ¼	16 (homestead March 15, 1886)	40·00
NE. ¼ NW. ¼	16 (homestead March 15, 1886)	40·00
W. ½ NW. ¼	16 (reserved per Secretary's order of March 13, 1890)	80·00
SE. ¼ NW. ¼	16 (reserved per Secretary's order of March 13, 1890)	40·00
NE. ¼ NE. ¼	16 (reserved per Secretary's order of March 13, 1890)	40·00
N. ½ SW. ¼	16 (reserved per Secretary's order of March 13, 1890)	80·00
SE. ¼ SW. ¼	16 (reserved per Secretary's order of March 13, 1890)	40·00
N. ½ SE. ¼	16 (reserved per Secretary's order of March 13, 1890)	80·00
SW. ¼ SE. ¼	16 (reserved per Secretary's order of March 13, 1890)	40·00
S. ½ NW. ¼	15 (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	80·00
SW. ¼	15. (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	160·00
SE. ¼	15. (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	160·00
NE. ¼ NE. ¼	22. (reserved per Secretary's order of March 13, 1890)	40·00
NE. ¼ NW. ¼	21. (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	40·00
NW. ¼ NE. ¼	21. (selected by N. P. R. R. November 8, 1886, act of July 2, 1864)	40·00
		2,238·90

RESERVOIR SITE No. 19.

On South Fork of Smith River, 20 miles above White Sulphur Springs, at Rocky Gap, in Meagher County, Montana.

Drainage basin comprises about 12 square miles, and varies in elevation from 5,600 to 7,000 feet. No running water except in spring. Little or no timber.

Site includes parts of Secs. 29 and 32, T. 7 N., R. 8 E., principal meridian, Montana.

Dam located in NE. ¼ of NW. ¼ Sec. 32.

Height of dam is 25 feet.

Bench mark is pile of rocks at water line at north end of dam.

Altitude of top contour, 5,625 feet.

Area inclosed by top contour, 120 acres.

Capacity about 1,125 acre-feet.

Stone obtainable, but no timber in vicinity.

Reservoir partly settled.

Irrigable lands immediately below reservoir.

Recommended for segregation in letter of January 8, 1890.

Lands segregated for reservoir.

					Acres.
SE. ¼ SW. ¼	Sec.	29,	T. 7 N.,	R. 8 E.	40
S. ½ SE. ¼		29	7	8	80
NE. ¼		32	7	8	160
E. ½ NW. ¼		32	7	8	80
N. ½ SE. ¼		32	7	8	80
Area segregated					440

Action affecting the titles of lands segregated for Reservoir Site No. 19 has been taken as follows:

					Acres.
S. ½ SE. ¼	Sec. 29,	T. 7 N.,	R. 8 E	.....	80
SE. ¼ SW. ¼	29	7	8	(reserved by order of Secretary, March 13, 1890)	40
E. ½ NW. ¼	32	7	8	(reserved by order of Secretary, March 13, 1890)	80
NE. ¼	32	7	8	.....	160
N. ½ SE. ¼	32	7	8	.....	80
					440

Selected by Northern Pacific Railroad, November 6, 1886. Act of July 2, 1864.

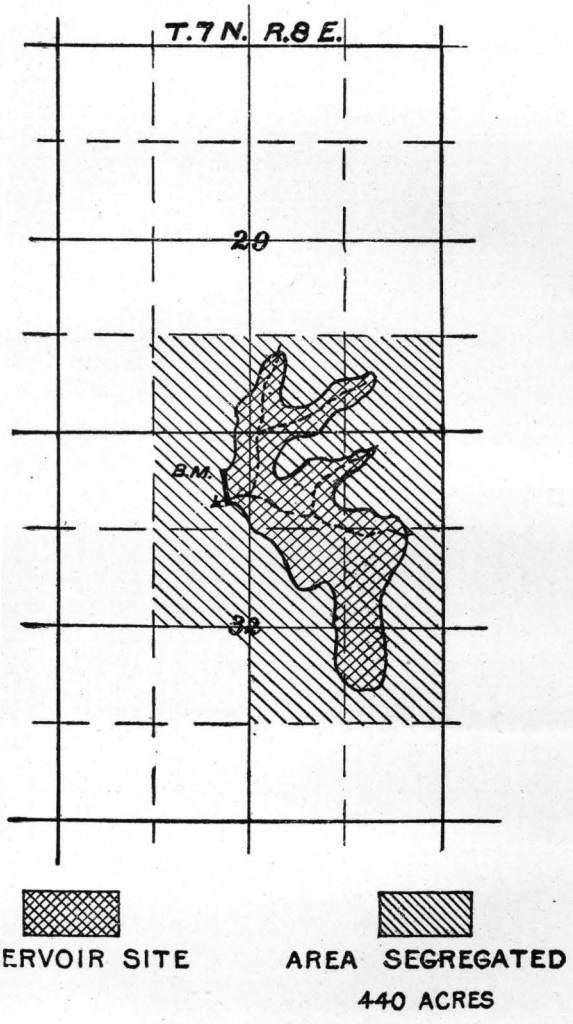


FIG. 165.—Reservoir Site No, 19, on Smith River (South Fork), about 20 miles above White Sulphur Springs, at Rocky Gap.

Reservoir Site No. 20.

On South Fork of Smith River, about 13 miles above White Sulphur Springs, in Meagher County, Montana.

Drainage basin covers about 50 square miles and varies in elevation from 5,300 to 7,000 feet. The water supply is abundant in spring, but little water flows throughout the year. There is a little scattering timber on high hills.

Reservoir located on Secs. 8 and 9, T. 7 N., R. 7 E., prin. mer., Montana.

Dam in SW. ¼ of NW. ¼ Sec. 9, and SE. ¼ of NE. ¼ Sec. 8.

Height of dam, 30 feet.

Bench mark is pile of rocks on water line on east end of dam.

Altitude of top contour, 5,330 feet.

Area of reservoir, 110 acres.

Capacity, 1,230 acre-feet.

Stone obtainable but no timber.

Partly settled.

Irrigable lands immediately below dam.

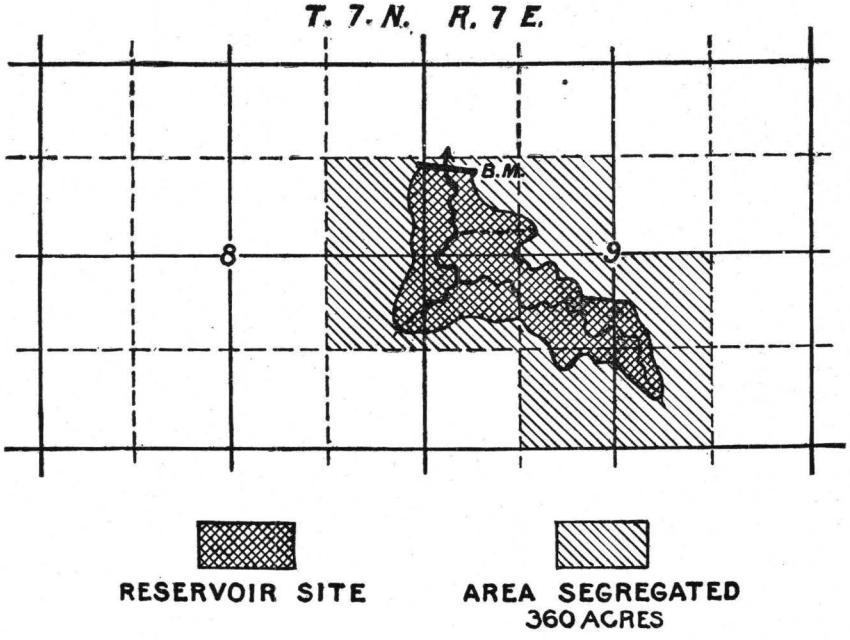


Fig. 166.—Reservoir Site No. 20, on South Fork of Smith River, about 13 miles from White Sulphur Springs, on Livingston stage road.

Lands segregated for reservoir.

				Acres.
SE. ¼ NE. ¼	Sec. 8,	T. 7 N.,	R. 7 E.	40
NE. ¼ SE. ¼	8	7	7	40
S. ½ NW. ¼	9	7	7	80
N. ½ SW. ¼	9	7	7	80
SE. ¼ SW. ¼	9	7	7	40
W. ½ SE. ¼	9	7	7	80
Total				360

Action affecting the titles to lands segregated for Reservoir Site No. 20 has been taken as follows:

					Acres.
SE. ¼ NE. ¼ Sec.	8,	T.	7	N., R. 7 E.	40
NE. ¼ SE. ¼	8	7	7	(reserved by Secretary's order of March 13, 1890	40
S. ½ NW. ¼	9	7	7		80
N. ½ SW. ¼	9	7	7		80
SE. ¼ SW. ¼	9	7	7		40
W. ½ SE. ¼	9	7	7		80
					360

All of Sec. 9 selected by Northern Pacific Railroad Company, March 8, 1866. Act of July 2, 1864.

Reservoir Site No. 21.

Basin on stage road 3 miles west of Confederate Gulch, in Meagher County, Montana.

Altitude of drainage basin, 4,000 feet. Character of topography, valley and mountains.

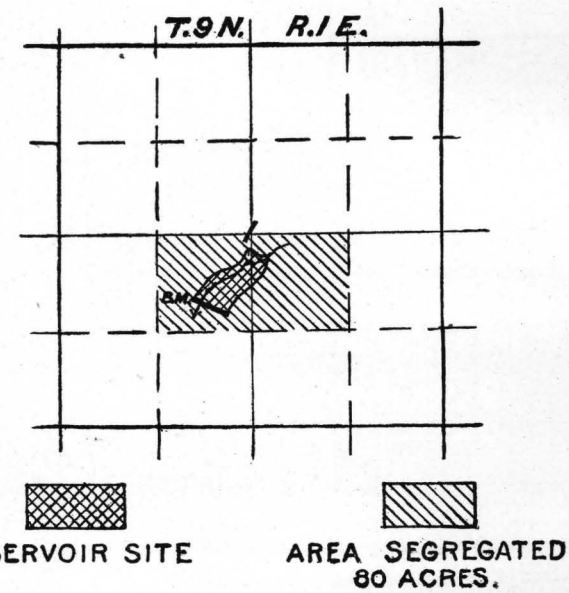


Fig. 167.—Reservoir Site No. 21, basin on stage road, 3 miles west of mouth of Confederate Gulch.

Site is located in T. 9, R. 1 E., Sec. 1.

Dam is located in NE. ¼ of SW. ¼ Sec. 1.

Height of dam, 10 feet.

Bench mark is rock monument on top contour at west end of dam. Approximate altitude, 4,000 feet.

Altitude of top contour, 4,000 feet.

Area inclosed by top contour, 15 acres.

Lands segregated for reservoir.

					Acres.
NE. ¼ SW. ¼ Sec.	1,	T.	9	N., R. 1 E.	40
NW. ¼ SE. ¼	1	9	1		40
Area segregated					80

Action affecting the titles to lands segregated for Reservoir Site No. 21 has been taken as follows:

	Acres.
NW. ¼ SE. ¼ Sec. 1, T. 9 N., R. 1 E	40
NE. ¼ SW. ¼ 1 9 1	40
	80

Selected by Northern Pacific Railroad Company, July 28, 1886. Act of July 2, 1864.

Reservoir Sites Nos. 22 and 23.

Basin on Northern Pacific Railroad on Mitchell Creek (dry), 1½ miles west of Clasoil Station, in Lewis and Clarke counties, Montana.

Site located in T. 9 N., R. 2 W., Sec. 2.

Dams located in SE. ¼ of NE. ¼, and in NE. ¼ of NW. ¼ Sec. 2.

Height of dams, 15 feet each.

Bench mark east end of railroad trestle, at top contour in each case.

Area inclosed by top contour, 50 acres.

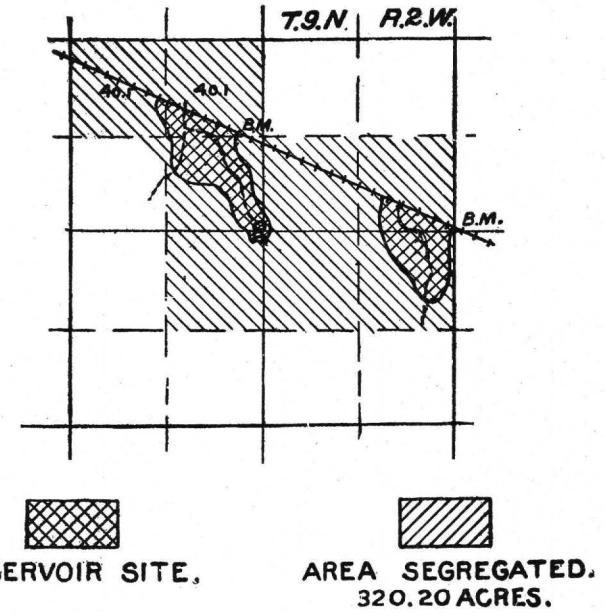


Fig. 168.—Reservoir Sites Nos. 22 and 23, basin on Northern Pacific Railroad, on Mitchell Creek (dry), 1½ miles west of Clasoil Station.

Lands segregated for reservoirs.

No. 23.				Acres.
Lot 4, Sec.	2,	T. 9 N.,	R. 2 W	40·1
Lot 3	2	9	2	40·1
SE. ¼ NW. ¼	2	9	2	40·0
NE. ¼ SW. ¼	2	9	2	40·0
SW. ¼ NE. ¼	2	9	2	40·0
NW. ¼ SE. ¼	2	9	2	40·0
Total				240·2

No. 22.				Acres.
SE. ¼ NE. ¼	Sec. 2,	T. 9 N.,	R. 2 W.	40
NE. ¼ SE. ¼	2	9	2	40
Total				80

Action affecting the titles to lands segregated for Reservoir Sites Nos. 22 and 23 has been taken as follows:

				Acres.
Lots 3 and 4,	Sec. 2,	T. 9 N.,	R. 2 W.	80·2
SE. ¼ NW. ¼	2	9	2	40·0
S. ½ NE. ¼	2	9	2	80·0
N. ½ SE. ¼	2	9	2	80·0
NE. ¼ SW. ¼	2	9	2	40·0
				320·0

All of Sec. 2 selected by Montana Territory, May 20, 1882. Act of February 18, 1881. Approved March 18, 1889.

Reservoir Site No. 24.

On Big Hole River, 5 miles below Glen Station (Utah and Northern R. R.), in Beaver Head County, Montana.

Altitude of drainage basin from 5,000 to 10,000 feet. Character of topography, mountainous.

Reservoir is located in T. 3 S., R. 9 W.; T. 4 S., R. 9 W.; T. 4 S., R. 8 W., and T. 5 S., R. 8 W.

Dam is located in the NE. ¼ of SE. ¼ Sec. 4, T. 5 S., R. 8 W.

Height of dam, 100 feet.

Bench mark, rock monument on top contour, at north end of dam. Approximate altitude, 5,000 feet.

Altitude of top contour, 5,000 feet.

Area inclosed by top contour, 11,800 acres.

Lands segregated.

				Acres.
NW. ¼	Sec. 34,	T. 3 S.,	R. 9 W.	160·0
SW. ¼	34	3	9	160·0
SE. ¼ NE. ¼	4	4	9	40·0
SE. ¼	4	4	9	160·0
Lots 3, 4	3	4	9	81·7
S. ½ NW. ¼	3	4	9	80·0
SW. ¼	3	4	9	160·0
SE. ¼	3	4	9	160·0
SW. ¼ NE. ¼	3	4	9	40·0
NE. ¼	9	4	9	160·0
E. ½ SE. ¼	9	4	9	80·0
All	10	4	9	640·0
E. ½ NE. ¼	16	4	9	80·0
NW. ¼	15	4	9	160·0
NE. ¼	15	4	9	160·0
SE. ¼	15	4	9	160·0
N. ½ SW. ¼	15	4	9	80·0
SE. ¼ SW. ¼	15	4	9	40·0
SW. ¼	14	4	9	160·0
SW. ¼ SE. ¼	14	4	9	40·0
E. ½ NW. ¼	22	4	9	80·0

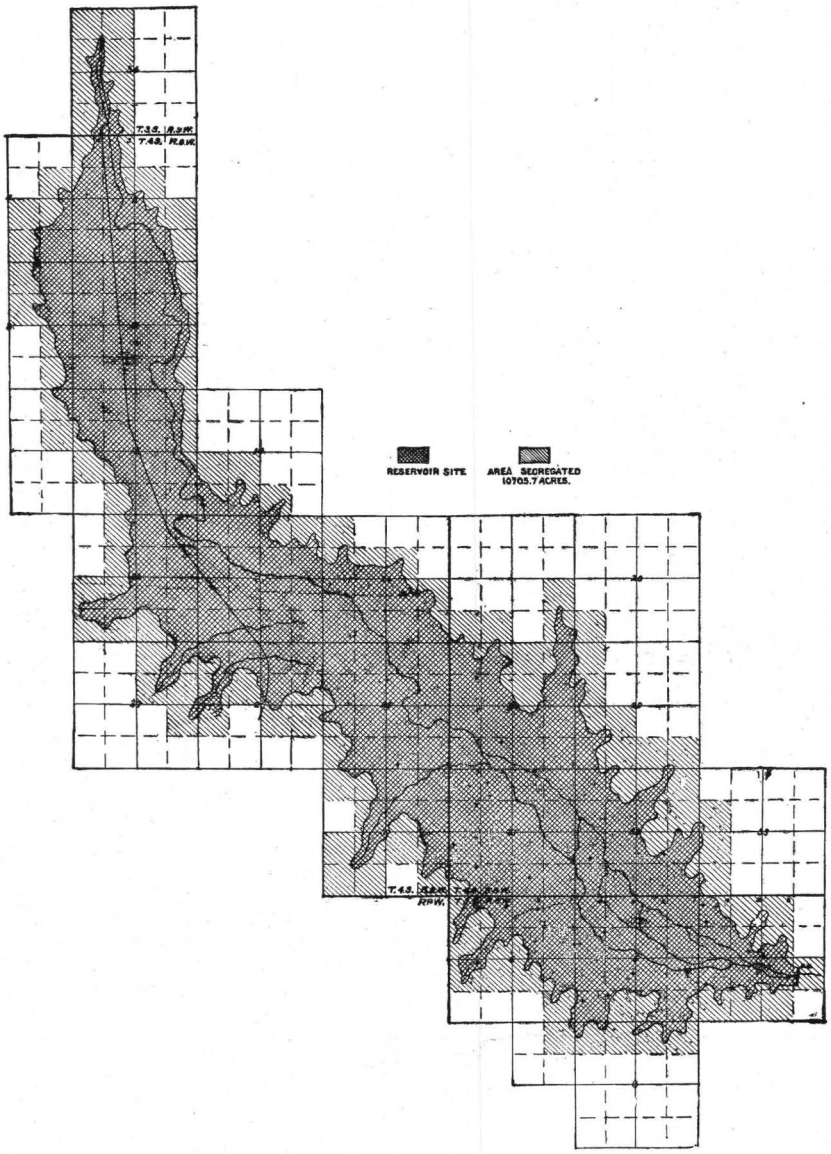


FIG. 169.—Reservoir Site No. 24, on Big Hole River, 5 miles below Glen Station, Utah and Northern Railroad.

					Acres.
SW. ¼	Sec. 22,	T. 4	S., R. 9	W	160·0
SE. ¼	22	4	9		160·0
NE. ¼	22	4	9		160·0
All	23	4	9		640·0
NW. ¼ NW. ¼	24	4	9		40·0
S. ½ NW. ¼	24	4	9		80·0
SW. ¼ NE. ¼	24	4	9		40·0
SW. ¼	24	4	9		160·0
SE. ¼	24	4	9		160·0
Lot 4	19	4	8		37·4
SE. ¼ SW. ¼	19	4	8		40·0
E. ½ SE. ¼	19	4	8		80·0
SW. ¼ SW. ¼	20	4	8		40·0
W. ½ NW. ¼	29	4	8		80·0
SW. ¼	29	4	8		160·0
S. ½ SE. ¼	29	4	8		80·0
NE. ¼	30	4	8		160·0
SE. ¼	30	4	8		160·0
Lots 1, 2	30	4	8		75·0
E. ½ NW. ¼	30	4	8		80·0
Lots 3, 4	30	4	8		75·8
E. ½ SW. ¼	30	4	8		80·0
Lots 1, 2	31	4	8		74·2
E. ½ NW. ¼	31	4	8		80·0
Lots 3, 4	31	4	8		70·4
E. ½ SW. ¼	31	4	8		80·0
NE. ¼	31	4	8		160·0
SE. ¼	31	4	8		160·0
All	32	4	8		640·0
SW. ¼ NW. ¼	33	4	8		40·0
W. ½ SW. ¼	33	4	8		80·0
All	25	4	9		640·0
NE. ¼	26	4	9		160·0
NW. ¼	26	4	9		160·0
N. ½ SE. ¼	26	4	9		80·0
NW. ¼ SW. ¼	26	4	9		40·0
NE. ¼	27	4	9		160·0
NE. ¼ SE. ¼	37	4	9		40·0
NE. ¼	36	4	9		160·0
SW. ¼	36	4	9		160·0
NW. ¼ NW. ¼	36	4	9		40·0
E. ½ NW. ¼	36	4	9		80·0
NW. ¼ SE. ¼	36	4	9		40·0
E. ½ SE. ¼	36	4	9		80·0
Lots 3, 4	6	5	8		73·7
Lot 5	6	5	8		35·0
SE. ¼ NW. ¼	6	5	8		40·0
Lots 1, 2	6	5	8		77·6
S. ½ NE. ¼	6	5	8		80·0
N. ½ SE. ¼	6	5	8		80·0
SE. ¼ SE. ¼	6	5	8		40·0
Lot 6	6	5	8		35·6
NE. ¼ SW. ¼	6	5	8		40·0
Lots 3, 4	5	5	8		77·0
S. ½ NW. ¼	5	5	8		80·0

					Acres.
Lots 1, 2,	Sec. 5,	T. 5 S.,	R. 8 W		77·1
S. ½ NE. ¼	5	5	8		80·0
SE. ¼	5	5	8		160·0
SW. ¼	5	5	8		160·0
Lots 3, 4	4	5	8		76·9
S. ½ NW. ¼	4	5	8		80·0
Lot 2	4	5	8		38·3
SW. ¼ NE. ¼	4	5	8		40·0
N. ½ SE. ¼	4	5	8		80·0
SW. ¼ SE. ¼	4	5	8		40·0
SW. ¼	4	5	8		160·0
N. ½ NE. ¼	8	5	8		80·0
N. ½ NW. ¼	8	5	8		80·0
NE. ¼ NE. ¼	7	5	8		40·0
Area segregated					10,705·7

Action affecting the titles to lands segregated for Reservoir Site No. 24 has been taken as follows:

					Acres.
NW. ¼	Sec. 34,	T. 3 S.,	R. 9 W.	(desert, June 14, 1880)	160·00
E. ½ SW. ¼	34	3	9	(desert, June 14, 1880)	80·00
SE. ¼	3	4	9	(desert, August 1, 1883)	160·00
SW. ¼ NE. ¼	3	4	9	(desert, August 1, 1883)	40·00
S. ½ NW. ¼	3	4	9	(desert, August 1, 1883)	80·00
Lots 3, 4	3	4	9	(desert, August 1, 1883)	81·70
SW. ¼	3	4	9	(preemption, October 18, 1886)	160·00
N. ½ SW. ¼	10	4	9	(desert, December 18, 1877)	80·00
NW. ¼	10	4	9	(desert, December 18, 1877)	160·00
NE. ¼	10	4	9	(desert, December 18, 1877)	160·00
N. ½ SE. ¼	10	4	9	(desert, December 18, 1877)	80·00
SE. ¼ SE. ¼	10	4	9	(desert, December 18, 1877)	40·00
S. ½ SW. ¼	10	4	9	(preemption, June 16, 1874)	80·00
SW. ¼ SE. ¼	10	4	9	(preemption, June 16, 1874)	40·00
W. ½ SW. ¼	14	4	9	(homestead, March 9, 1880)	80·00
SE. ¼ SW. ¼	14	4	9	(homestead, March 9, 1880)	40·00
NE. ¼ SW. ¼	14	4	9	(homestead, August 4, 1890)	40·00
NE. ¼	15	4	9	(desert, August 1, 1883)	160·00
SE. ¼	15	4	9	(desert, August 1, 1883)	160·00
N. ½ SW. ¼	15	4	9	(desert, August 1, 1883)	80·00
SE. ¼ SW. ¼	15	4	9	(desert, August 1, 1883)	40·00
S. ½ NW. ¼	15	4	9	(desert, August 1, 1883)	80·00
N. ½ NW. ¼	15	4	9	(desert, August 1, 1883)	80·00
NE. ¼ NW. ¼	15	4	9	(preemption, June 16, 1874)	40·00
SW. ¼ SE. ¼	24	4	9	(preemption, August 15, 1886)	40·00
S. ½ SW. ¼	24	4	9	(preemption, August 15, 1886)	80·00
NW. ¼ SW. ¼	24	4	9	(preemption, August 15, 1886)	40·00
NE. ¼ SE. ¼	23	4	9	(preemption, May 16, 1889)	40·00
S. ½ NE. ¼	23	4	9	(preemption, May 16, 1889)	80·00
NW. ¼ NE. ¼	23	4	9	(preemption, May 16, 1889)	40·00
NW. ¼ SE. ¼	23	4	9	(preemption, March 13, 1889)	40·00
N. ½ SW. ¼	23	4	9	(preemption, March 13, 1889)	80·00
SW. ¼ NW. ¼	23	4	9	(preemption, March 13, 1889)	40·00
S. ½ SE. ¼	23	4	9	(homestead, February 26, 1884)	80·00
S. ½ SW. ¼	23	4	9	(homestead, February 26, 1884)	80·00

					Acres.
E. ½ SW. ¼	Sec. 22;	T. 4	S., R. 9	W (desert, February 11, 1881)	80·00
E. ½ NW. ¼	22	4	9	(desert, February 11, 1881)	80·00
NE. ¼ SE. ¼	22	4	9	(desert, January 26, 1878)	40·00
SW. ¼ SW. ¼	22	4	9	(homestead, April 27, 1885)	40·00
N. ½ SE. ¼	25	4	9	(preemption, April 14, 1890)	80·00
S. ½ NE. ¼	25	4	9	(preemption, April 14, 1890)	80·00
NE. ¼ NW. ¼	25	4	9	(timber, December 24, 1886	40·00
NW. ¼ SW. ¼	25	4	9	(homestead, February 26, 1884)	40·00
W. ½ NW. ¼	25	4	9		80·00
SE. ¼ NW. ¼	25	4	9	(homestead, February 26, 1884)	40·00
N. ½ NE. ¼	25	4	9	(timber, December 24, 1886)	80·00
NE. ¼ NW. ¼	26	4	9	(desert, January 26, 1878)	40·00
NW. ¼ SW. ¼	26	4	9	(desert, February 17, 1890)	40·00
NW. ¼ SE. ¼	26	4	9	(desert, February 17, 1890)	40·00
NE. ¼	27	4	9	(homestead, August 11, 1883)	160·00
NE. ¼ SE. ¼	27	4	9	(homestead, February 17, 1887)	40·00
NW. ¼ SE. ¼	36	4	9	(preemption, May 10, 1875)	40·00
E. ½ SW. ¼	36	4	9	(preemption, May 10, 1875)	80·00
SE. ¼ SW. ¼	29	4	8	(preemption, March 2, 1876)	40·00
SW. ¼ SE. ¼	29	4	8	(preemption, March 2, 1876)	40·00
SW. ¼ NW. ¼	29	4	8	(preemption, March 29, 1876)	40·00
W. ½ SW. ¼	29	4	8	(preemption, March 29, 1876)	80·00
NE. ¼ SW. ¼	29	4	8	(preemption, March 29, 1876)	40·00
E. ½ SE. ¼	30	4	8	(desert, April 11, 1878)	80·00
S. ½ NE. ¼	30	4	8	(desert, April 11, 1878)	80·00
NW. ¼ NE. ¼	30	4	8	(desert, April 11, 1878)	40·00
NE. ¼ NW. ¼	30	4	8	(desert, April 11, 1878)	40·00
Lot 1	30	4	8	(desert, April 11, 1878)	37·40
Lots 2, 3, 4	30	4	8	(homestead, March 8, 1880)	113·40
SE. ¼ SW. ¼	30	4	8	(homestead, March 8, 1880)	40·00
SE. ¼ NW. ¼	31	4	8	(preemption, November 24, 1884)	40·00
NE. ¼ SW. ¼	31	4	8	(preemption, November 24, 1884)	40·00
Lots 2, 3	31	4	8	(preemption, November 24, 1884)	72·30
SE. ¼ SW. ¼	31	4	8	(desert, August 30, 1883)	40·00
S. ½ SE. ¼	31	4	8	(homestead, December 8, 1884)	80·00
N. ½ SE. ¼	31	4	8	(preemption, May 7, 1888)	80·00
N. ½ NE. ¼	32	4	8	(preemption, March 2, 1876)	80·00
NW. ¼	32	4	8	(homestead, June 6, 1878	160·00
E. ½ SE. ¼	32	4	8	(homestead, March 8, 1880)	80·00
SW. ¼ SE. ¼	32	4	8	(homestead, March 8, 1880)	40·00
SE. ¼ SW. ¼	32	4	8	(homestead, March 8, 1880)	40·00
W. ½ SW. ¼	32	4	8	(preemption, May 7, 1888)	80·00
SW. ¼ SW. ¼	33	4	8	(preemption, March 29, 1876	40·00
NW. ¼ SW. ¼	33	4	8	(preemption, March 29, 1876	40·00
SW. ¼ NW. ¼	33	4	8	(preemption, March 29, 1876	40·00
S. ½ NE. ¼	5	5	8	(preemption, December 26, 1884)	80·00
NE. ¼ SE. ¼	5	5	8	(preemption, December 26, 1884)	40·00
Lots 1, 2, 3	5	5	8	(preemption, November 16, 1885)	115·60
SE. ¼ NW. ¼	5	5	8	(preemption, November 16, 1885)	40·00
NW. ¼ SW. ¼	4	5	8	(preemption, December 26, 1884)	40·00
S. ½ NE. ¼	6	5	8	(desert, December 8, 1884)	80·00
SE. ¼ NW. ¼	6	5	8	(desert, December 8, 1884)	40·00
Lots 2, 3	6	5	8	(homestead, December 8, 1884)	77·00
					6,098·80

Reservoir Site No. 25.

On Black-tail Deer Creek at Dailey's Ranch, in Beaver Head County, Montana.

Altitude of drainage basin from 6,000 to 10,000 feet; character of topography, mountainous.

Site is located in T. 9 S., R. 8 W., Sec. 24; T. 9 S., R. 7 W., Secs. 19, 20, 29, and 30.

Dam is located in SW. ¼ of SE. ¼, Sec. 24, T. 9 S., R. 8 W.

Height of dam, 40 feet.

Bench mark, bottom of corner of log cabin on south side of dam at water line Approximate altitude, 6,000 feet.

Altitude of top contour, 6,000 feet.

Area inclosed by top contour, 600 acres.

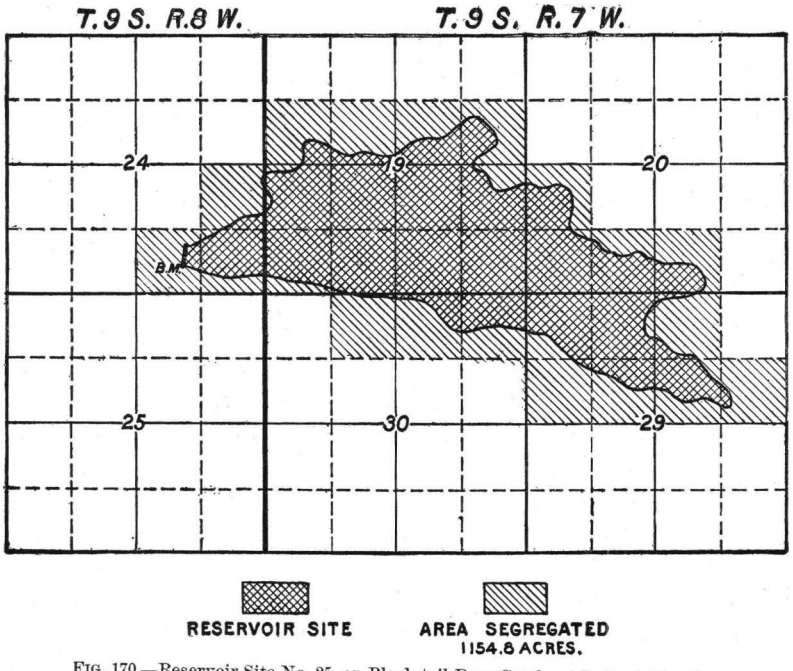


Fig. 170.—Reservoir Site No. 25, on Black-tail Deer Creek, at Dailey's Ranch.

Lands segregated for reservoir.

					Acres.
SW. ¼ SE. ¼	Sec. 24,	T. 9 S.,	R. 8 W		40·00
E. ½ SE. ¼	24	9	8		80·00
E. ½ SW. ¼	19	9	7		80·00
Lot 3	19	9	7		38·30
Lot 4	19	9	7		38·40
SE. ¼	19	9	7		160·00
SE. ¼ NW. ¼	19	9	7		40·00
Lot 2	19	9	7		38·10
S. ½ NE. ¼	19	9	7		80·00
NE. ¼ NW. ¼	30	9	7		40·00
N. ½ NE. ¼	30	9	7		80·00
NW. ¼	29	9	7		160·00
NW. ¼ NE. ¼	29	9	7		40·00

					Acres.
S. ½ NE. ¼	Sec. 29,	T. 9 S.,	R. 7		80·00
SW. ¼ SE. ¼	20	9	7		40·00
S. ½ SW. ¼	20	9	7		80·00
NW. ¼ SW. ¼	20	9	7		40·00
					1,154·80

Action affecting the titles of lands segregated for Reservoir Site No. 25 has been taken as follows:

					Acres.
Lot 3	Sec. 19,	T. 9 S.,	R. 7 W		38·30
NE. ¼ SW. ¼	19	9	7		40·00
SE. ¼ NW. ¼	19	9	7		40·00
SW. ¼ NE. ¼	19	9	7	(homestead, November 10, 1884)	40·00
SE. ¼ SW. ¼	19	9	7		40·00
SE. ¼	19	9	7		160·00
SE. ¼ NE. ¼	19	9	7	(desert land, August 11, 1883)	40·00
SW. ¼ SE. ¼	20	9	7		40·00
S. ½ SW. ¼	20	9	7		80·00
NW. ¼ SW. ¼	20	9	7	(desert land, March 7, 1879)	40·00
E. ½ NE. ¼	29	9	7	(preemption, March 1, 1884)	80·00
NW. ¼	29	9	7	(homestead, June 2, 1888)	160·00
SE. ¼ NE. ¼	29	9	7	(preemption, January 25, 1886)	40·00
N. ½ NE. ¼	30	9	7	(preemption, November 6, 1884)	80·00
					918·30

Reservoir Site No. 26.

On Beaver Head River, at Dailey's Pinnacle, in Beaver Head County, Montana.

Altitude of drainage basin from 5,400 to 10,000 feet. Character of topography, mountainous.

Site is located in T. 9 S., R. 10 W., Secs. 2, 3, 10, 11, 15, 16, 20, 21, 22, 28, and 29.

Dam is located in NW. ¼ of S. E. ¼ Sec. 2.

Height of dam, 125 feet.

Bench mark, top of rock pinnacle at north end of dam at water line. Approximate altitude, 5,500 feet.

Altitude of top contour, 5,500 feet.

Area inclosed by top contour, 1,400 acres.

Lands segregated for reservoir.

				Acres.
W. ½ SE. ¼	Sec. 2,	T. 9 S.,	R. 10 W	80
SW. ¼	2	9	10	160
S. ½ NW. ¼	2	9	10	80
E. ½ SE. ¼	3	9	10	80
NW. ¼	11	9	10	160
NW. ¼ NE. ¼	11	9	10	40
SW. ¼	11	9	10	160
NE. ¼	10	9	10	160
SE. ¼	10	9	10	160
E. ½ SW. ¼	10	9	10	80
N. ½ NE. ¼	15	9	10	80
SW ¼ NE. ¼	15	9	10	40
NW. ¼	15	9	10	160
SW. ¼	15	9	10	160

				Acres.
NW. ¼ NW. ¼	Sec. 22,	T. 9 S.,	R. 10	40
SE. ¼ NE. ¼	16	9	10	40
SE. ¼	16	9	10	160
SE. ¼ SW. ¼	16	9	10	40
NE. ¼	21	9	10	160
E. ½ NW. ¼	21	9	10	80
SW. ¼ NW. ¼	21	9	10	40
NW. ¼ SE. ¼	21	9	10	40
SW. ¼	21	9	10	160
SE. ¼ SE. ¼	20	9	10	40
W. ½ NW. ¼	28	9	10	80
NW. ¼ SW. ¼	28	9	10	40
E. ½ NE. ¼	29	9	10	80
NE. ¼ SE. ¼	29	9	10	40
Area segregated				2,640

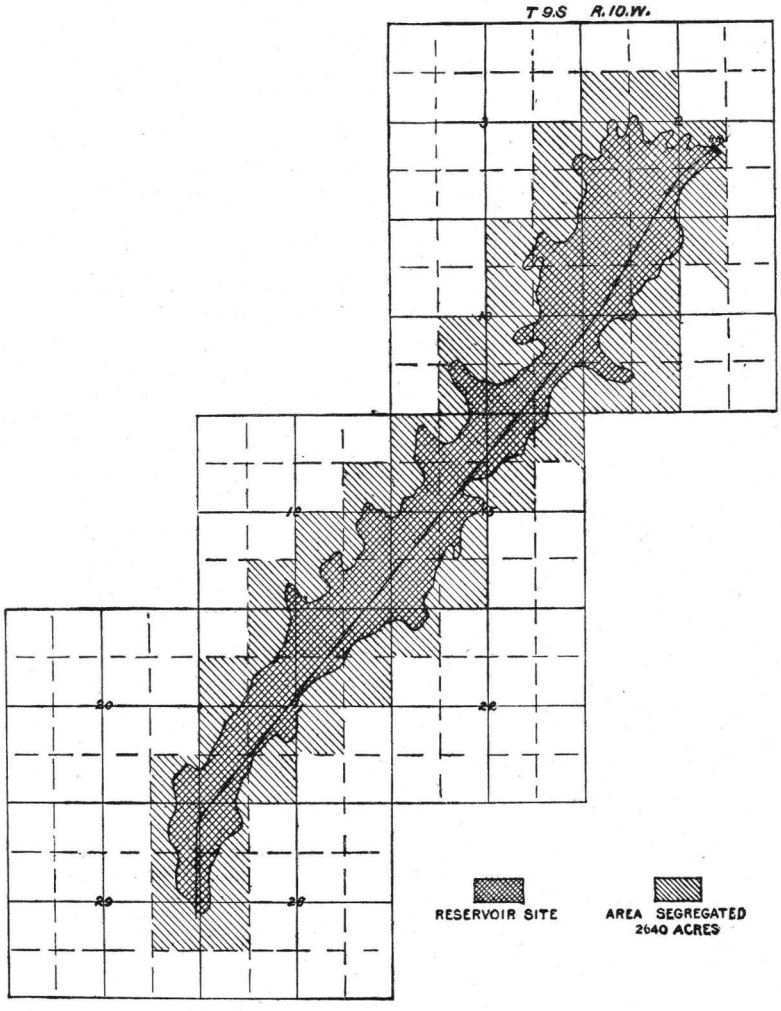


FIG. 171.—Reservoir Site No. 26, on Beaver Head River, at Dailey's Pinnacle.

Action affecting titles to land segregated for Reservoir Site No. 26 has been taken as follows:

					Acres.
NW. ¼ SE. ¼	Sec. 2,	T. 9 S.,	R. 10 W.	(homestead, September 16, 1885)	40
NE. ¼ SW. ¼	2	9	10	(homestead, September 16, 1885)	40
S. ½ SW. ¼	2	9	10	(homestead, September 16, 1885)	80
NW. ¼ NE. ¼	11	9	10	(preemption, August 4, 1886)	40
NE. ¼ NW. ¼	11	9	10	(preemption, August 4, 1886)	40
W. ½ NW. ¼	11	9	10	(preemption, August 4, 1886)	80
NW. ¼ SW. ¼	11	9	10	(preemption, July 13, 1885)	40
NE. ¼ NE. ¼	10	9	10	(preemption, July 13, 1885)	40
S. ½ SE. ¼	10	9	10	(preemption, July 13, 1885)	80
E. ½ SW. ¼	10	9	10	(homestead, April 14, 1890)	80
NW. ¼ SE. ¼	10	9	10	(homestead, April 14, 1890)	40
E. ½ SW. ¼	15	9	10	(homestead, June 27, 1885)	80
W. ½ NE. ¼	15	9	10	(homestead, June 27, 1885)	80
NW. ¼ NW. ¼	15	9	10	(desert, May 23, 1890)	40
NE. ¼ SW. ¼	15	9	10	(preemption, July 13, 1885)	40
SW. ¼ SW. ¼	15	9	10	(preemption, July 13, 1885)	40
SW. ¼ NW. ¼	15	9	10	(preemption, July 13, 1885)	40
NE. ¼	21	9	10	(desert, December 22, 1883)	160
SE. ¼ NW. ¼	21	9	10	(desert, December 22, 1683)	40
SW. ¼ NW. ¼	21	9	10	(desert, March 19, 1890)	40
SW. ¼	21	9	10	(homestead, November 2, 1885)	160
W. ½ NW. ¼	28	9	10	(desert, December 22, 1883)	80
					1,400

Reservoir Site No. 27.

On Red Rock River, 3 miles east of Lima, Montana.

Site is located in T. 13 S., R. 8 W., Sec. 36; T. 13 S., R. 7 W., Secs. 30, 31, 32, and 33; T. 14 S., R. 7 W., Secs 5 and 6.

Dam is located in NW. ¼ of SE. ¼, Sec. 36.

Height of dam, 40 feet.

Bench mark, rock monument at water line at south end of dam.

Area inclosed by top contour, 1,200 acres.

Lands segregated for reservoir.

				Acres.
NE. ¼	Sec. 36,	T. 13 S.,	R. 8 W	160·00
N. ½ SE. ¼	36	13	8	80·00
SE. ¼ SE. ¼	36	13	8	40·00
Lot 4	30	13	7	36·50
SE. ¼ SW. ¼	30	13	7	40·00
Lot 1	31	13	7	36·40
Lot 2	31	13	7	36·30
E. ½ NW. ¼	31	13	7	80·00
NE. ¼ SE. ¼	31	13	7	160·00
SE. ¼ SE. ¼	31	13	7	160·00
E. ½ SW. ¼	31	13	7	80·00
Lot 3	31	13	7	36·10
Lot 4	31	13	7	35·90
S. ½ NW. ¼	32	13	7	80·00
NE. ¼ NW. ¼	32	13	7	40·00
NE. ¼	32	13	7	160·00
SE. ¼	32	13	7	160·00
E. ½ SW. ¼	32	13	7	80·00

					Acres.
NW. ¼ SW. ¼	Sec. 32,	T. 13 S.,	R. 7 W		40·00
SW. ¼ NW. ¼	33	13	7		40·00
N. ½ SW. ¼	33	13	7		80·00
Lot 4	6	14	7		36·10
Lot 3	6	14	7		39·60
Lot 2	6	14	7		39·50
Lot 1	6	14	7		39·40
Lot 3	5	14	7		39·30
Lot 2	5	14	7		39·20
Area segregated					1, 894·30

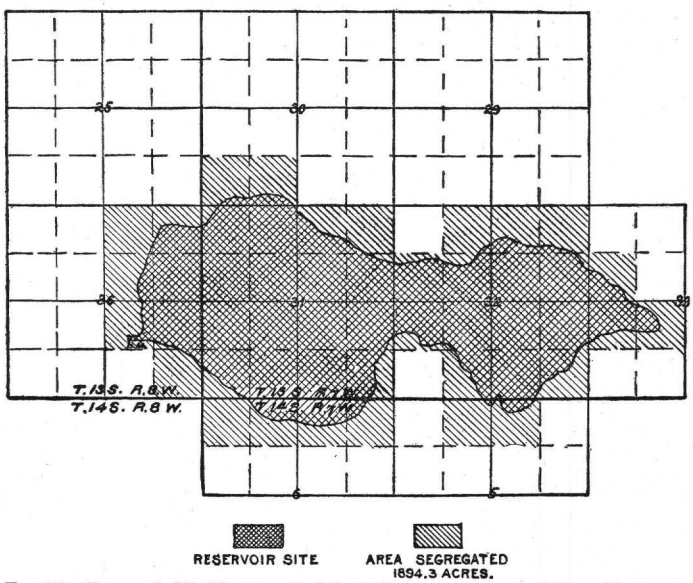


FIG. 172.—Reservoir Site No. 27, on Red Rock River, 3 miles east of Lima, Montana.

Action affecting titles to land segregated for Reservoir Site No. 27, has been taken as follows:

					Acres.
Lots 1, 2, 3, 4,	Sec. 6,	T. 14 S.,	R. 7 W.	(timber, June 15, 1888)	154·60
SW. ¼ NW. ¼	33	13	7	(homestead, June 3, 1890)	40·00
NE. ¼ SW. ¼	33	13	7	(preemption, April 24, 1885)	40·00
NW. ¼ SW. ¼	33	13	7	(homestead, June 3, 1890)	40·00
SW. ¼ NW. ¼	32	13	7	(preemption, October 14, 1885)	40·00
NE. ¼ NW. ¼	32	13	7	(preemption, October 14, 1885)	40·00
NW. ¼ NE. ¼	32	13	7	(preemption, October 14, 1885)	40·00
SE. ¼ NW. ¼	32	13	7	(timber, April 26, 1886)	40·00
SW. ¼ NE. ¼	32	13	7	(timber, April 26, 1886)	40·00
SE. ¼ NE. ¼	32	13	7	(homestead, June 3, 1890)	40·00
NE. ¼ SE. ¼	32	13	7	(homestead, June 3, 1890)	40·00
NE. ¼	31	13	7	(preemption, December 8, 1885)	160·00
Lots 1, 2	31	13	7	(desert, May 4, 1885)	72·70
E. ½ NW. ¼	31	13	7	(desert, May 4, 1885)	80·00
SE. ¼	31	13	7	(timber, April 27, 1885)	160·00
E. ½ SW. ¼	31	13	7	(homestead, April 27, 1885)	80·00
Lots 3, 4	31	13	7	(homestead, April 27, 1885)	72·00
					1, 029·30

Reservoir Site No. 28.

On Ruby River, 4 miles north of Pullers Springs, in Madison County, Montana.

Altitude of drainage basin from 5,300 to 10,000 feet. Character of topography, mountainous.

Site is located in T. 7 S., R. 4 W., Secs. 8, 17, 18, 19, and 20.

Dam is located in SW. ¼ of SE. ¼ Sec. 8.

Height of dam, 35 feet.

Bench mark, rock monument at water line at east end of dam.

Altitude of top contour, 5,300 feet.

Area inclosed by top contour, 400 acres.

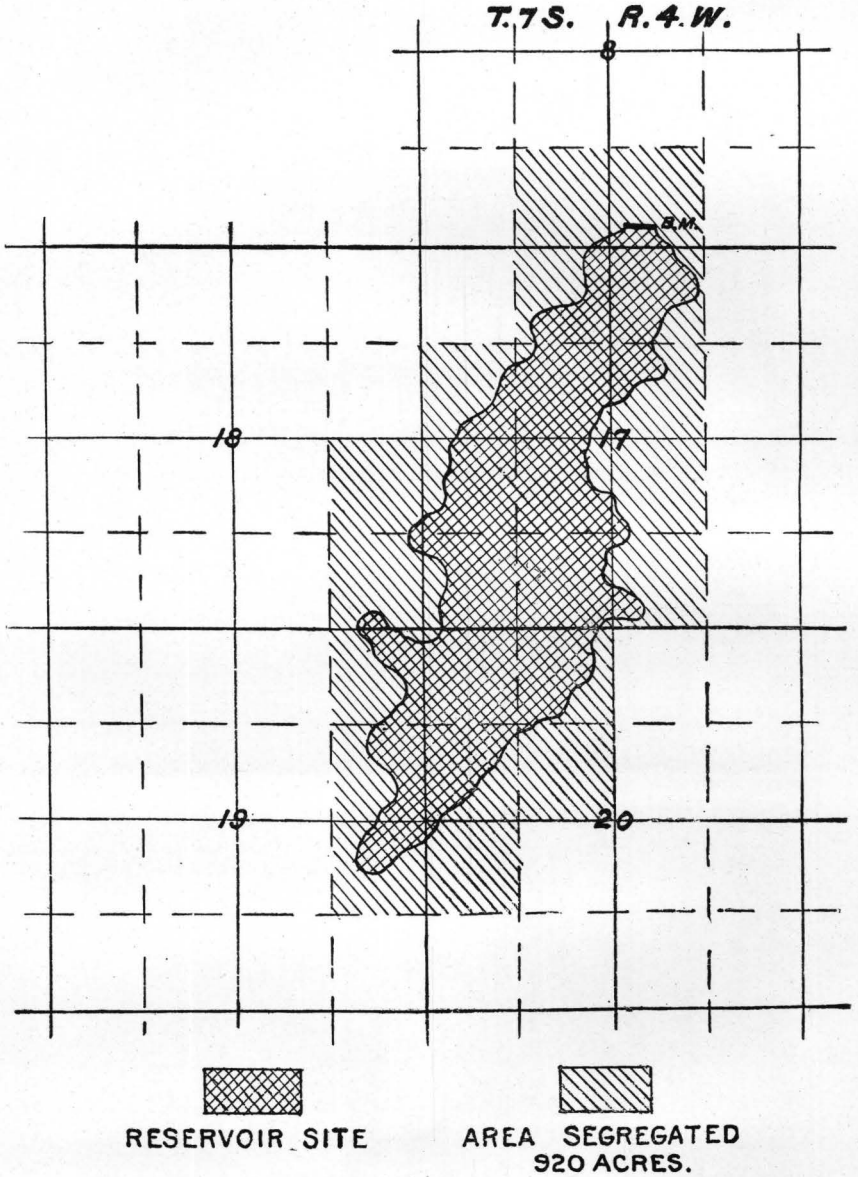


FIG. 173.—Reservoir Site No. 28, on Ruby River, 4 miles north of Pullers Springs.

Lands segregated for reservoir.

					Acres.
SW. ¼ SE. ¼	Sec. 8,	T. 7	S., R. 4	W	40
SE. ¼ SW. ¼	8	7	4		40
W. ½ NE. ¼	17	7	4		80
E. ½ NW. ¼	17	7	4		80
SW. ¼ NW. ¼	17	7	4		40
SW. ¼	17	7	4		160
W. ½ SE. ¼	17	7	4		80
E. ½ SE. ¼	18	7	4		80
NW. ¼	20	7	4		160
NW. ¼ SW. ¼	20	7	4		40
E. ½ NE. ¼	19	7	4		80
NE. ¼ SE. ¼	19	7	4		40
Area segregated					920

Action affecting the titles to lands segregated for Reservoir Site No. 28 has been taken as follows:

					Acres.
SE. ¼ SW. ¼	Sec. 8,	T. 7	S., R. 4	W. (timber culture, March 16, 1885)	40
W. ½ SW. ¼	17	7	4		80
SW. ¼ NW. ¼	17	7	4		40
NE. ¼ SW. ¼	17	7	4	(timber culture, October 21, 1884)	40
SE. ¼ SW. ¼	17	7	4	(preemption, March 28, 1872)	40
E. ½ NW. ¼	17	7	4		80
NW. ¼ NE. ¼	17	7	4	(preemption, July 29, 1881)	40
E. ½ SE. ¼	18	7	4	(homestead, July 9, 1881)	80
E. ½ NE. ¼	19	7	4	(homestead, March 28, 1872)	80
N. ½ NW. ¼	20	7	4		80
SW. ¼ NW. ¼	20	7	4	(preemption, March 28, 1872)	40
					640

Reservoir Site No. 29.

Large alkali basin 1 mile northwest of Reservoir Site No. 30, in Choteau County, Montana.

Site is located in T. 25 N., R. 6 W., Secs. 5, 6, 7, and 18; T. 25 N., R. 7 W., Secs. 1, 11, 12, 13, and 14.

Dam is located in the N. ½ of NW. ¼ Sec. 5, T. 25 N., R. 6 W.

Height of dam, 20 feet.

Bench mark, pile of rocks at water line at east end of dam.

Area inclosed by top contour, 2,800 acres.

Lands segregated for reservoir.

					Acres.
Lot 4	Sec. 5,	T. 25 N.,	R. 6	W	39·60
Lot 3	5	25	6		39·20
S. ½ NW. ¼	5	25	6		80·00
Lot 2	5	25	6		38·90
N. ½ SW. ¼	5	25	6		80·00
SW. ¼ SW. ¼	5	25	6		40·00
Lots 3 and 4	6	25	6		79·30
Lot 5	6	25	6		39·10

					Acres.
SE. ¼ NW. ¼	Sec.	6,	T. 25 N.,	R. 6 W	40·00
Lots 6 and 7		6	25	6	77·00
E. ½ SW. ¼		6	25	6	80·00
Lots 1 and 2		6	25	6	79·70
S. ½ NE. ¼		6	25	6	80·00
SE. ¼		6	25	6	160·00
NE. ¼		7	25	6	160·00
SE. ¼		7	25	6	160·00
Lots 1 and 2		7	25	6	76·40
E. ½ NW. ¼		7	25	6	80·00
Lots 3 and 4		7	25	6	76·70
E. ½ SW. ¼		7	25	6	80·00
Lot 1		18	25	6	38·50
NE. ¼ NW. ¼		18	25	6	40·00
NE. ¼		13	25	7	160·00
NW. ¼		13	25	7	160·00
NW. ¼ SW. ¼		13	25	7	40·00
NE. ¼		14	25	7	160·00
N. ½ SE. ¼		14	25	7	80·00
E. ½ NW. ¼		14	25	7	80·00
SE. ¼ SW. ¼		11	25	7	40·00
SE. ¼		11	25	7	160·00
NE. ¼		11	25	7	160·00
All		12	25	7	640·00
S. ½ SE. ¼		2	25	7	80·00
SE. ¼		1	25	7	160·00
SW. ¼		1	25	7	160·00
SE. ¼ NW. ¼		1	25	7	40·00
S. ½ NE. ¼		1	25	7	80·00
Lots 1 and 2		1	25	7	79·80
Area segregated					3,944·20

Action affecting the titles of lands segregated for Reservoir Site No. 29 has been taken as follows:

						Acres.
NE. ¼ SE. ¼	Sec.	11,	T. 25 N.,	R. 7 W.	(desert, November 16, 1889)	40·00
S. ½ SE. ¼		11	25	7	(preemption, August 31, 1888)	80·00
SE. ¼ SW. ¼		11	25	7	(preemption, August 31, 1888)	40·00
S. ½ NW. ¼		12	25	7	(timber, December 30, 1889)	80·00
S. ½ NE. ¼		12	25	7	(timber, December 30, 1889)	80·00
SW. ¼		12	25	7	(desert, November 16, 1889)	160·00
W. ½ SE. ¼		12	25	7	(desert, November 16, 1889)	80·00
W. ½ NE. ¼		13	25	7	(desert, November 16, 1889)	80·00
NW. ¼		13	25	7	(desert, November 16, 1889)	160·00
NW. ¼ SW. ¼		13	25	7	(desert, November 16, 1889)	40·00
NE. ¼		14	25	7	(preemption, October 21, 1886)	160·00
NE. ¼ NW. ¼		14	25	7	(preemption, August 31, 1888)	40·00
SE. ¼ NW. ¼		14	25	7	(homestead, November 6, 1889)	40·00
Lots 1 and 2		7	25	6	(timber, July 7, 1890)	76·40
NE. ¼ NW. ¼		7	25	6	(timber, July 7, 1890)	40·00
NW. ¼ NE. ¼		7	25	6	(timber, July 7, 1890)	40·00
						1,236·40

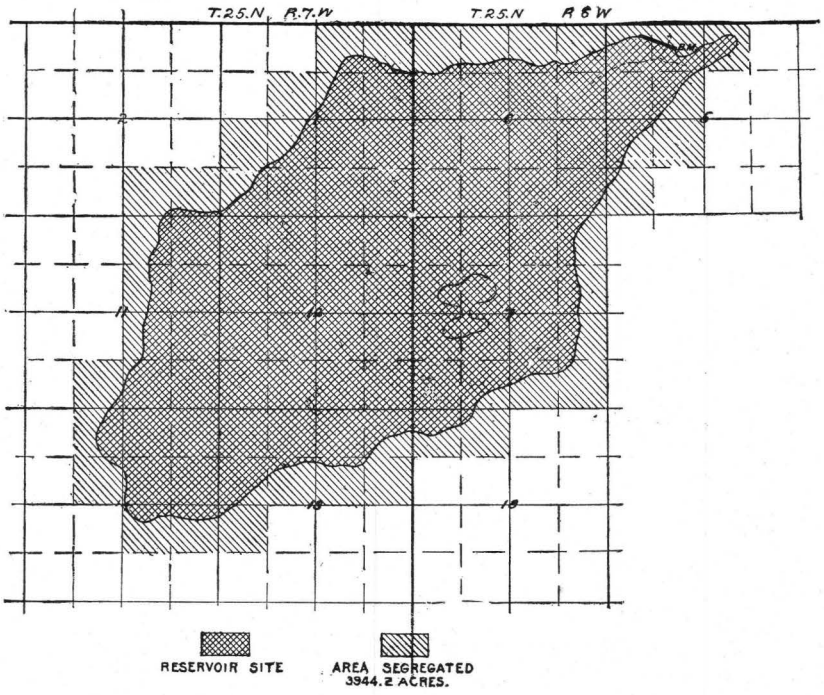


FIG. 174.—Reservoir Site No. 29, large alkali basin, 1 mile northwest of Reservoir Site No. 30

RESERVOIR SITE NO. 30.

Dry Lake, 2 miles west of Monkman's Ranch, in Choteau County, Montana.
Site is located in T. 25 N., R. 6 W., Secs. 8, 17, and 18.
Dam is located in NW. ¼ of NW. ¼ Sec. 17.
Height of dam, 15 feet.
Bench mark, none.
Area inclosed by top contour, 200 acres.

Lands segregated for reservoir.

				Acres.
S. ½ SW. ¼ Sec.	8,	T. 25 N.,	R. 6 W.	80
S. ½ SE. ¼	8	25	6	80
N. ½ NE. ¼	17	25	6	80
NW. ¼	17	25	6	160
NW ¼ SW. ¼	17	25	6	40
NE. ¼ SE. ¼	18	25	6	40
SE. ¼ NE. ¼	18	25	6	40
Area segregated				520

Action affecting the titles of lands segregated for Reservoir Site No. 30 has been taken as follows:

				Acres.
NW. ¼ Sec.	17,	T. 25 N.,	R 6 W.	160
N. ½ NE. ¼	17	25	6	80
				240

Reserved July 19, 1889. Letter of Secretary, August 5, 1889.

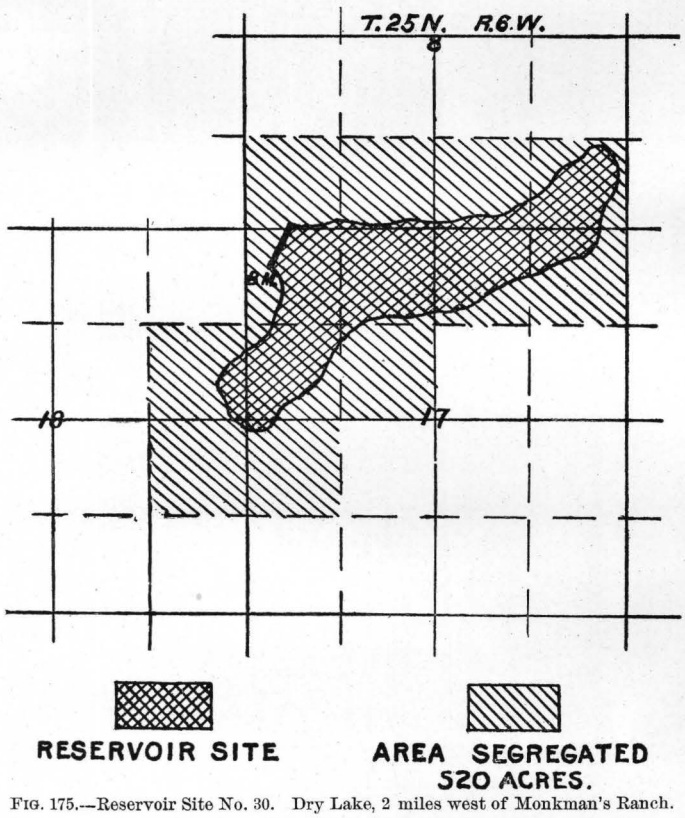


FIG. 175.—Reservoir Site No. 30. Dry Lake, 2 miles west of Monkman's Ranch.

RESERVOIR SITE No. 31.

On Box Elder Creek, in Cascade County, Montana, 1 mile below where stage road from Great Falls to Belt crosses Box Elder Creek.

Altitude of drainage basin from 3,600 to 7,000 feet. Character of topography, "bench lands;" no water in Box Elder Creek during summer months; very little timber; area of drainage basin 85 square miles.

Reservoir site located in T. 20 N., R. 5 E., Secs. 21, 22, 26, 27, and 28.

Dam is located in the W. ½ of NW. ¼, Sec. 22.

Height of dam 46 feet.

Bench mark, stake at south end of dam, on top contour; approximate altitude 3,600 feet.

Altitude of top contour 3,600 feet.

Area inclosed by top contour 180 acres.

Approximate content of reservoir 3,000 acre-feet.

Reservoir site is settled.

Irrigable lands are along Box Elder Creek below reservoir site.

Lands segregated.

				Acres.
NW. ¼ NW. ¼	Sec. 22,	T. 20 N.,	R. 5 E	40
S. ½ NW. ¼	22	20	5	80
SW. ¼ NE. ¼	22	20	5	40
E. ½ SE. ¼	21	20	5	80
W. ½ SW. ¼	22	20	5	80
NE. ¼ SW. ¼	22	20	5	40
NW. ¼ SE. ¼	22	20	5	40

				Acres.
E. ½ NE. ¼ Sec.	28,	T. 20 N.,	R. 5	80
N. ½	27	20	5	320
NE. ¼ SW. ¼	27	20	5	40
NW. ¼ SE. ¼	27	20	5	40
W. ½ NW. ¼	26	20	5	80
Area segregated				960

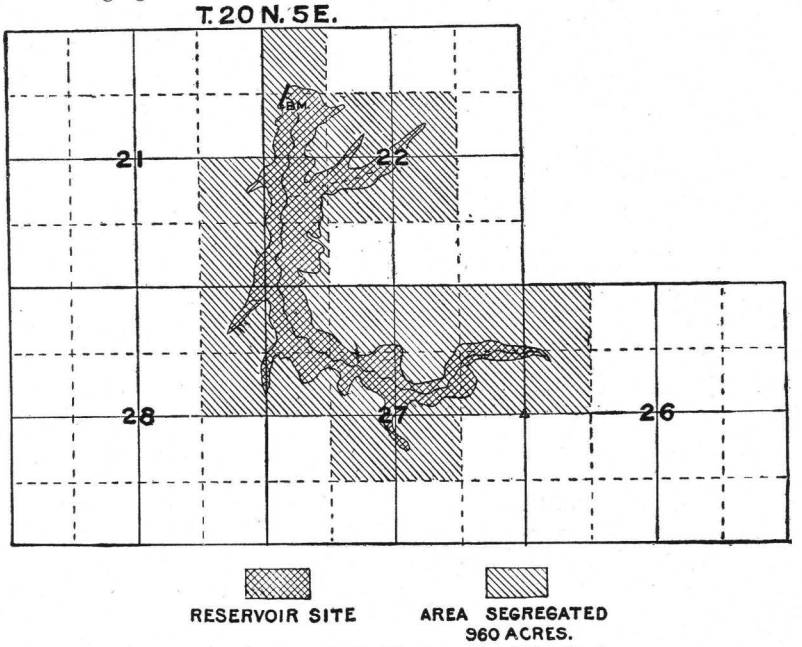


FIG. 176.—Reservoir Site No. 31, on Box Elder Creek.

Action affecting the titles of lands segregated for Reservoir Site No. 31 has been taken as follows:

					Acres.
E. ½ SE. ¼ Sec.	21,	T. 20 N.,	R. 5 E	(preemption, May 9, 1890	80
W. ½ NW. ¼	22	20	5	(homestead, March 20, 1890)	80
W. ½ SW. ¼	22	20	5	(timber, April 16, 1887)	80
SW. ¼ NW. ¼	26	20	5	(preemption, March 16, 1889)	40
SE. ¼ NW. ¼	27	20	5	(preemption, March 16, 1889)	40
S. ½ NE. ¼	27	20	5	(preemption, March 16, 1889)	80
W. ½ NW. ¼	27	20	5	(timber, November 5, 1888)	80
NE. ¼ NW¼	27	20	5	(timber, November 5, 1888)	40
NW. ¼ NE. ¼	27	20	5	(timber, November 5, 1888)	40
NE. ¼ NE. ¼	28	20	5	(preemption, May 9, 1890)	40
SE. ¼ NW. ¼	22	20	5	(reserved per Sec'y's order, March 13, 1890)	40
SW. ¼ NE. ¼	22	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NE. ¼ SW. ¼	22	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NW. ¼ SE. ¼	22	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NE. ¼ NE. ¼	27	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NW. ¼ NW. ¼	26	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NE. ¼ SW. ¼	27	20	5	(reserved per Sec'y's order, March 13, 1890)	40
NW. ¼ SE. ¼	27	20	5	(reserved per Sec'y's order, March 13, 1890)	40
SE. ¼ NE. ¼	28	20	5	(reserved per Sec'y's order, March 13, 1890)	40
					960

RESERVOIR SITE NO. 32.

On West Fork of Otter Creek, 4 miles east of Kibbey, Cascade County, Montana.

Altitude of drainage basin from 5,000 to 7,000 feet. Character of topography, mountainous; a small stream of water in creek during the entire year; about one-fourth of basin covered with timber.

Reservoir site is located in T. 16 N., R. 8. E., Sec. 14.

Dam is located in NE. ¼ of NW. ¼, Sec. 14.

Height of dam, 66 feet.

Bench mark, stake on top contour at each end of dam. Altitude 5,000 feet, approximate.

Altitude of top contour, 5,000 feet.

Area inclosed by top contour, 70 acres.

Approximate content of reservoir, 1,500 acre-feet.

Material (rock) for construction to be found on site.

Reservoir site is unsettled.

Irrigable lands are along Otter Creek, commencing at a point 2 miles below the site.

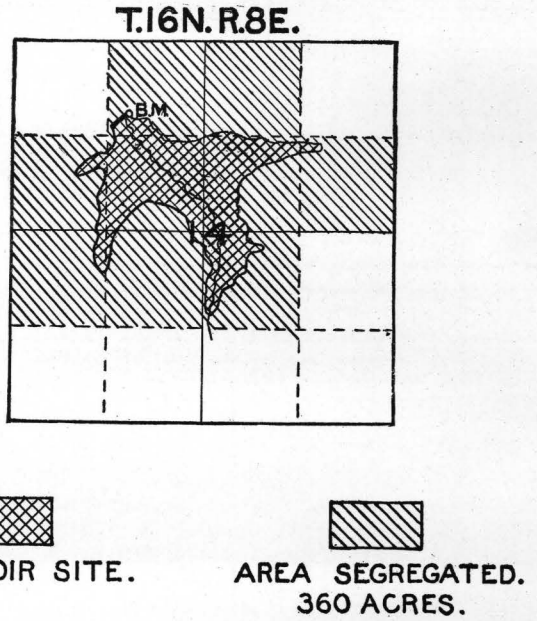


FIG. 177.—Reservoir Site No. 32, on West Fork of Otter Creek, 4 miles east of Kibbey.

Lands segregated for reservoir.

				Acres.
NW. ¼ NE. ¼ Sec.	14, T.	16 N., R.	8 E	40
S. ½ NE. ¼	14	16	8	80
NW. ¼ SE. ¼	14	16	8	40
N. ½ SW. ¼	14	16	8	80
S. ½ NW. ¼	14	16	8	80
NE. ¼ NW. ¼	14	16	8	40
Area segregated				360

Land Office records show area segregated to be all public land.

Reservoir Site No. 33.

On Sage Creek, 4 miles west of Utica, in Fergus County, Montana.

Altitude of drainage basin from 4,900 feet to 8,000 feet; no water in Sage Creek during the summer months; area of drainage basin, 25 square miles.

Site located in T. 14 N., R. 12 E., Secs. 10 and 11, principal meridian of Montana.

Dam located in NW. ¼ of SW. ¼, Sec. 11.

Height of dam, 21 feet.

West end of dam marked by a stake; approximate elevation, 4,900 feet.

Altitude of top contour, 4,900 feet.

Area inclosed by top contour, 30 acres.

Approximate content of reservoir, 250 acre-feet.

Material (rock) for construction could be obtained within 2 miles of site.

Reservoir site unsettled.

Irrigable lands are along Sage Creek bottom.

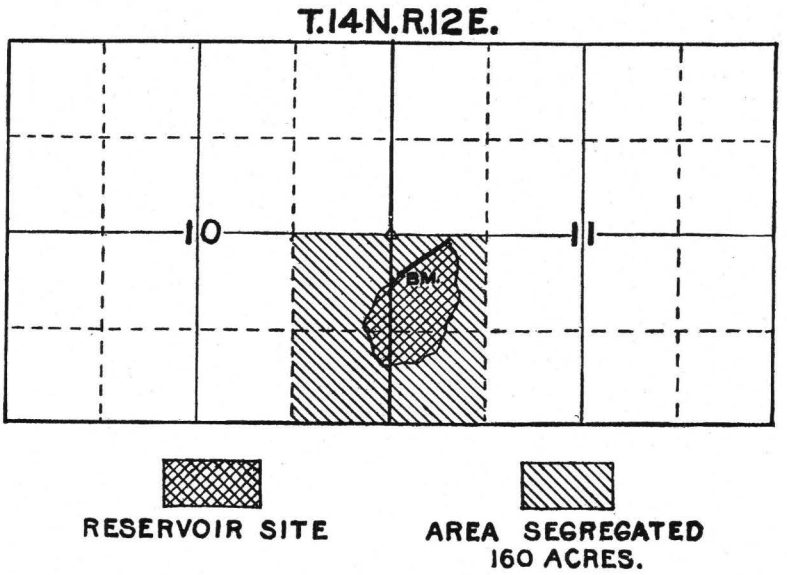


Fig. 178.—Reservoir Site No. 33, near Sage Creek, 4 miles west of Utica.

Lands segregated for reservoir.

	Acres.
W. ½ SW. ¼ Sec. 11, T. 14 N., R. 12 E	80
E. ½ SE. ¼ 10 14 12	80
Total 4 quarter quarter-sections	160

Action affecting the titles of lands segregated for Reservoir Site No. 33 has been taken as follows:

					Acres.
W. ½ SW. ¼ Sec.	11,	T. 14 N.,	R. 12 E		80
NE. ¼ SE. ¼	10	14	12	(reserved by order of Secretary, March 13, 1890)	40
SE. ¼ SE. ¼	10	14	12	(timber culture, May 10, 1890)	40
					160

Reservoir Site No. 34.

Reservoir site at forks of Judith River, on Middle Fork, 13 miles west of Utica, in Fergus County, Montana.

Area of drainage basin, 120 square miles. Character of topography, mountainous. About one-half of basin covered with timber. A large quantity of running water during the entire year. Altitude of basin, 5,000 to 8,000 feet.

Reservoir site located in T. 13 N., R. 11 E., in Secs. 34, 35, and 36.

Dam is located in SW. ¼ of NW. ¼ Sec. 36.

Height of dam, 76 feet.

Bench mark, stake on top contour, at north end of dam. Approximate altitude, 5,000 feet.

Altitude of top contour, 5,000 feet.

Area inclosed by top contour, 100 acres.

Approximate content of reservoir, 3,000 acre-feet.

Material (rock) for construction on site.

Reservoir site is unsettled.

Irrigable lands along the Judith River immediately below reservoir site.

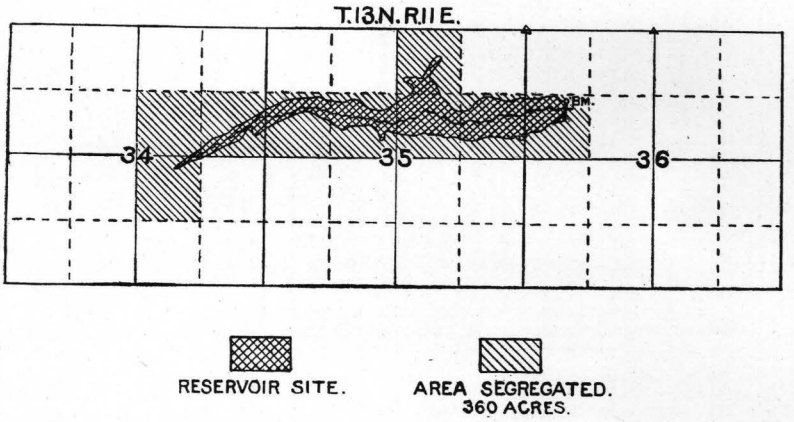


Fig. 179.—Reservoir Site No. 34, at forks of Judith River, on Middle Fork, 13 miles west of Utica.

Recommended for segregation in letter to Secretary of the Interior dated February 27, 1891.

Lands segregated for reservoir.

				Acres.
NW. ¼ SE. ¼ Sec.	34,	T. 13 N.,	R. 11 E	40·00
S. ½ NE. ¼	34	13	11	80·00
S. ½ NW. ¼	35	13	11	80·00
S. ½ NE. ¼	35	13	11	80·00
NW. ¼ NE. ¼	35	13	11	40·00
SW. ¼ NW. ¼	36	13	11	40·00
Area segregated				360·00

Land Office records show area segregated to be all public land.

Reservoir Site No. 35.

Dry basin 2½ miles north of Utica, in Fergus County, Montana.

Altitude of drainage basin, 4,900 feet; character of topography "bench land"; no water within 6 miles of basin; no timber.

Reservoir site located in T. 14 N., R. 13 E., Sec. 5, prin. meridian of Montana.

Bench mark, stake on north side of site, 1,755 feet from NE. corner of Sec. 5 and 1,425 feet from ¼-mile corner between NE. corner and SE. corner of Sec. 5; approximate altitude, 4,900 feet.

Altitude of top contour, 4,900 feet.

Area inclosed by top contour, 35 acres.

Approximate content of reservoir, 200 acre-feet.

Reservoir site unsettled.

Irrigable lands in immediate vicinity of reservoir site.

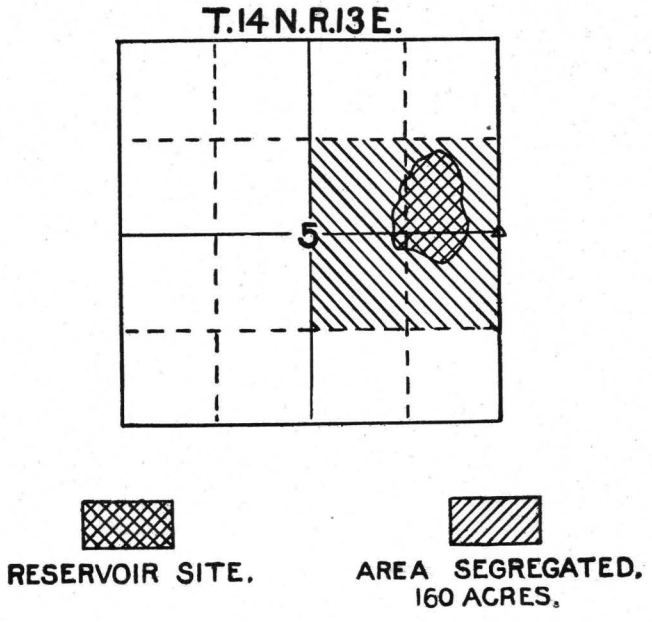


Fig. 180.—Reservoir Site No. 35, North Utica Lake, 2½ miles north of Utica.

Lands segregated for reservoir.

	Acres.
S. ½ NE. ¼ Sec. 5, T. 14 N., R. 13 E	80
N. ½ SE. ¼ 5 14 13	80
Area segregated	160

Action affecting titles to lands segregated for Reservoir Site No. 35 has been taken as follows:

		Acres.
S. ½ NE. ¼ Sec. 5, T. 14 N., R. 13 E.		80
N. ½ SE. ¼ 5 14 13	(reserved by order Secretary, March 13, 1890)	80
		160

Reservoir Site No. 36.

Dry lake basin, 1½ miles north of Utica and 1 mile southeast of Reservoir Site No. 35, in Fergus County, Montana.

Altitude of drainage basin, about 4,900 feet; character of topography "bench lands;" no water within 6 miles of site; no timber.

Site located in Sec. 9, T. 14 N., R. 13 E., principal meridian of Montana.

Dam located in SW. ¼ of NE. ¼ Sec. 9.

Height of dam, 3 feet.

Bench mark, a stake at each end of dam at water line.

Altitude of top contour, 4,900 feet.

Area enclosed by top contour, 55 acres.

Approximate content reservoir, 350 acre-feet.

Reservoir site settled.

Irrigable lands in vicinity of reservoir site.

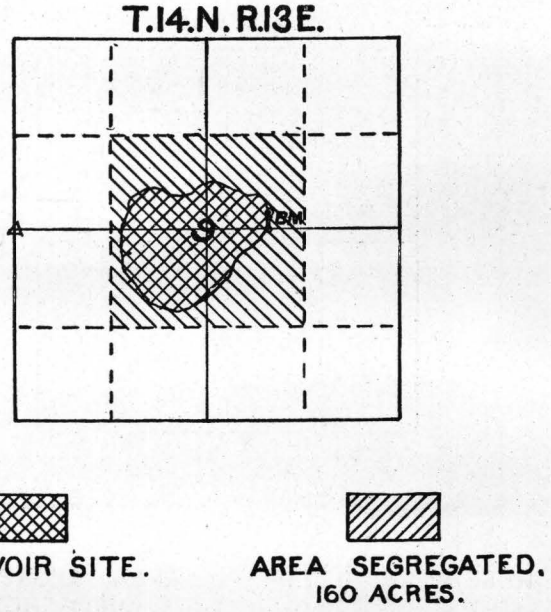


Fig. 181.—Reservoir site No. 36, South Utica Lake, 1½ miles north of Utica.

Lands segregated for reservoir.

	Acres.
SW. ¼ NE. ¼ Sec. 9, T. 14 N., R. 13 E	40
NW. ¼ SE. ¼ 9 14 13	40
NE. ¼ SW. ¼ 9 14 13	40
SE. ¼ NW. ¼ 9 14 13	40
Area segregated	160

Action affecting the titles to lands segregated for Reservoir Site No. 36 has been taken as follows:

	Acres.
SW. ¼ NE. ¼ Sec. 9, T. 14 N., R. 13 E	40
NW. ¼ SE. ¼ 9 14 13	40
NE. ¼ SW. ¼ 9 14 13	40
SE. ¼ NW. ¼ 9 14 13	40
Homestead, July 8, 1890.	160

All section 9 reserved, per Secretary's order, March 15, 1890.

Reservoir Site No. 37.

Lebo Lake, on stage road from Big Elk post-office to Big Timber, 1 mile south of Big Elk post-office, Montana.

Altitude of drainage basin, 5,000 to 9,000 feet; character of topography, valley and mountain.

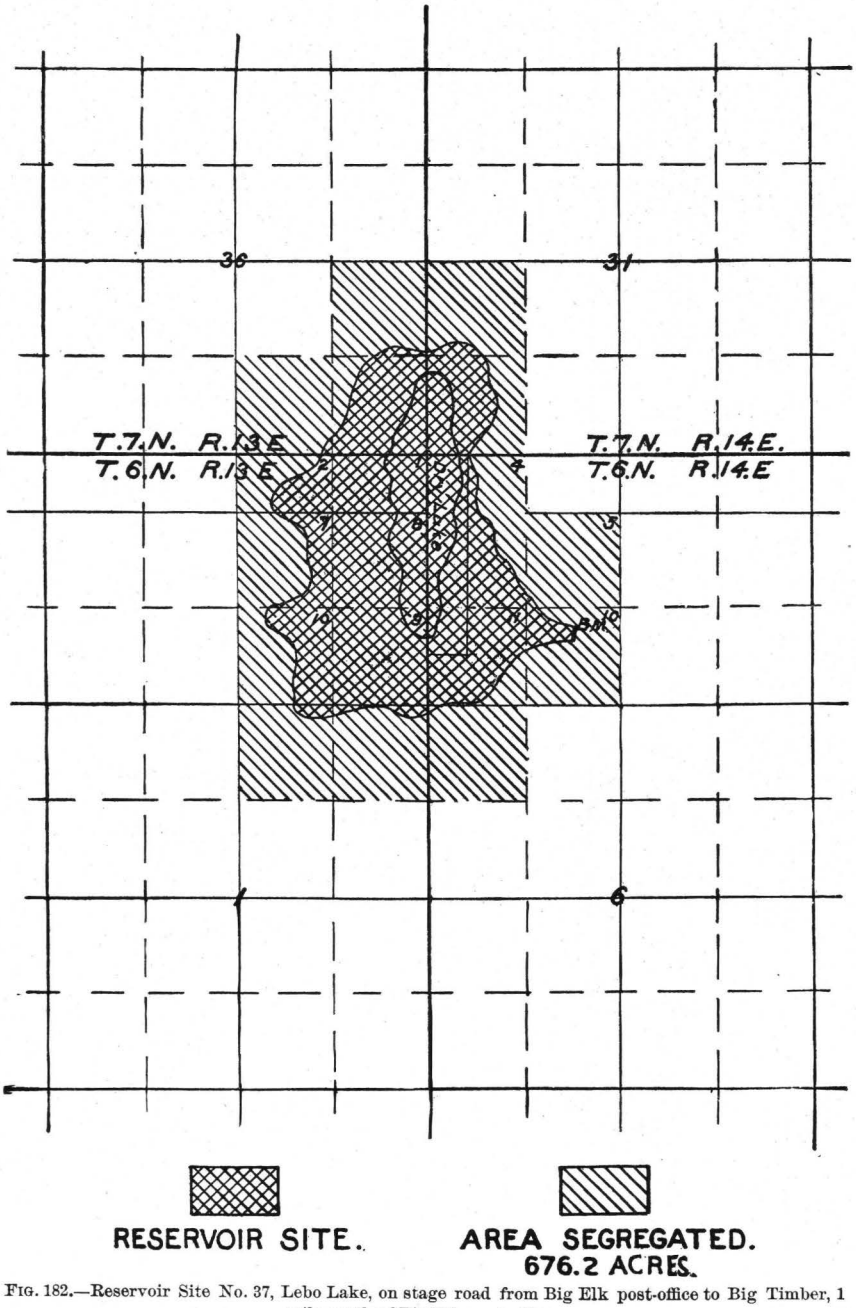


Fig. 182.—Reservoir Site No. 37, Lebo Lake, on stage road from Big Elk post-office to Big Timber, 1 mile south of Big Elk post-office.

Site is located in T. 6 N., R. 13 E., Sec. 1; T. 6 N., R. 14 E., Sec. 6; T. 7 N., R. 13 E., Sec. 36; T. 7 N., R. 14 E., Sec. 31.

Dam located in lot 10 of Sec. 6, T. 6 N., R. 14 E.

Height of dam, 10 feet.

Bench mark, two flat rocks at water line at north end of dam; altitude, 5,000 feet.

Altitude of top contour, 5,000 feet.

Lands segregated for reservoir.

				Acres.
NE. ¼ SE. ¼	Sec. 36,	T. 7 N.,	R. 13 E	40·0
S. ½ SE. ¼	36	7	13	80·0
W. ½ SW. ¼	31	7	14	80·0
N. ½ NE. ¼	1	6	13	80·0
Lots 7, 8, 9, 10	1	6	13	160·0
Lots 1, 2	1	6	13	45·1
NW. ¼ NW. ¼	6	6	14	40·1
Lots 5, 10	6	6	14	80·0
Lot 11	6	6	14	31·6
Lot 4	6	6	14	39·4
Area segregated				676·2

And such portion of Sec. 6, T. 6 N., R. 14 E., as, according to map of survey approved November 24, 1877, was unsurveyed.

Action affecting the titles to lands segregated for Reservoir Site No. 37 has been taken as follows:

				Acres.
N. ½ NE. ¼	Sec. 1,	T. 6 N.,	R. 13 E	80·0
Lots 7, 8, 9, 10	1	6	13	160·0
Lots 1, 2	1	6	13	45·1
W. ½ SW. ¼	31	7	14	80·0
				365·1

Reservoir Site No. 38.

Site 1½ miles above Martinsdale, on flat one-half mile south of Copperopolis road, in Meagher County, Montana.

Altitude of drainage basin from 6,000 to 8,000 feet; character of topography, mountainous.

Site is located in T. 8 N., R. 11 E., Secs. 2 and 3.

Dam is located in NW. ¼ of SW. ¼ Sec. 2; in SW. ¼ of SW. ¼ Sec. 2; in SE. ¼ of NE. ¼ Sec. 3.

Height of dam 35 feet.

Bench mark, pile of rocks 400 feet west of north end of dam and 5 feet above water line; altitude 6,000 feet.

Altitude of top contour, 6,000 feet.

Area inclosed by top contour, 250 acres.

Lands segregated for reservoir.

				Acres.
Lot 3	Sec. 3,	T. 8 N.,	R. 11 E	43·00
Lot 4	3	8	11	43·20
S. ½ NW. ¼	3	8	11	80·00
Lot 2	3	8	11	42·60
S. ½ NE. ¼	3	8	11	80·00
E. ½ SW. ¼	3	8	11	80·00
SE. ¼	3	8	11	160·00
SW. ¼ NW. ¼	2	8	11	40·00
W. ½ SW. ¼	2	8	11	80·00
Area segregated				648·08

Action affecting the titles of lands segregated for Reservoir Site No. 38 has been taken as follows:

				Acres.
SW. ¼ of NW. ¼ Sec.	2,	T. 8 N.,	R. 11 E	40·00
W. ½ SW. ¼	2	8	11	80·00
Reserved by order of Secretary, March 13, 1890.				
Lot 3	3	8	11	43·00
Lot 4	3	8	11	43·20
S. ½ NW. ¼	3	8	11	80·00
Lot 2	3	8	11	42·60
S. ½ NE. ¼	3	8	11	80·00
E. ½ SW. ¼	3	8	11	80·00
SE. ¼	3	8	11	160·00
				648·80

Selected by Northern Pacific Railroad Company, February 26, 1885. Act of July 2, 1864. Resolution of May 31, 1870.

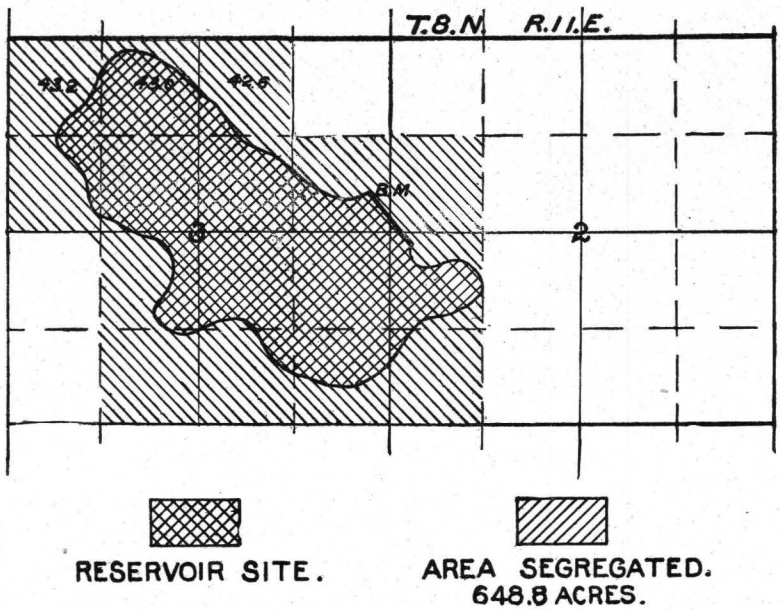


FIG. 183.—Reservoir Site No. 38; site 1½ miles above Martinsdale on flat one-half mile south of Copperopolis road.

NEW MEXICO.

RESERVOIR SITES, NUMBERED 1 TO 39, INCLUSIVE.

(Recommended for segregation in letter to the Secretary of the Interior dated February 27, 1891.)

RESERVOIR SITE NO. 1.

Is situated at Horse Lake, Rio Arriba County, New Mexico.

Location of site, partly on Tierra Amarilla grant and partly on unsurveyed land, but if surveyed would fall in T. 30 N., R. 1 E.

Location of dam, at southern extremity of the lake.

Height of dam, 40 feet.

Bench mark, a pile of rocks at each end on the water line.

Area of reservoir site, 1,120 acres.

Capacity of reservoir approximately 21,000 acre-feet.

Material for construction of dam in the immediate vicinity.

There are no settlements within this reservoir site.

The water can be used to irrigate land lying between the reservoir and the Chama River.

Partly on Tierra Amarilla grant and partly on unsurveyed land.

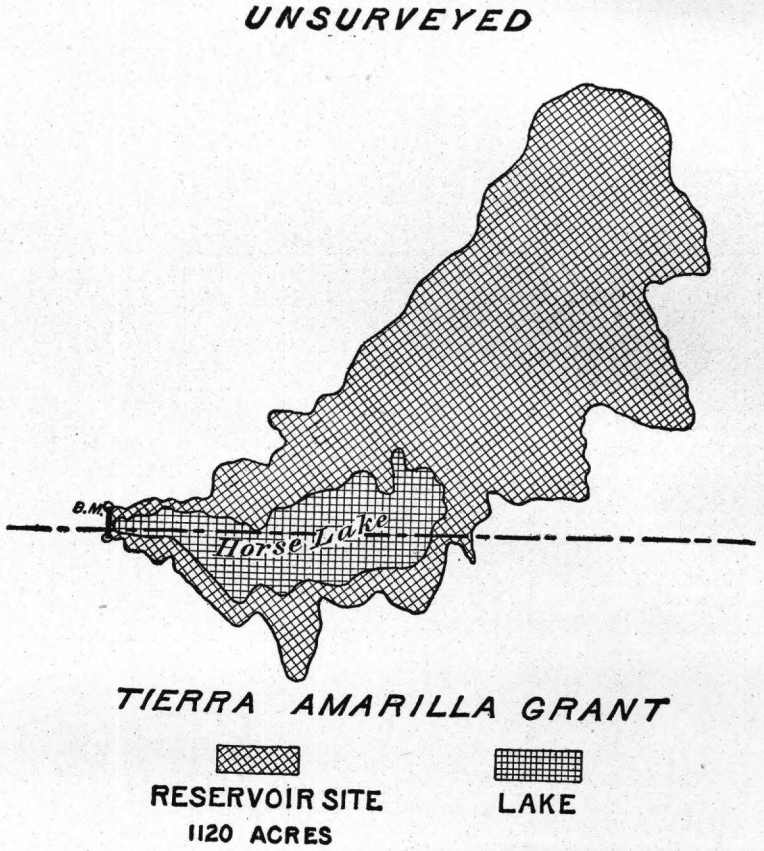


FIG. 184.—Reservoir Site No. 1, at Horse Lake, on western boundary of Tierra Amarilla grant.

RESERVOIR SITE NO. 2.

Is situated at Boulder Lake, Rio Arriba County, New Mexico.

The topography of the drainage basin is chiefly of the plains character and is partly timbered.

Location of site, on unsurveyed land, but, if surveyed, would fall in T. 29 N., R. 1 E.

Location of dam, about 1 mile below Boulder Lake, at the point where the drainage enters a narrow canyon.

Height of dam, 100 feet.

Bench mark, a pile of rocks at each end on water line. Altitude of about 7,500 feet.

Area of reservoir, 2,250 acres.
Capacity of reservoir approximately 51,000 acre-feet.
Material for construction of dam near at hand.

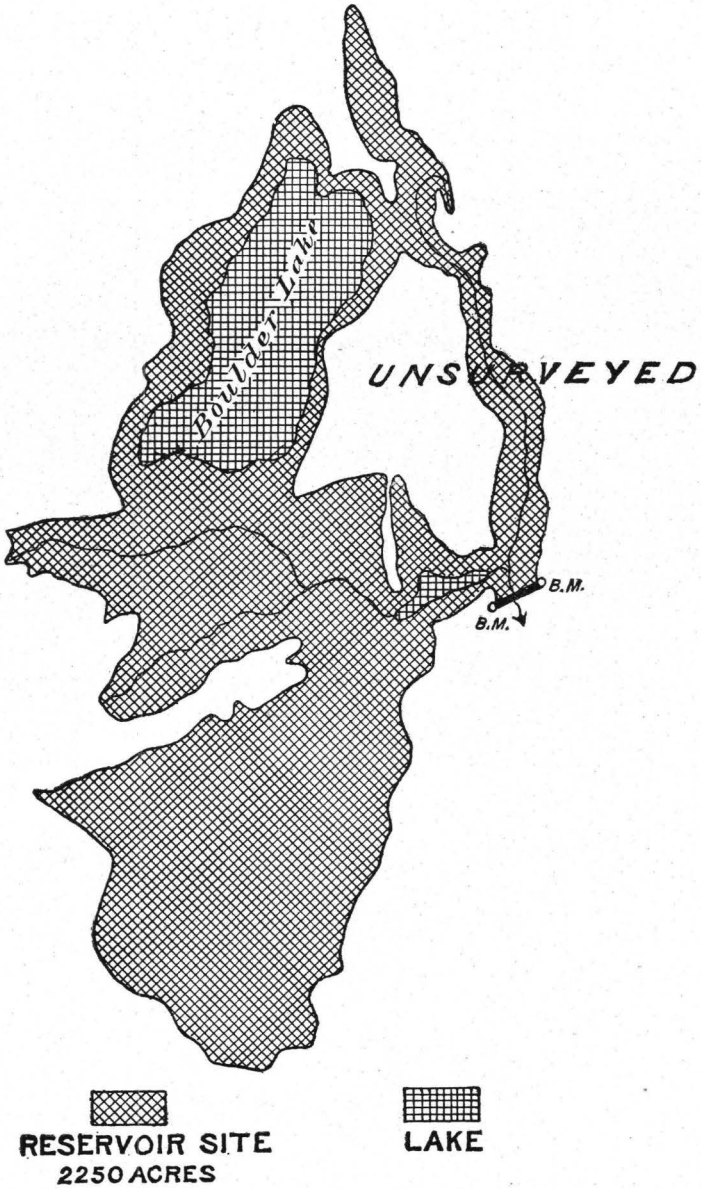


FIG. 185.—Reservoir Site No. 2, at Boulder Lake, near Continental Divide, about 20 miles south of Colorado line.

There are no settlements in this reservoir site.
Water can be used for irrigating lands on the plains a few miles east of the site.
All on unsurveyed land.

RESERVOIR SITE NO. 3.

Is situated at Stinking Lake, Rio Arriba County, New Mexico.

The drainage basin is rolling and partly timbered and is bounded on the west by the continental divide.

Location of site on unsurveyed land, but cut by the New Mexico Principal Meridian, and if the land were surveyed would lie in T. 27 and 28 N., R. 1 E. and 1 W.

Location of dam, near the eastern extremity of the lake.

Height of dam, 50 feet.

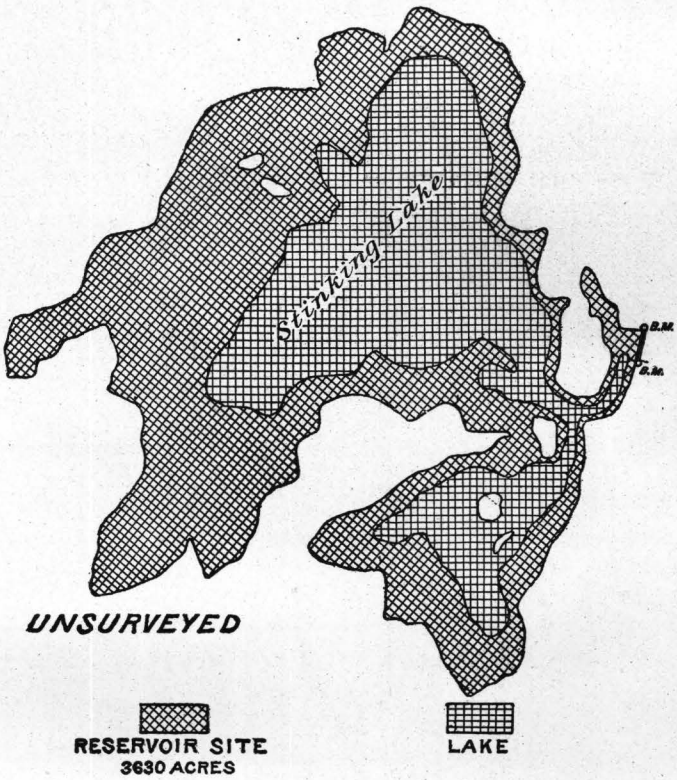


FIG. 186—Reservoir Site No. 3, at Stinking Lake, near Continental Divide, about thirty miles south of Colorado line.

Bench mark, a pile of rocks at each end on water line.

Altitude of about 7,500 feet.

Area of reservoir, 3,630 acres.

Capacity of reservoir approximately 125,000 acre-feet.

Material for construction near at hand.

Only one settler's cabin is on this reservoir site.

Water east of reservoir site can be used to irrigate the valley of Rio Chama.

All on unsurveyed land.

Reservoir Site No. 4.

Is situated on Vallecitos Creek, Rio Arriba County, New Mexico.
Drainage basin partly timbered.
Location of dam, a few hundred feet below where stream enters a narrow canyon.
Height of dam, 100 feet.
Dam marked by stone monument at each end.
Altitude of drainage basin, from 7,000 to 8,000 feet.
Area of reservoir, 100 acres.
Capacity of reservoir about 3,500 acre-feet.
Material for construction of dam at site.
No settlements on site.
Water would be used in the valleys of the Rios Caliente and Chama.

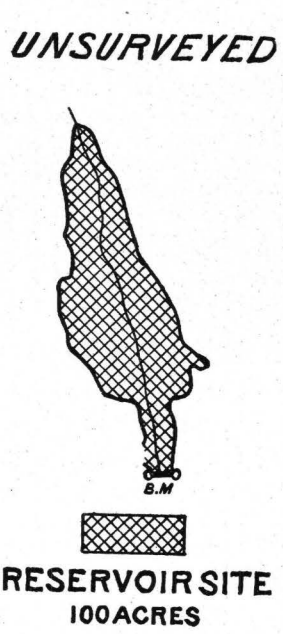


Fig. 187.—Reservoir Site No. 4, on Vallecitos Creek.

Reservoir Site No. 5.

Is situated near El Rito, Rio Arriba County, New Mexico.
Drainage area largely timbered. Stream has swift fall, but is hardly perennial.
Location of site, Sec. 9, T. 25 N., R. 7 E.
Location of dam, at entrance of narrow canyon near center of section.
Height of dam, 150 feet.
Dam marked at each end by stone monument.
Altitude, about 7,000 to 8,000 feet.
Area of reservoir, 60 acres.
Capacity of reservoir, 3,000 acre-feet.
Stone for construction of dam at site.
No settlements are on this site.
Water would be used in Chama Valley.

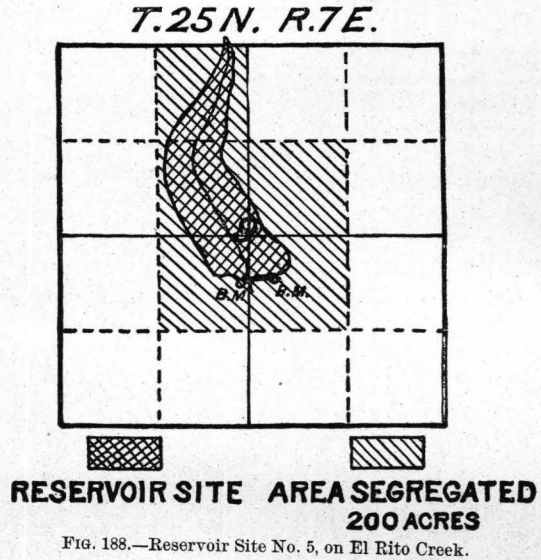


FIG. 188.—Reservoir Site No. 5, on El Rito Creek.

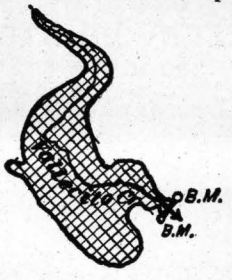
Lands segregated.

				Acres.
E. ½ NW. ¼ Sec.	9,	T. 25 N.,	R. 7 E.	80
SW. ¼ NE. ¼	9	25	7	40
NW. ¼ SE. ¼	9	25	7	40
NE. ¼ SW. ¼	9	25	7	40
Area segregated				200

Land Office records show all lands segregated to be public lands.

RESERVOIR SITE NO. 6.

Is situated on Rio Vallecitos, Rio Arriba County, New Mexico.
Stream very swift, 10 feet wide and 7 inches deep.



RESERVOIR SITE

AREA SEGREGATED

60 ACRES.

FIG. 189.—Reservoir Site No. 6, on Vallecitos Creek.

Location of dam, Sec. 10, T. 25 N., R. 8 E.
Height of dam, 80 feet.
Bench mark, stone monument at each end.
Altitude of drainage basin, about 7,000 feet.
Area of reservoir, 60 acres.
Capacity of reservoir, 1,800 acre-feet.
Stone for construction of dam at site.
No settlements are on this site.

Reservoir Site No. 7.

Is situated on Rio Caliente, Rio Arriba County, New Mexico.
Drainage basin partly timbered. Stream moderately swift, 10 or 12 feet wide and 6 to 10 inches deep.
Most of the reservoir is in T. 5 N.
Location of dam, Sec. 1, T. 24 N., R. 8 E.
Height of dam, 80 feet.
Bench mark, stone monument at each end.
Altitude of drainage basin, from 7,000 to 8,000 feet.
Area of reservoir, 330 acres.
Capacity of reservoir, approximately, 10,000 acre-feet.
Stone for construction of dam at site.
No settlements are on this reservoir site.
Water would be used for irrigating the Chama Valley.

Lands segregated.

					Acres.
E. ½ NW. ¼	Sec. 25,	T. 25 N.,	R. 8	E	80·00
W. ½ NE. ¼	25	25	8		80·00
W. ½ SE. ¼	25	25	8		80·00
E. ½ SW. ¼	25	25	8		80·00
SW. ¼ SW. ¼	25	25	8		40·00
SE. ¼ SE. ¼	35	25	8		40·00
W. ½	36	25	8		320·00
W. ½ SE. ¼	36	25	8		80·00
SE. ¼ SE. ¼	36	25	8		40·00
SW. ¼ NE. ¼	36	25	8		40·00
Lots 1, 2, 3, and 4	1	24	8		143·60
Lot 1	2	24	8		35·20
Area segregated					1,058·80

Land Office records show all the land segregated to be public land.

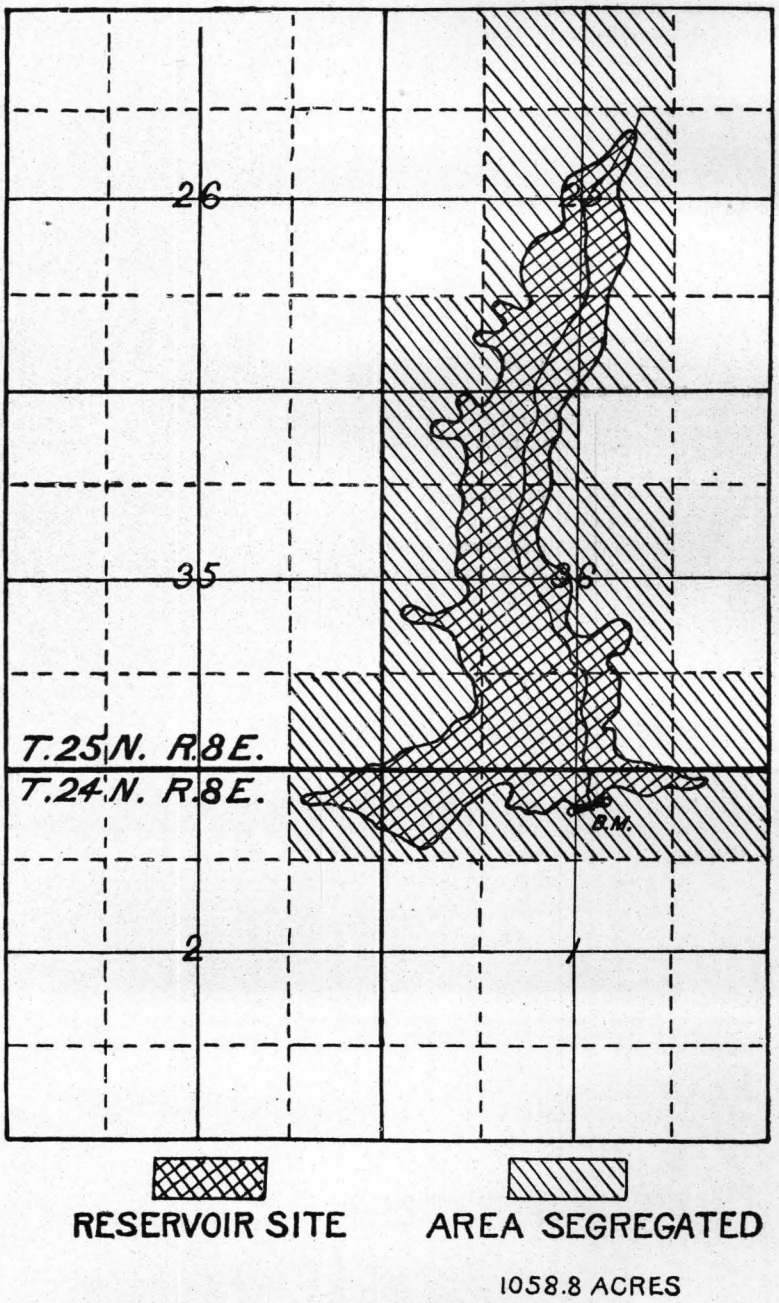


FIG. 190.—Reservoir Site No. 7, on Rio Caliente.

Reservoir Site No. 8.

Is situated on Rio Hondo, Taos County, New Mexico.
Drainage basin largely timbered.
Location of dam, about a mile above the village of Hondo, at a point where the stream enters a narrow gorge.
Height of dam, 100 feet.
Bench mark.
Area of reservoir, 50 acres.
Capacity of reservoir, 1,000 acre-feet.
Material for construction near site.
No settlements are on this site.
Water from this reservoir would be used in the valley of the Rio Grande.
All on unsurveyed land.

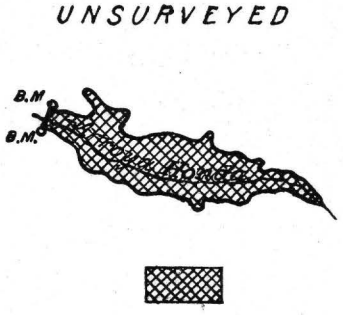


Fig. 191.—Reservoir Site No. 8, on Rio Hondo, north of Taos.

Reservoir Site No. 9.

Is situated on Rio Colorado, Taos County, New Mexico.
Drainage basin partly timbered.
Location of dam, on unsurveyed land, about 15 miles east of the village of Cuesta.
Height of dam, 100 feet.
Altitude of drainage basin approximately, 8,000 feet.
Area of reservoir, 270 acres.
Capacity of reservoir, approximately, 9,000 acre-feet.
Material for construction at site.
Some settlements are on site, comprising 20 or 30 houses.
Water would be used in the valley of the Rio Grande.
All on unsurveyed lands.

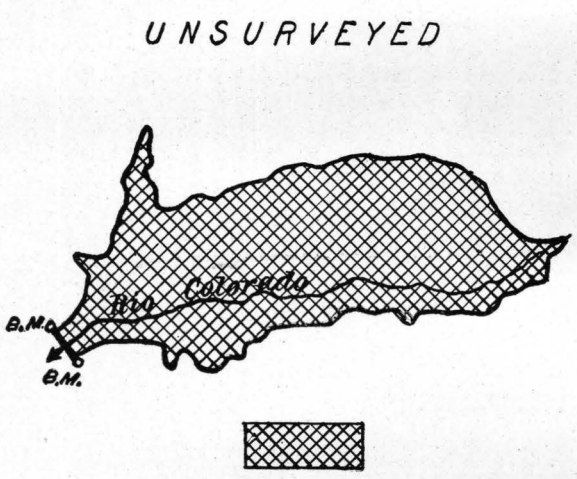


FIG. 192.—Reservoir Site No. 9, on Rio Colorado, 20 miles north of Taos and 15 miles east of Rio Grande.

RESERVOIR SITE NO. 10.

Is situated on Picuris Indian Reservation, Taos County, New Mexico.
Drainage basin largely timbered.
Location of dam, on Rio Picuris, just below point of rocks on north side of creek.
Height of dam, 60 feet.
Bench mark, monument of rock at each end.
Altitude, 7,000 and 8,000 feet.
Area of reservoir, 62 acres.
Capacity of reservoir, 1,200 acre-feet.
Material for construction at site.
One or two small adobe houses on site.
Water would be used in Rio Grande Valley.
All on Picuris grant.

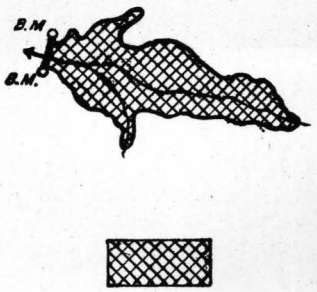


FIG. 193.—Reservoir Site No. 10, on Picuris Creek.

Reservoir Site No. 11.

Is situated on Picuris Pueblo Reservation, Taos County, New Mexico.

Drainage basin largely timbered.

Location of dam, below junction of Rio Picuris with Rio Lusio, where stream enters narrow canyon.

Height of dam, 80 feet.

Bench mark, stone monuments at each end. Altitude from 7,000 to 8,000 feet.

Area of reservoir, 236 acres.

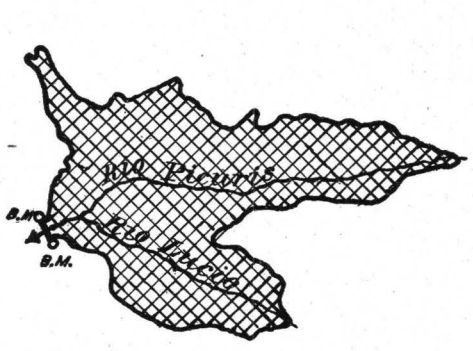


Fig. 194.—Reservoir Site No. 11, on Picuris Pueblo Grant.

Approximate capacity of reservoir, 6,000 acre-feet.

Stone for construction at site.

Several settlements, comprising twenty or thirty houses, are on this site.

Reservoir Site No. 12.

Is situated on the Rio Grande, between Española and San Ildefonso, in Santa Fé and Rio Arriba counties, New Mexico.

Drainage basin includes all the basin of the Rio Grande above San Ildefonso; also almost every variety of climate and topography.

The reservoir is almost wholly on the San Ildefonso Indian Reservation, a small point at the upper end reaching into the Santa Clara Reservation.

Location of dam, at crossing of Santa Fé Southern Railroad.

Height of dam, 50 feet.

Bench mark, stone monument at each end, in line of dam, but 100 feet above water. Altitude from 6,000 to 13,000 feet above sea level.

Approximate area of reservoir, 1,500 acres.

Approximate capacity of reservoir, 30,000 acre-feet.

A spillway could be built at west end of dam.
Material for construction at and near site.
Only a few adobe houses occur within this site.

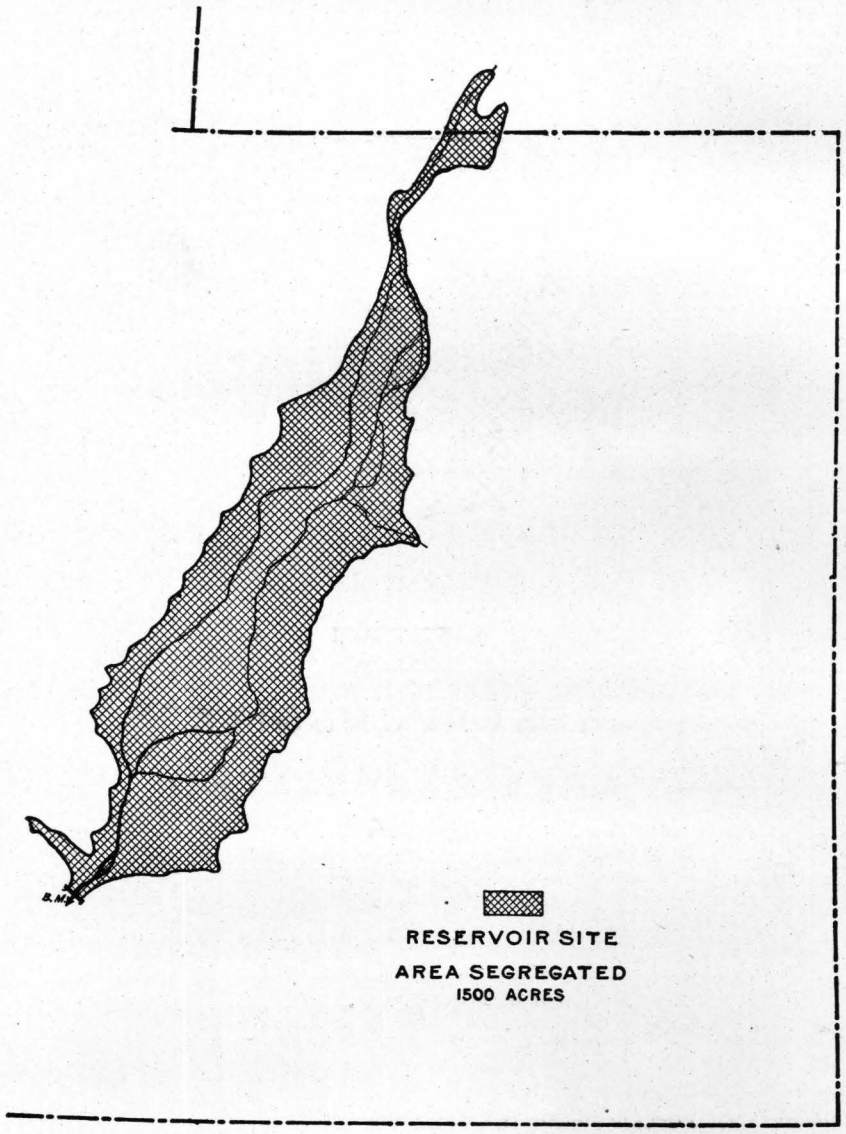


FIG. 195.—Reservoir Site No. 12; dam site at Santa Fé southern crossing of Rio Grande.

Water would be used in the Rio Grande Valley at Peña Blanca and below.
All on San Ildefonso and Santa Clara grants. Area of reservoir, 1,500 acres.

Reservoir Site No. 13.

Is situated in Valle Grande, Tewan Mountains, on southern part of Baca location No. 1, Bernalillo County, New Mexico.

Drainage basin is distinguished by heavy falls of snow in winter and considerable rain in summer.

The dam is at the point where the east fork of Jemez Creek enters a narrow canyon at the lower extremity of Valle Grande.

Bench mark, stone monument at west end of dam.

Area of reservoir, 4,030 acres.

Capacity of reservoir, approximately, 18,000 acre-feet.

A spillway can be conveniently constructed at either end of the dam.

Material for construction of dam at the site.

No settlements are on this site.

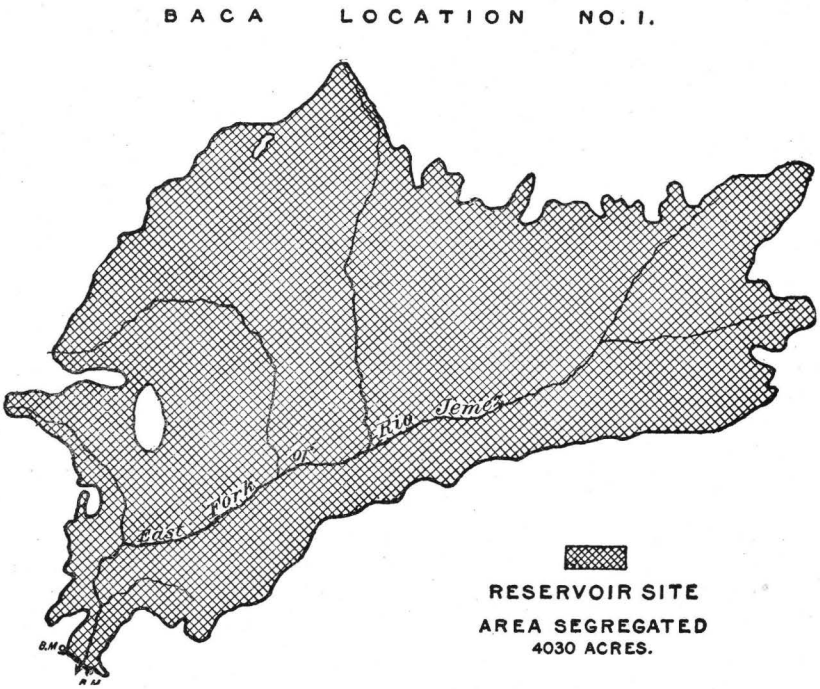


Fig. 196.—Reservoir Site No. 13, on east fork of Rio Jemez, in Valle Grande.

The water can be diverted from Jemez Creek for irrigation purposes, near Jemez Pueblo, and used on the plains south of that place.

Reservoir Site No. 14.

Is situated on Baca location No. 1, Rio Arriba County, New Mexico.

Drainage basin mostly timbered.

Dam at narrow place just at the mouth of the Valle Santa Rosa, on Jemez Creek.

Height of dam, 53½ feet.

Bench mark, stone monument at south end and three stakes at north end. Altitude, about 9,000 to 10,000 feet.

Area of reservoir, approximately, 256 acres.

Capacity of reservoir, 5,000 acre-feet.

Spillway could be constructed at north end of dam.
Stone for construction at site.
No settlements are in this reservoir site.
The water would be used on the mesa south of Jemez pueblo.

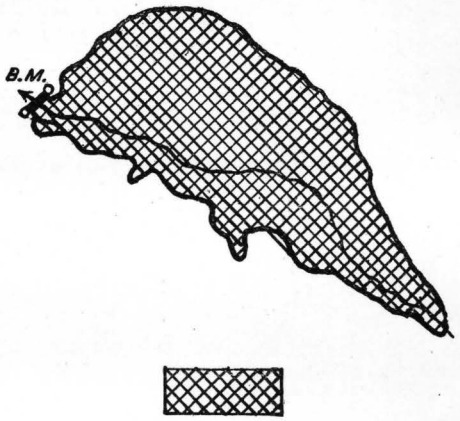


FIG. 197.—Reservoir Site No. 14, on San Antonio Creek.

RESERVOIR SITE NO. 15.

Is situated on Baca location No. 1, in San Antonio Valley, Rio Arriba County, New Mexico.

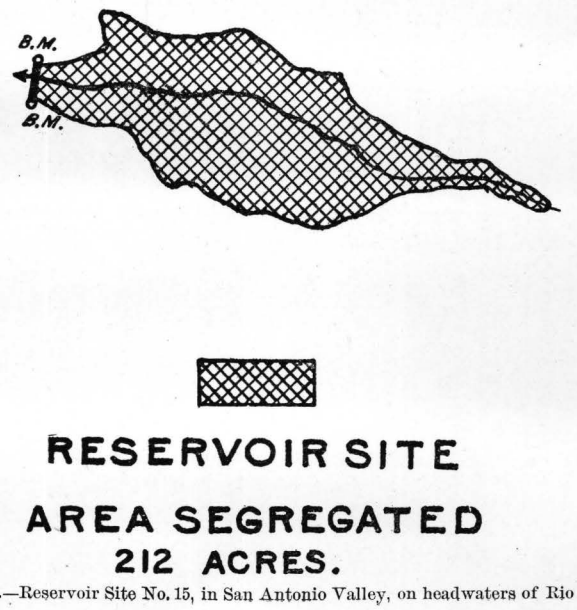


FIG. 198.—Reservoir Site No. 15, in San Antonio Valley, on headwaters of Rio Jemez.

Drainage basin receives large annual precipitation.
Dam at narrow part of San Antonio Valley, near its head.
Height of dam, 57 feet.
Altitude of drainage basin is between 8,500 and 11,000 feet.
Area of reservoir, 212 acres.
Approximate capacity of reservoir, 4,500 acre-feet.
Rock for building a dam here would have to be hauled considerable distance.
There are no settlements on this rerervoir site.
Water stored here would be used on mesa south of Jemez pueblo.

Reservoir Site No. 16.

Is situated on Baca location No. 1, Rio Arriba County, New Mexico.

Drainage basin receives a large annual precipitation of snow and rain. It is about one-half timbered.

Dam at narrow part of the valley of Jemez Creek, in San Antonio Valley, about 1 mile below the dam site of No. 15.

Height of dam, 58 feet.
The altitude of drainage basin is from 8,500 to 11,000 feet.
Area of reservoir, 575 acres.
Approximate capacity of reservoir, 13,000 acre-feet.

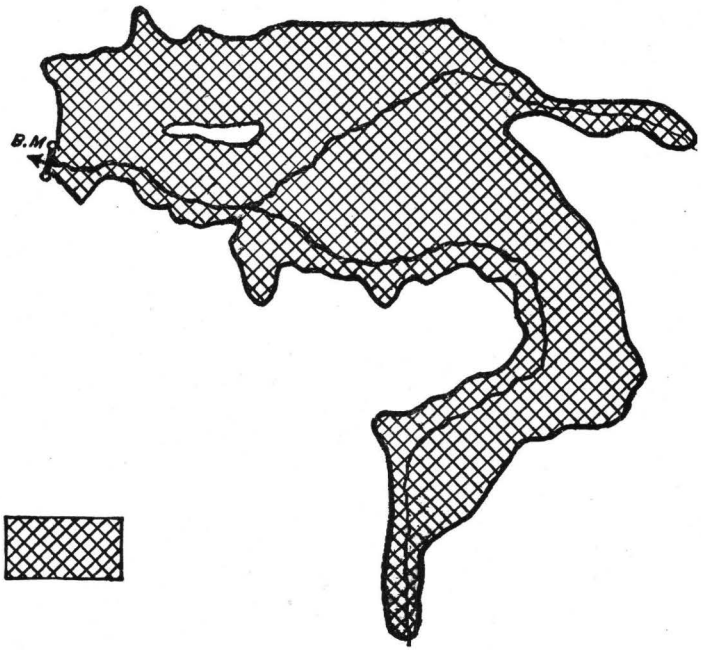


Fig. 199.—Reservoir Site No. 16, in Valle San Antonio, Jemez Mountains.

At a point one-half mile due north of dam site is a low divide, where, with 6 feet of excavation, an excellent spillway could easily be constructed.

Material for construction at site.

There are no settlements within this reservoir site.

Water would be diverted near Jemez pueblo and used for irrigating the mesa south of that place.

Reservoir Site No. 17.

Is situated in lower San Antonio Valley, on Baca location No. 1, Rio Arriba County, New Mexico.

Location of site: It is near the west line of the Baca location, and if surveyed would lie in T. 20 N., R. 3 E.

The dam is to be across Jemez Creek at the point where it enters a narrow canyon at the lower end of San Antonio Valley.

Height of dam, 70 feet.

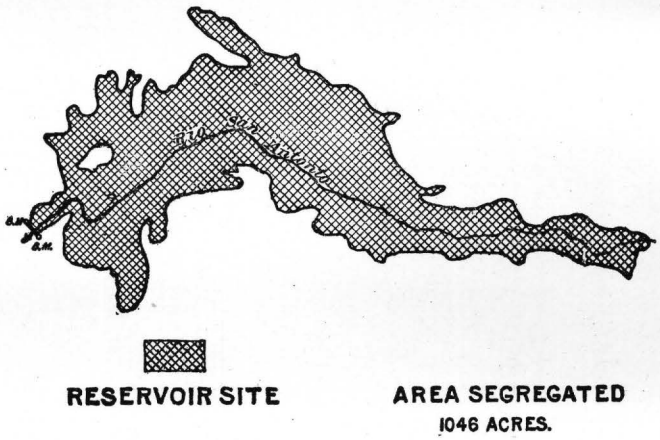


Fig. 200.—Reservoir Site No. 17, on Rio San Antonio, in San Antonio Valley, Jemez Mountains.

West end is marked by "B. M." cut in flat stone; east end by three stakes.

Area of reservoir, 1,046 acres.

Approximate capacity of reservoir, 32,000 acre-feet.

Stone for construction at site.

There are no settlements within this reservoir site.

Water stored in this reservoir might be used in part for irrigating the Valle la Nueva, and for diversion onto the mesa south of Jemez Pueblo.

Reservoir Site No. 18.

Is situated on Ojo del Espíritu Santo grant, Bernalillo County, New Mexico.

Drainage basin timbered only in the upper part.

Dam on Rio Salado, about 10 miles west of Jemez pueblo.

Height of dam, 60 feet.

Marked with wooden stakes. Altitude of drainage basin, 7,000 to 9,000 feet.

Area of reservoir, 155 acres.

Approximate capacity, 3,700 acre-feet.

Material for construction will have to be transported a mile or more.

No settlements occur on site.

Water would be used on mesa south of Rio Jemez.

All on Ojo del Espíritu Santo grant.

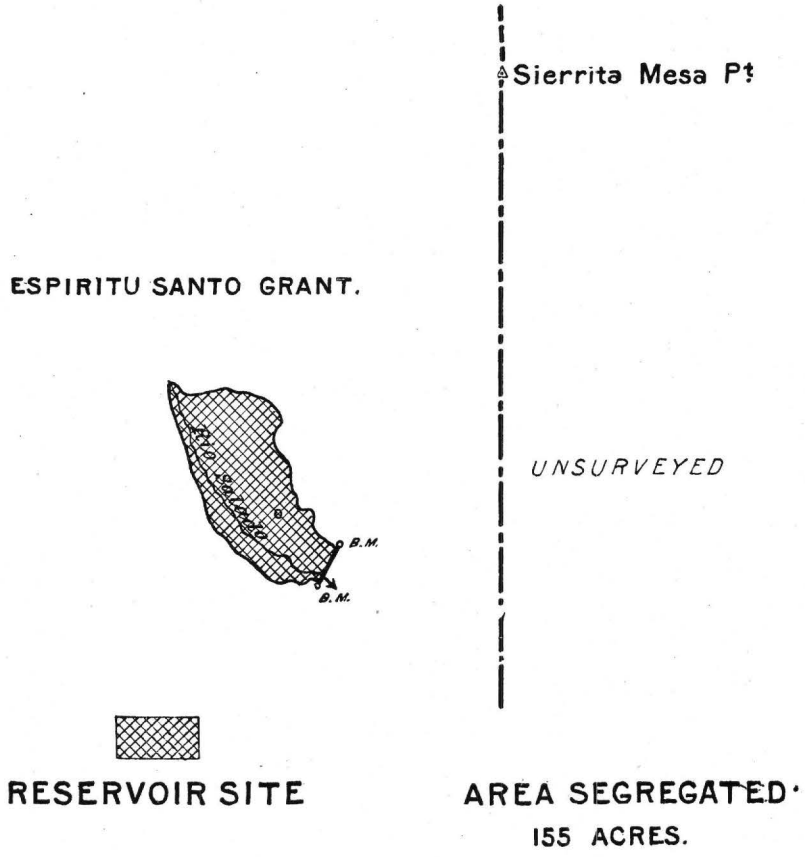


FIG. 201.—Reservoir Site No. 18, in southern part of Espíritu Santo grant, on the Rio Salado.

RESERVOIR SITE NO. 19.

Is situated below Pueblo of Santa Ana, Bernalillo County, New Mexico.

Drainage basin includes nearly all the Jemez basin; nearly all timbered.

Dam at entrance of narrow canyon about 4 miles below Santa Ana on unsurveyed land.

Height of dam, 90 feet.

Marked by monument at each end.

Area of reservoir, 1,640 acres.

Approximate capacity, 60,000 acre-feet.

Spillway could be constructed at either end of dam, but would be expensive.

Material for construction at site.

No houses nor valuable land in this site.

Water could be used in Rio Grande Valley.

Partly on Santa Ana Grant, and partly on unsurveyed land.

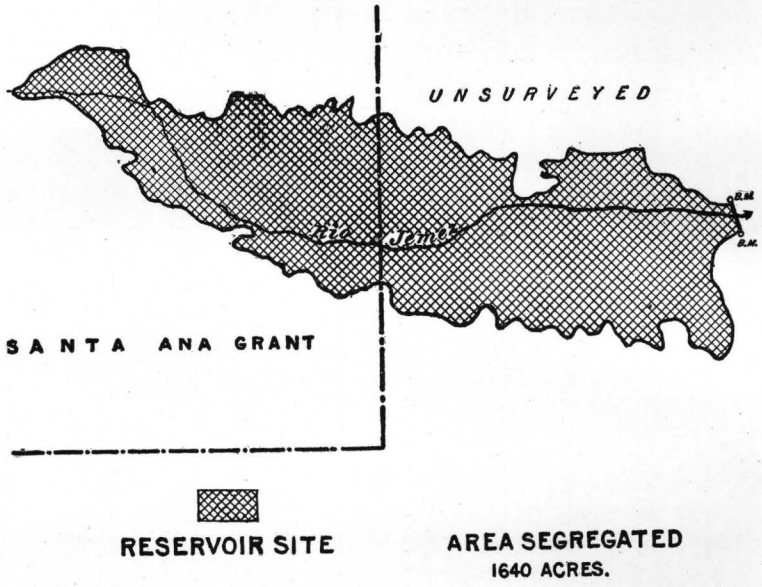


FIG. 202.—Reservoir Site No. 19, on Rio Jemez, below the Pueblo of Santa Ana.

RESERVOIR SITE NO. 20.

Is situated on Santa Fé Creek, 8 miles above Santa Fé, Santa Fé County, New Mexico.

Drainage basin nearly all timbered.

Dam near west line of Sec. 24, T. 17 N., R. 10 E.

Height of dam, 72 feet.

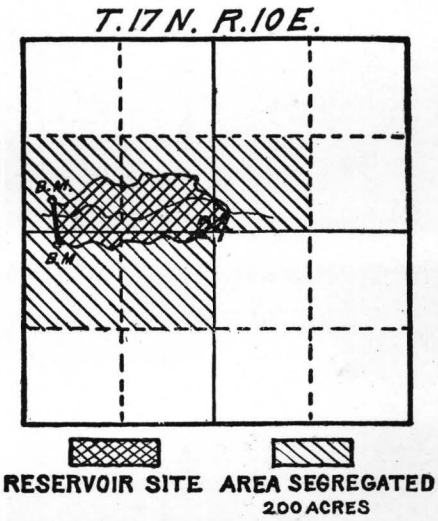


FIG. 203.—Reservoir Site No. 20, on Santa Fé Creek, 7 miles east of Santa Fé.

Bench mark, stone monument at each end.

Altitude of drainage basin from 8,000 to 12,000 feet.

Area of reservoir, 40 acres.

Approximate capacity of reservoir, 1,100 acre-feet.
Material for construction at site.
No houses are found within this site.
Water would be used on plains south of Santa Fé.

Lands segregated for reservoir.

	Acres.
S. ½ NW. ¼ Sec. 24, T. 17 N., R. 10 E	80
N. ½ SW. ¼ 24 17 10	80
SW. ¼ NE. ¼ 24 17 10	40
Area segregated	200

Action affecting titles to lands segregated for Reservoir Site No. 20 has been taken as follows:

	Acres.
SW. ¼ NE. ¼ Sec. 24, T. 17 N., R. 10 E. (homestead, 1887)	40
NE. ¼ SW. ¼ 24 17 10 E. (homestead, 1887)	40
	80

Reservoir Site No. 21.

Is situated at the village of Condilo, Rio Arriba County, New Mexico.

Drainage basin has an altitude of from 6,000 to 10,000 feet and receives a large precipitation annually, and both creeks furnish perennial streams. Most of the basin is timbered.

The reservoir is on unsurveyed land, but would fall in T. 20 N., R. 11 E., if the country were surveyed.

Dam is at junction of Rios Medio and Frijole, where they enter a canyon and form the Santa Cruz.

Fig. 204.—Reservoir Site No. 21, at the town of Condilo, at Junction of Rio Frijole and Rio Medio.

Height of dam, 50 feet.
Bench mark, stone monument at each end.
Area of reservoir, 45 acres.
Capacity of reservoir, 800 acre-feet.
A spillway could be constructed at north end of dam, but would have to be blasted through solid rock.
Stone for construction at site.
One or two small houses are located in this reservoir.
Water would be used on the mesa south of the reservoir.
All on unsurveyed land.

Reservoir Site No. 22.

It is situated on Rio Mora, Mora County, New Mexico.
Drainage basin more than half timbered.

This site is all on Mora grant,
Dam at narrow gap just above town of La Cueva, on unsurveyed land.

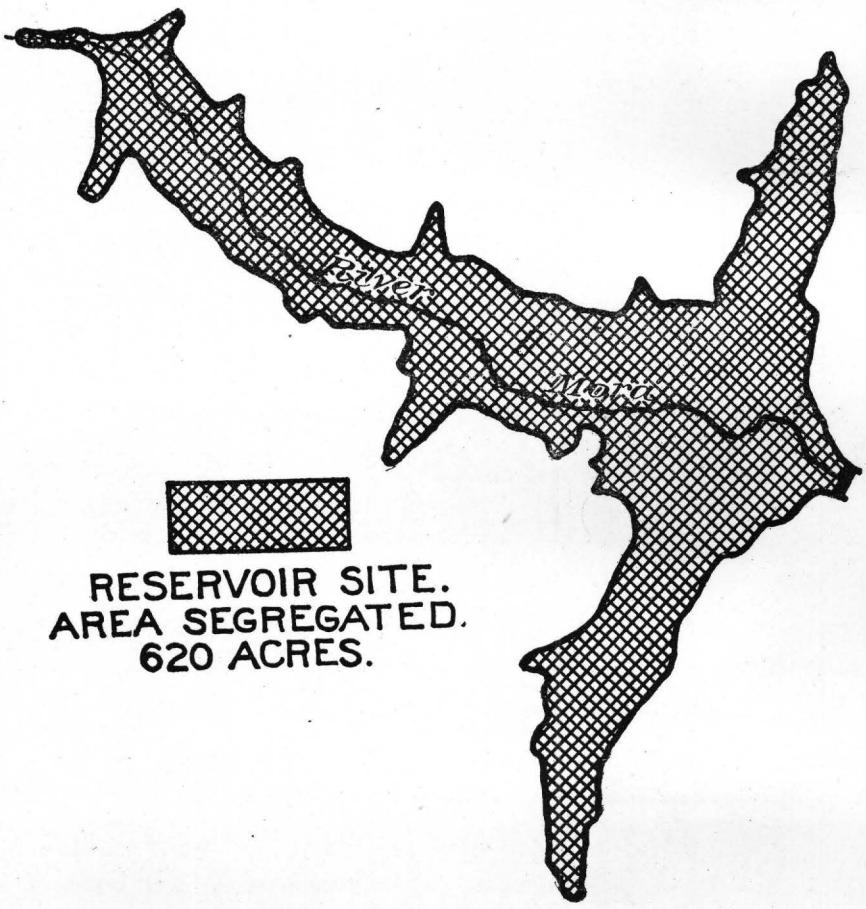


FIG. 205.—Reservoir Site No. 22, on Rio Mora, just above La Cueva.

Height of dam, 60 feet.
Drainage basin varies in altitude from 7,000 to 10,000 feet.
Area of reservoir, 620 acres.
Approximate capacity of reservoir, 5,400 acre-feet.
Several houses on this site.
Water would be used on low mesas near Rio Mora, about Los Alamos.
All on Mora grant.

RESERVOIR SITE NO. 23.

Is situated at Buena Vista, Mora County, New Mexico.

Drainage basin of this reservoir is all the upper Rio Mora, upper half of which is timbered.

The reservoir is on the Mora grant, which has never been surveyed.

Dam across Mora River, where it enters a narrow canyon about 3 miles below La Cueva, New Mexico.

Height of dam, 90 feet.
Bench mark, stone monument at each end.
Altitude of drainage basin ranging from 7,000 to 11,000 feet.
Area of reservoir, 1,770 acres.
Capacity of reservoir approximately, 38,000 acre-feet.
At the above height of dam, 90 feet, there is a natural spillway.
Stone for construction at site.

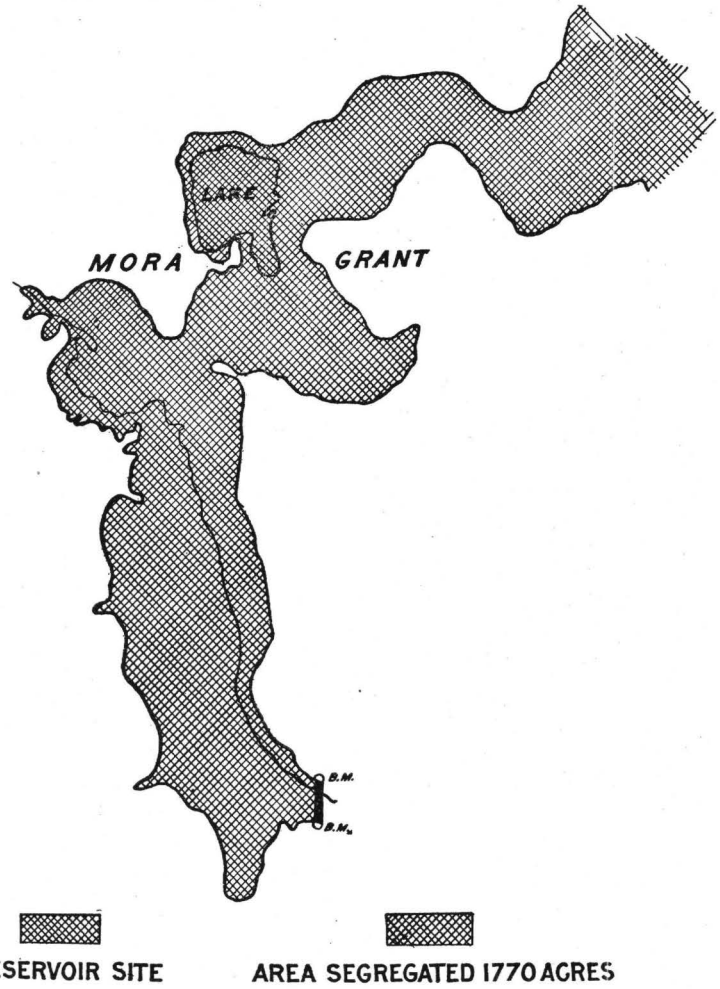


FIG. 206.—Reservoir Site No. 23, just below La Cueva, on Mora River.

The village of Buena Vista occurs within the site, and a great many houses would be submerged by the construction of this dam.
Water would be used in the valley of the Mora and on adjacent mesas.
All on Mora grant.

RESERVOIR SITE NO. 24.

Is situated at Sapello, San Miguel County, New Mexico.
Drainage basin is mostly timbered. Both creeks are perennial. Las Tusas Creek

is the boundary between Mora and Las Vegas grants, and the reservoir lies wholly within these grants.

Dam at junction of Manuelitos and Las Tusas creeks.
Height of dam, 100 feet.
Bench mark, monument of stone at each end.
Altitude of drainage basin from 6,700 to 10,000 feet.
Area of reservoir, 1,037 acres.
Approximate capacity of reservoir, 41,000 acre-feet.
Material for construction at site.
The villages of Las Tusas and Sapello are in this site.
Water would be used on mesa in vicinity of Sapello Creek and Mora Valley.
All on Mora and Las Vegas grants.

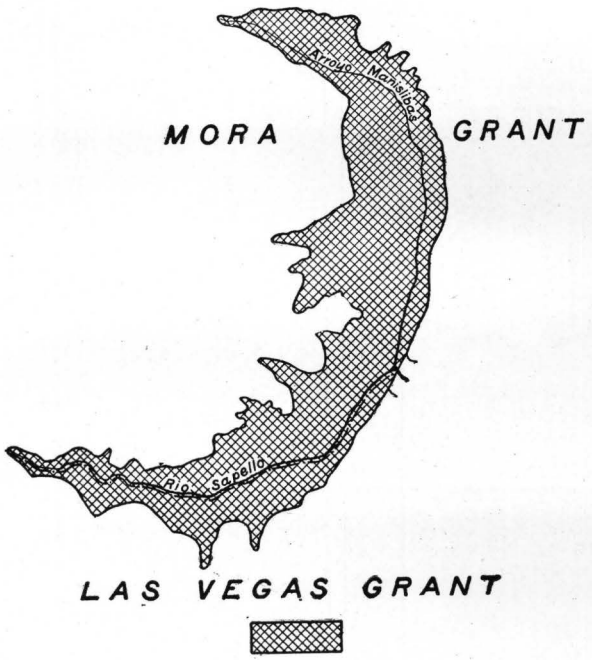


FIG. 207.—Reservoir Site No. 24, at the town of Sapello, New Mexico.

RESERVOIR SITE NO. 25.

Is situated at Cherry Valley Lake, Mora County, New Mexico.
Drainage basin about half timbered.
This is a natural reservoir, requiring no dam, and it is to be filled by canal from Mora River, and water to be drawn out by another canal.
Altitude about 6,000 feet. Drainage basin from 6,000 to 10,000 feet.
Area of reservoir, 800 acres.
Approximate capacity of reservoir, 15,000 acre-feet.
Three or four houses occur in this site.
Water would be used in lower valley of Mora and Canadian rivers.

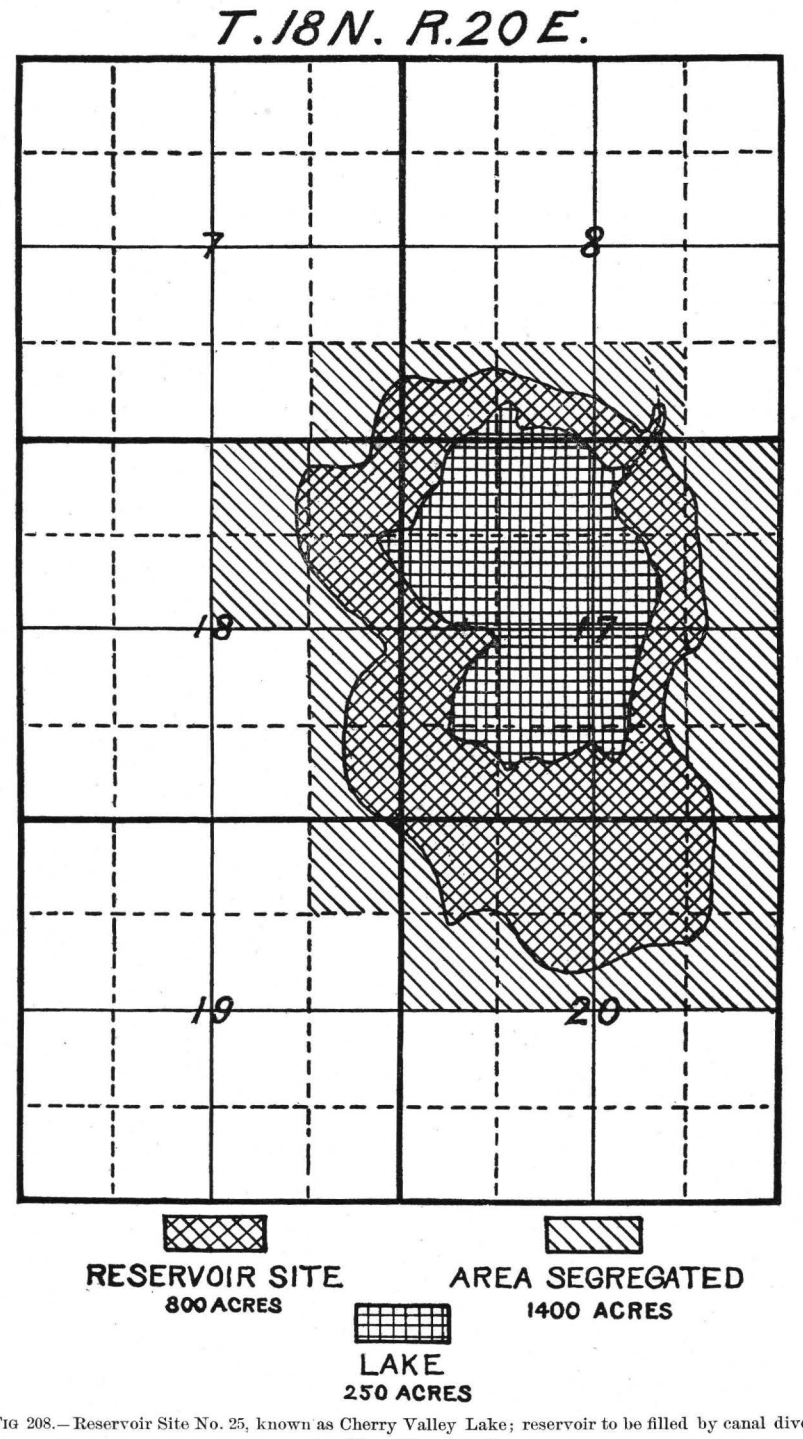


FIG 208.—Reservoir Site No. 25, known as Cherry Valley Lake; reservoir to be filled by canal diverting Mora River into it.

Lands segregated for reservoir.

				Acres.
SE. ¼ SE. ¼	Sec. 7,	T. 18 N.,	R. 20 E	40
S. ½ SW. ¼	8	18	20	80
SW. ¼ SE. ¼	8	18	20	40
All	17	18	20	640
NE. ¼	18	18	20	160
E. ½ SE. ¼	18	18	20	80
NE. ¼ NE. ¼	19	18	20	40
N. ½	20	18	20	320
Area segregated				1,400

Land Office records show area segregated to be all on Mora grant.

Reservoir Site No. 26.

Is situated at Puertocito, 5 miles west of Las Vegas, San Miguel County, New Mexico.

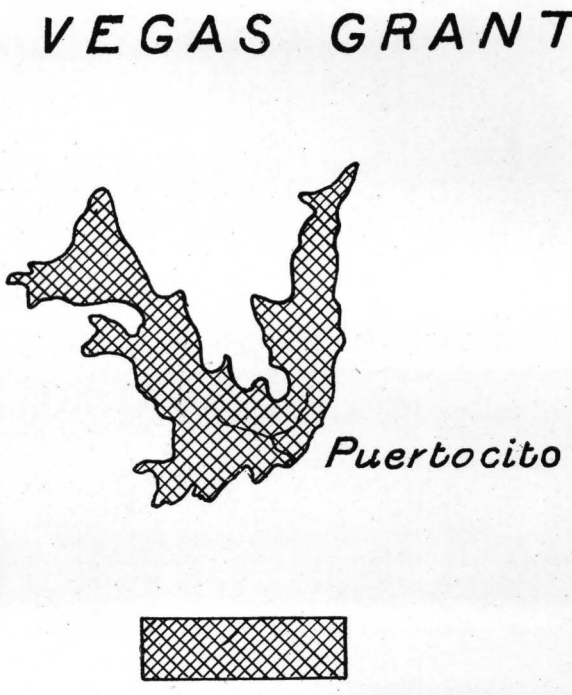


Fig. 209.—Reservoir Site No. 26, at Puertocito, 5 miles west of Las Vegas.

Drainage basin about one-third timbered.
Dam across narrow gap just above village of Puertocito, on Las Vegas grant.
Height of dam, 100 feet.
Drainage basin has an altitude of from 6,000 to 7,000 feet.
Area of reservoir, 170 acres.
Approximate capacity of reservoir, 5,800 acre-feet.

Spillway could be constructed at north end of dam, but would be expensive.
Material for construction at site.
Several small houses are on this site
Water would be used on flats south of Las Vegas.
All on Las Vegas grant.

Reservoir Site No. 27.

Is situated on Rio Pecos, Santa Fé County, New Mexico.

Drainage basin includes all the Upper Pecos, from 7,000 to 12,000 feet in altitude; nearly all timbered.

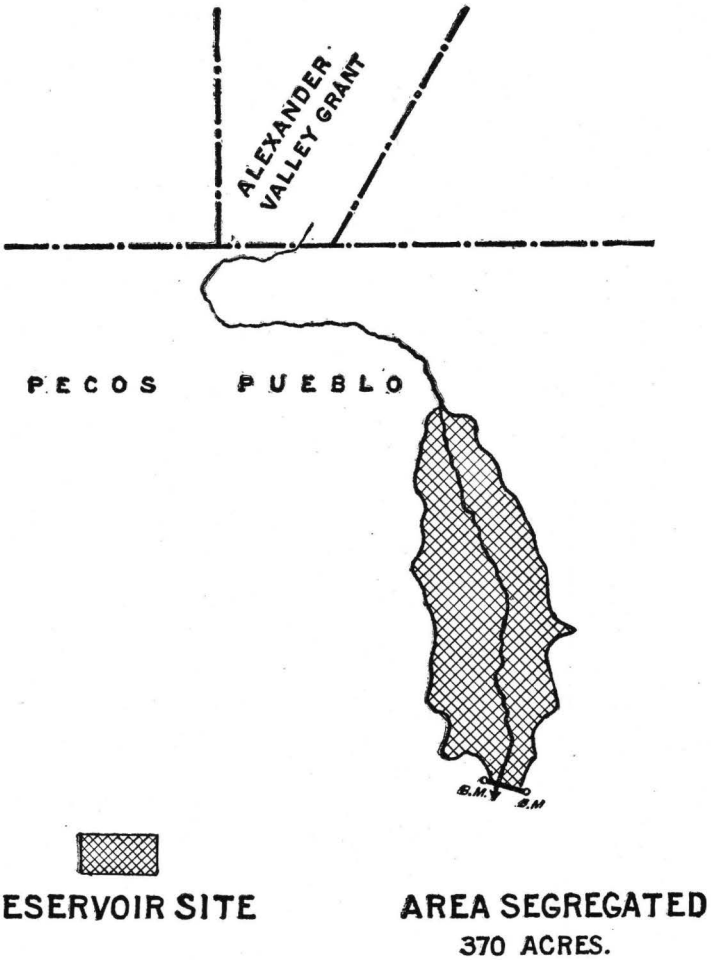


Fig. 210.—Reservoir Site No. 27, on Pecos River, just below Pecos town.

Dam at entrance of canyon about 2 miles below Pecos town, on Pecos grant.
Height of dam, 75 feet.
Bench mark, monument at each end.
Area of reservoir, approximately, 370 acres.
Approximate capacity of reservoir, 8,800 acre-feet.
Material for construction at site.

About a dozen houses are on this site.
Water would be used in valley of Lower Pecos.
All on Pecos Pueblo grant.

Reservoir Site No. 28.

Is situated on Rio Pecos on unsurveyed land in San Miguel County, New Mexico.
Drainage basin includes all the Upper Pecos, and is mostly timbered. Altitude of from 7,000 to 11,000 feet.
Dam at narrow place just below village of Gusana.

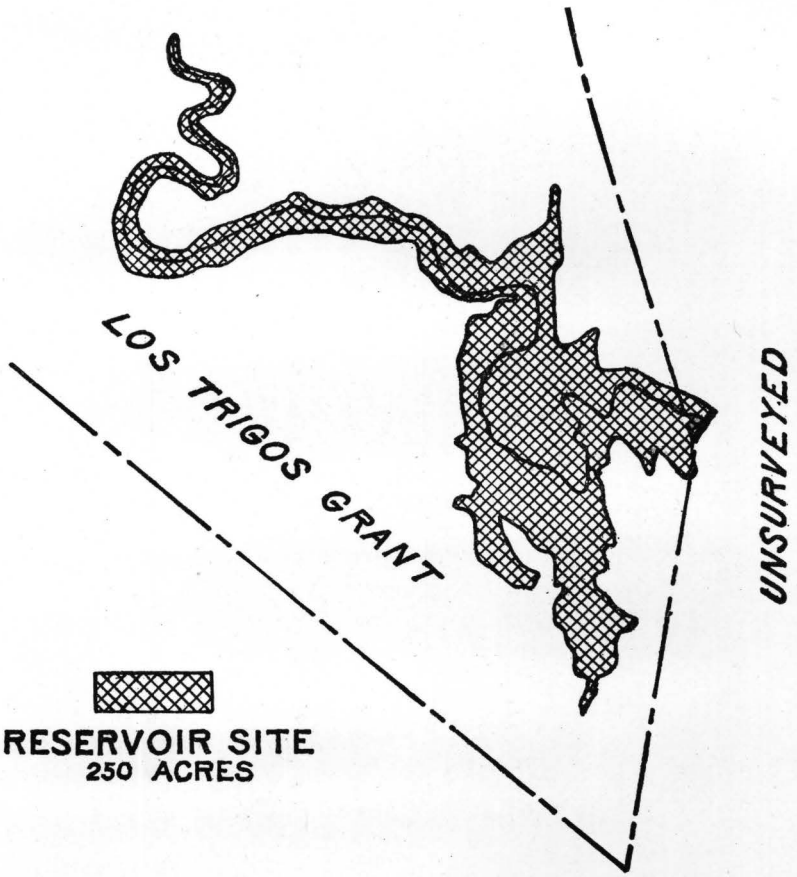


Fig. 211.—Reservoir Site No. 28, at Gusana, on Rio Pecos.

Height of dam, 82 feet.
Bench mark, monument of rocks at each end.
Area of reservoir, 250 acres.
Approximate capacity of reservoir, 7,800 acre-feet.
Stone for construction at site.
About a dozen houses occur on this site.
Water would be used in the lower valley of the Pecos.
All on Los Trigos grant and unsurveyed land.

Reservoir Site No. 29.

Is situated on Rio Grande, Bernalillo County, New Mexico.

The drainage basin of this reservoir includes all the Upper Rio Grande, at altitudes of from 6,000 to 12,000 feet.

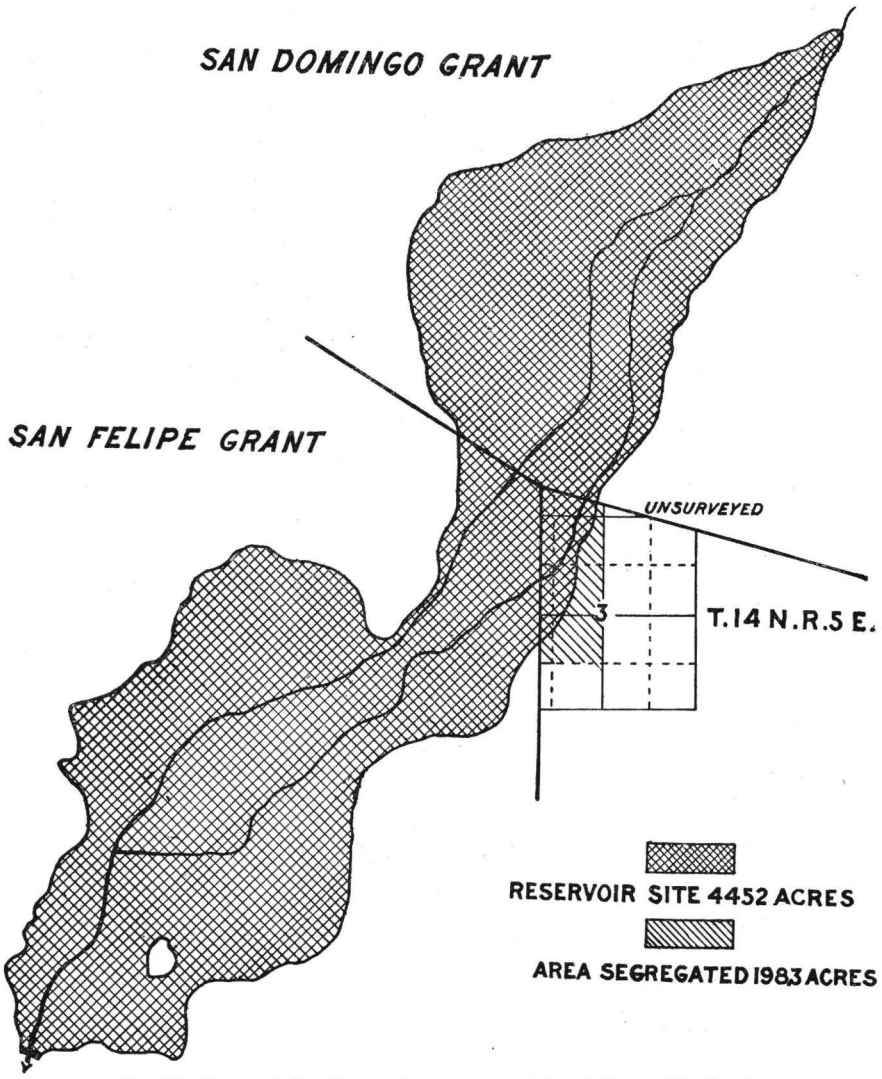


Fig. 212.—Reservoir Site No. 29, above the town of San Felipe, on Rio Grande.

Lands segregated for reservoir.

	Acres.
NW. ¼ NE. ¼ Sec. 3, T. 14 N., R. 5 E	40·00
E. ½ NW. ¼ 3 14 5	80·00
NE. ¼ SW. ¼ 3 14 6	40·00
Lots 1, 2, 3, and 4, Sec. 3, T. 14 N., R. 5 E	38·30
Area segregated	198·30

Dam just above town of San Felipe, on San Felipe Indian Reservation.
Height of dam, 31 feet.
Bench mark, stone monument at each end.
Area of reservoir, 4,452 acres.
Approximate capacity of reservoir, 87,000 acre-feet.
About 100 yards east of the east end of dam a good spillway could be constructed with only a few feet excavation in loose sand, where road goes over the hill.
Material for construction at west end.
About a dozen houses stand on the site of the reservoir.
Water would be used in Lower Rio Grande basin and adjoining mesas.
Mostly on San Felipe and San Domingo Indian Reservations.

Reservoir Site No. 30.

Is situated on Laguna Indian Reservation, Valencia County, New Mexico.
The drainage basin is from 6,000 to 8,000 feet in altitude and is timbered only in the upper part.

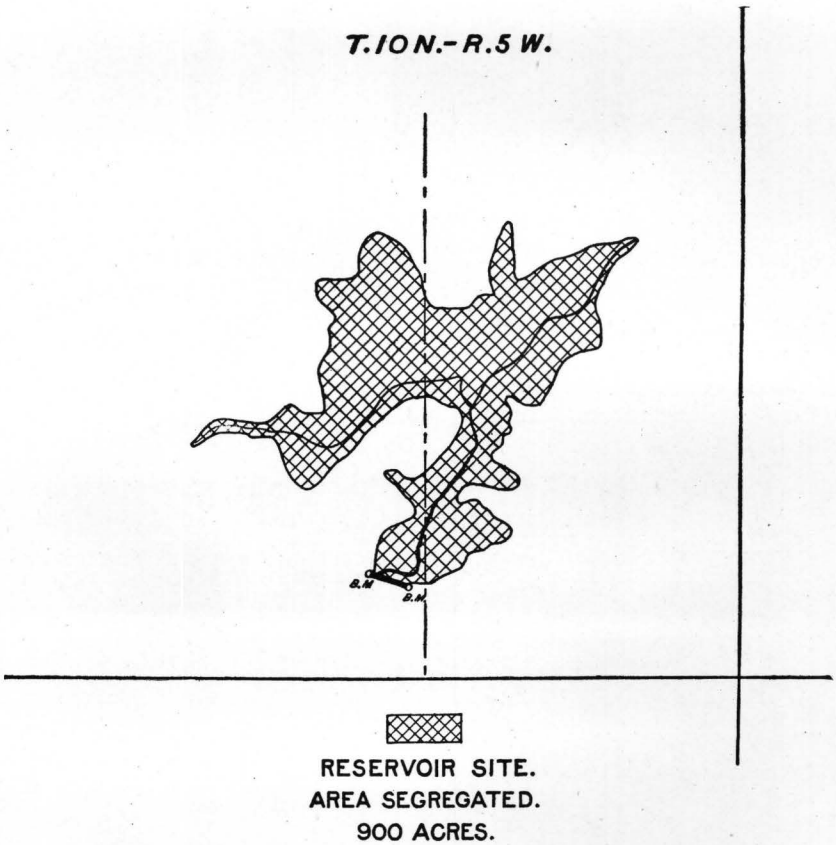


Fig. 213.—Reservoir Site No. 30, on Rio San José, Laguna Pueblo.

Dam is in T. 10 N., R. 5 W., which is unsectionized.
Height of dam, 46 feet.
Bench mark, stone monument at each end, and east end marked with B. M.
Area of reservoir, 900 acres.

Approximate capacity of reservoir, 20,000 acre-feet.
Material for construction of dam at site.
Several houses are on the site of this reservoir.
Water would be used on the uplands to the south of the Rio San José, and west of Rio Grande.
Partly on Laguna reservation and partly on unsurveyed land.

Reservoir Site No. 31.

Is situated on San Mateo Creek, Bernalillo County, New Mexico, near the line of Valencia County, New Mexico.
Drainage basin chiefly bare of timber. Altitude from 6,000 to 8,000 feet.
Dam in NE. ¼ of SW. ¼ Sec. 29, T. 13 N., R. 9 W.
Height of dam, 435 feet.
Bench mark, monument of stone at each end.
Area of reservoir, 380 acres.
Approximate capacity of reservoir, 5,500 acre-feet.
Rock for construction at site.
No settlements are on this site.
Water would be used in the valley of the creek below the site.

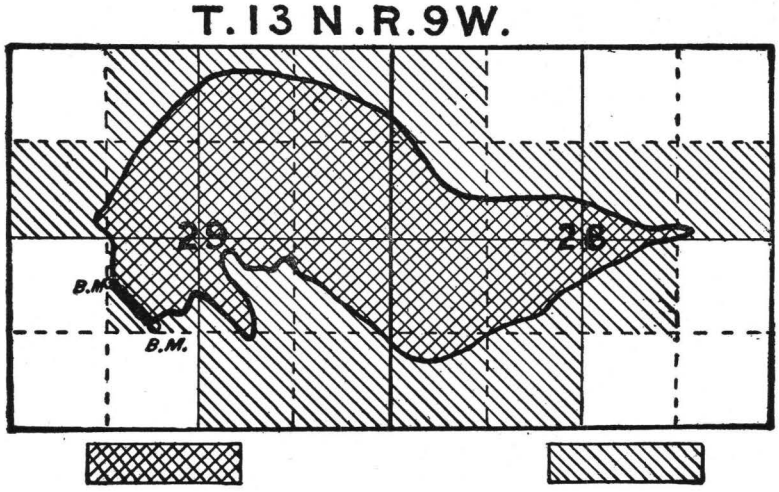


Fig. 214.—Reservoir Site No. 31, on San Mateo Creek.

Land segregated.

				Acres.
E. ½ Sec. 29, T. 13 N., R. 9 W				320
E. ½ NW. ¼	29	13	9	80
SW. ¼ NW. ¼	29	13	9	40
NE. ¼ SW. ¼	29	13	9	40
SW. ¼	28	13	9	160
S. ½ NW. ¼	28	13	9	80
NW. ¼ NW. ¼	28	13	9	40
S. ½ NE. ¼	28	13	9	80
NW. ¼ SE. ¼	28	13	9	40
Area segregated				880

Land Office records show area segregated to be all public lands.

RESERVOIR SITE NO. 32.

Is situated near south line of Bernalillo County, New Mexico.
Altitude of drainage basin about 7,000 feet.
Dam is in N. ½ of SW. ¼ Sec. 16, T. 13 N., R. 11 W
Height of dam, 19 feet.
Bench mark at each end.
Area of reservoir, 490 acres.
Approximate capacity, 3,000 acre-feet.
Material for construction of dam at site.
No settlements on this site.
Water would be used in valley just below site.

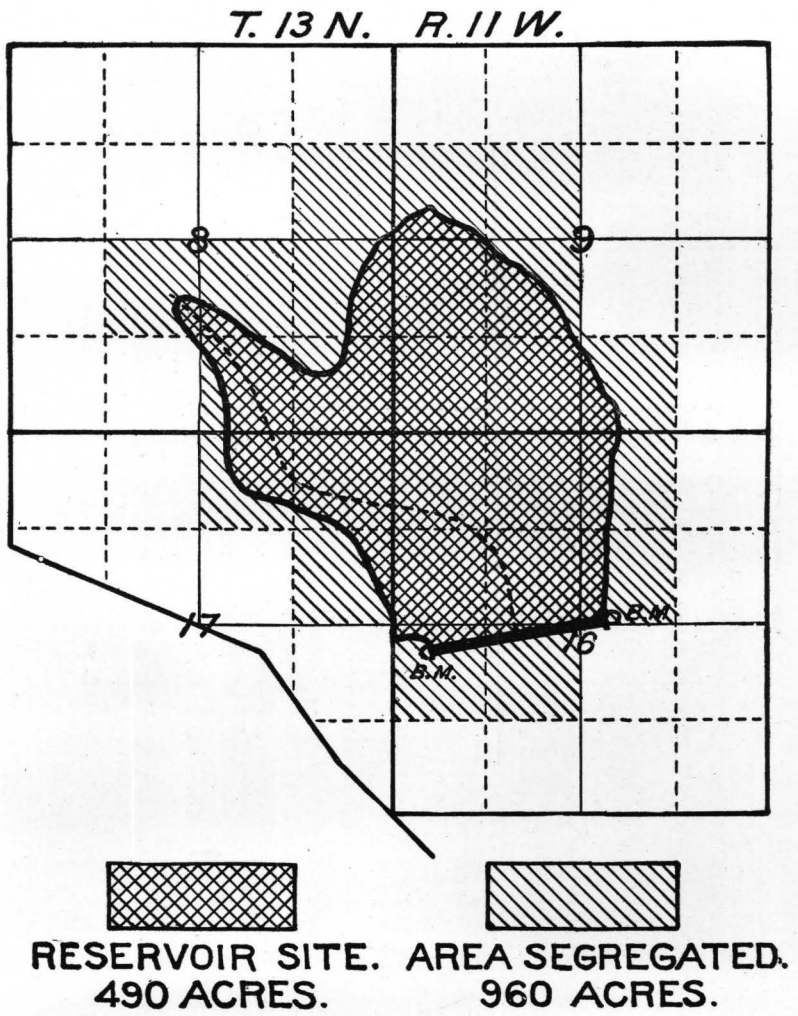


FIG. 215.—Reservoir Site No. 32, on Blue Water Creek, 6 miles above Blue Water Station, A. & P.R. R.

Land segregated.

					Acres.
SE. ¼	Sec. 8,	T. 13 N.,	R. 11 W		160
SE. ¼ NE. ¼	8	13	11		40
NE. ¼ SW. ¼	8	13	11		40
SW. ¼	9	13	11		160
S. ½ NW. ¼	9	13	11		80
SW. ¼ SE. ¼	9	13	11		40
NW. ¼	16	13	11		160
W. ½ NE. ¼	16	13	11		80
N. ½ SW. ¼	16	13	11		80
E. ½ NE. ¼	17	13	11		80
NW. ¼ NE. ¼	17	13	11		40
Area segregated					960

Action affecting titles to lands segregated for reservoir site No. 32 has been taken as follows:

					Acres.
SW. ¼	Sec. 9,	T. 13 N.,	R. 11 W	(selected by A. & P. R. R., June 21, 1890).	160
S. ½ NW. ¼	9	13	11	do	80
SW. ¼ SE. ¼	9	13	11	do	40
E. ½ NE. ¼	17	13	11	do	80
NW. ¼ NE. ¼	17	13	11	do	40
					400

RESERVOIR SITE NO. 33.

Is situated on Blue Water Creek, Valencia County, New Mexico.
Drainage basin nearly all timbered. Altitude from 7,000 to 9,000 feet.
Dam is in NE. ¼ of NW. ¼ Sec. 9, T. 12 N., R. 12 W.
Height of dam, 74·5 feet.
Bench mark, stone monument at each end of dam.
Area of reservoir, 1,900 acres.
Approximate capacity of reservoir, 53,000 acre-feet.
Natural spillway 1 mile north and a little east of dam site.
Abundant material for construction at site.
Several ranches are included in site.
Water would be used on plain 15 miles east of site.

Lands segregated for reservoir.

					Acres.
Lot 2,	Sec. 4,	T. 12 N.,	R. 12 W		38·68
Lot 3	4	12	12		38·44
Lot 4	4	12	12		38·20
SW. ¼ NE. ¼	4	12	12		40·00
S. ½ NW. ¼	4	12	12		80·00
SW. ¼	4	12	12		160·00
Lot 3	5	12	12		37·21
Lot 4	5	12	12		37·39
SW. ¼ NE. ¼	5	12	12		40·00
S. ½ NW. ¼	5	12	12		80·00
SE. ¼	5	12	12		160·00
N. ½ SW. ¼	5	12	12		80·00
SE. ¼ SW. ¼	5	12	12		40·00
Lot 1	6	12	12		37·00
Lot 2	6	12	12		36·77

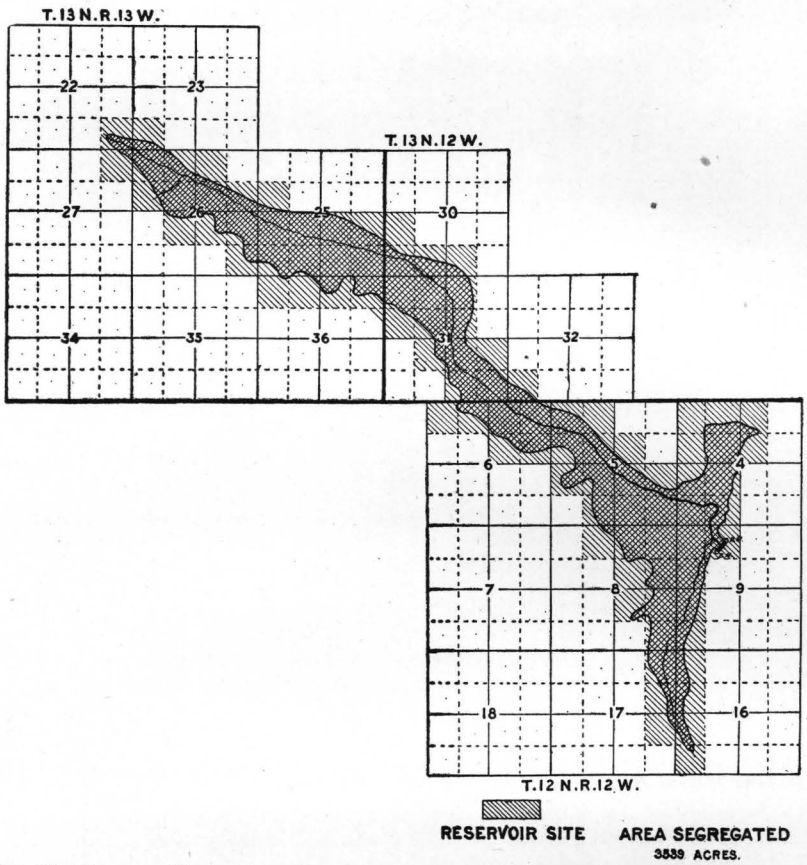


FIG. 216.—Reservoir Site No. 33, on Blue Water Creek, west of Blue Water Station, A. & P. R. R.

					Acres.
Lot 3	Sec. 6,	T. 12 N.,	R. 12 W	.....	36·54
Lot 4	6	12	12	.....	36·90
S. ½ NE. ¼	6	12	12	.....	80·00
NE. ¼	8	12	12	.....	160·00
NE. ¼ NW. ¼	8	12	12	.....	40·00
N. ½ SE. ¼	8	12	12	.....	80·00
SE. ¼ SE. ¼	8	12	12	.....	40·00
NE. ¼ NW. ¼	9	12	12	.....	40·00
W. ½ NW. ¼	9	12	12	.....	80·00
W. ½ SW. ¼	9	12	12	.....	80·00
E. ½ NE. ¼	17	12	12	.....	80·00
NE. ¼ SE. ¼	17	12	12	.....	40·00
W. ½ NW. ¼	16	12	12	.....	80·00
W. ½ SW. ¼	16	12	12	.....	80·00
Lot 3	30	13	12	.....	40·81
Lot 4	30	13	12	.....	40·89
SE. ¼ SW. ¼	30	13	12	.....	40·00
SW. ¼ SE. ¼	30	13	12	.....	40·00
Lot 1	31	13	12	.....	40·62
Lot 2	31	13	12	.....	40·44

					Acres.
E. ½ NW. ¼	Sec. 31,	T. 13 N.,	R. 12 W	.....	80·00
W. ½ NE. ¼	31	13	12	.....	80·00
NE. ¼ SW. ¼	31	13	12	.....	40·00
SE. ¼	31	13	12	.....	160·00
SW. ¼ SW. ¼	32	13	12	.....	40·00
SE. ¼ SE. ¼	22	13	13	.....	40·00
SW. ¼ SW. ¼	23	13	13	.....	40·00
SW. ¼ NW. ¼	25	13	13	.....	40·00
SW. ¼	25	13	13	.....	160·00
SE. ¼	25	13	13	.....	160·00
SE. ¼ SE. ¼	26	13	13	.....	40·00
N. ½ SE. ¼	26	13	13	.....	80·00
NW. ¼ NE. ¼	26	13	13	.....	40·00
S. ½ NE. ¼	26	13	13	.....	80·00
NE. ¼ SW. ¼	26	13	13	.....	40·00
NW. ¼	26	13	13	.....	160·00
NE. ¼ NE. ¼	27	13	13	.....	40·00
N. ½ NE. ¼	36	13	13	.....	80·00
N. ½ NW. ¼	36	13	13	.....	80·00
Area segregated				.....	3,539·89

Action affecting titles to lands segregated for Reservoir Site No. 35 has been taken as follows:

					Acres.
SW. ¼ SW. ¼	Sec. 23,	T. 13 N.,	R. 13 W.	(selected, A. & P. R. R., June 23, 1890).	40·00
S. ½	25	13	13	(selected, A. & P. R. R., June 23, 1890).	320·00
SW. ¼ NW. ¼	25	13	13	(selected, A. & P. R. R., June 23, 1890).	40·00
W. ½ NW. ¼	26	13	13	(timber, 1889)	80·00
NE. ¼ NE. ¼	27	13	13	(A. & P. R. R., 1890)	40·00
N. ½ NE. ¼	36	13	13	(school section)	80·00
N. ½ NW. ¼	36	13	13	(school section)	80·00
W. ½ NE. ¼	31	13	12	(A. & P. R. R., 1890)	80·00
SE. ¼	31	13	12	(A. & P. R. R., 1890)	160·00
NE. ¼ SW. ¼	31	13	12	(A. & P. R. R., 1890)	40·00
Lot 1	31	13	12	(A. & P. R. R., 1890)	40·62
Lot 2	31	13	12	(A. & P. R. R., 1890)	40·44
E. ½ NW. ¼	31	13	12	(A. & P. R. R., 1890)	80·00
Lot 3	5	12	12	.....	37·21
Lot 4	5	12	12	.....	37·39
SW. ¼ NE. ¼	5	12	12	.....	40·00
S. ½ NW. ¼	5	12	12	.....	80·00
SE. ¼	5	12	12	.....	180·00
N. ½ SW. ¼	5	12	12	.....	80·00
SE. ¼ SW. ¼	5	12	12	(selected, A. & P. R. R., June 23, 1890).	40·00
NE. ¼ NW. ¼	9	12	12	(selected, A. & P. R. R., 1890)	40·00
W. ½ NW. ¼	9	12	12	(selected, A. & P. R. R., 1890)	80·00
W ½ SW. ¼	9	12	12	(selected, A. & P. R. R., 1890)	80·00
E. ½ NE. ¼	17	12	12	(selected, A. & P. R. R., 1890)	80·00
NE. ¼ SE. ¼	17	12	12	(selected, A. & P. R. R., 1890)	80·00
W. ½ NW. ¼	16	12	12	(school section)	80·00
W. ½ SW. ¼	16	12	12	(school section)	80·00
Total				.....	2,195·66

RESERVOIR SITE NO. 34.

Situated on Agua Fria Creek, Valencia County, New Mexico.
Drainage basin mostly timbered. Altitude from 7,000 to 9,000 feet.
Three small dams in T. 10 N., R. 12 W.:

	Feet.
"A." NE. ¼ NE. ¼, Sec. 34, height	21
"B." SE. ¼ NE. ¼, Sec. 27, height	24
"C." W. ½ NW. ¼, Sec. 27, height	36

Area of reservoirs:

Area of reservoirs.

	Acre-feet.
"A." Area 82 acres, capacity	680
"B." Area 83 acres, capacity	660
"C." Area 128 acres, capacity	1,400

Material for construction obtainable near sites.
A few houses are located within these sites.

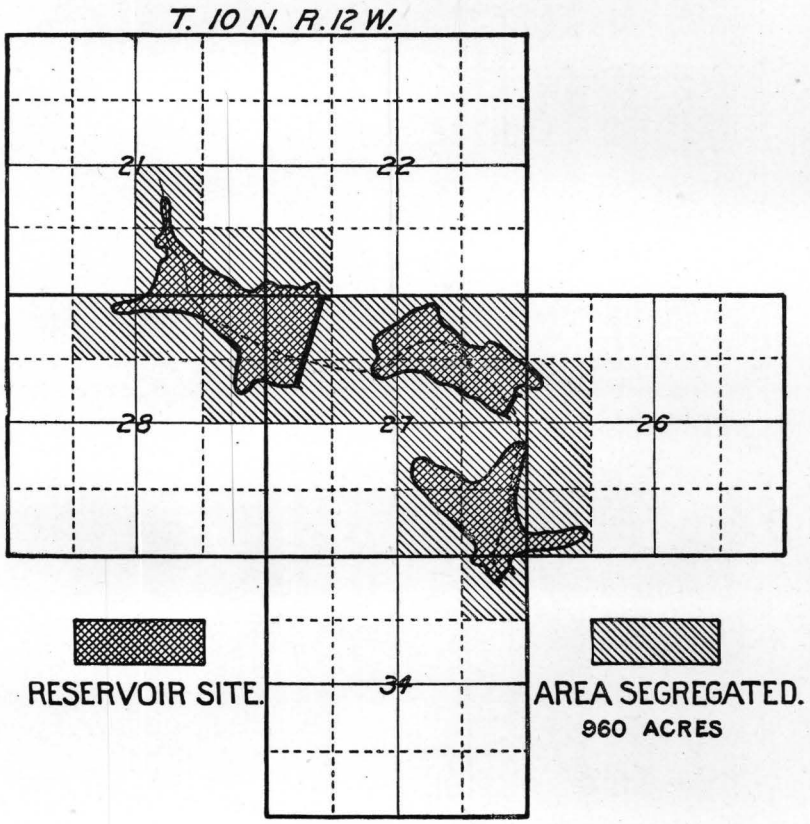


FIG. 217.—Reservoir Site No. 34, on Agua Fria Creek, Zuñi Plateau.

Lands segregated for reservoir.

					Acres.
W. ½ SE. ¼	Sec. 21,	T. 10 N.,	R. 12 W		80
SE. ¼ SE. ¼	21	10	12		40
SW. ¼ SW. ¼	22	10	12		40
SW. ¼ NW. ¼	26	10	12		40
W. ½ SW. ¼	26	10	12		80
E. ½	27	10	12		320
NW. ¼	27	10	12		160
E. ½ NE. ¼	28	10	12		80
NW. ¼ NE. ¼	28	10	12		40
NE. ¼ NW. ¼	28	10	12		40
NE. ¼ NE. ¼	34	10	12		40
Area segregated					960

Action affecting titles to lands segregated for Reservoir Site No. 36 has been taken as follows:

					Acres.
W. ½ SE. ¼	Sec. 21,	T. 10 N.,	R. 12 W	(selected by A. & P. R. R., June 23, 1890).	120
SE. ¼ SE. ¼	21	10	12		
SW. ¼ NW. ¼	26	10	12	(homestead)	40
SW. ¼ SE. ¼	27	10	12	(homestead)	40
N. ½	27	10	12	(selected by A. & P. R. R., June 23, 1890).	320
N. ½ SE. ¼	27	10	12	(selected by A. & P. R. R., June 23, 1890).	80
SE. ¼ SE. ¼	27	10	12	(selected by A. & P. R. R., June 23, 1890).	40
[Acres not segregated]					640

RESERVOIR SITE NO. 35.

Is situated on Rio Colorado, Valencia County, New Mexico.
Dam in SW. ¼, SE. ¼, Sec. 31, T. 6 N., R. 7 W.
Height of dam, 72 feet.
Each end marked with a stone monument.
Altitude of drainage basin from 6,000 to 7,000 feet.
Area of reservoir, 420 acres.
Approximate capacity of reservoir, 1,100 acre-feet.
Material for construction at site.
No settlements are on this site.
Water would be used in the lower valley of the same stream.

Lands segregated.

					Acres.
Lots 2, 3, and 4,	Sec. 31,	T. 6 N.,	R. 7 W		117·26
E. ½ SW. ¼	31	6	7		80·00
W. ½ SE. ¼	31	6	7		80·00
E. ½ NW. ¼	31	6	7		80·00
E. ½ SE. ¼	35	6	8		80·00
S. ½	36	6	8		320·00
S. ½ NE. ¼	36	6	8		80·00
SE. ¼ NW. ¼	36	6	8		40·00
Area segregated					877·26

Land Office records show all lands segregated to be public lands.

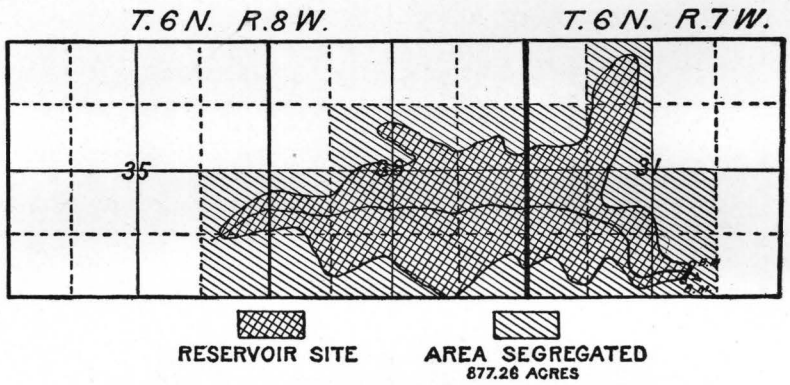


FIG. 218.—Reservoir Site No. 35, 15 miles south of Acoma Pueblo.

RESERVOIR SITE NO. 36.

Is situated on Rio Salado, Socorro County, New Mexico.

Dam just below junction of Rio Salado with Alamosa Creek, in NW. ¼, SW. ¼, Sec. 26, T. 3 N., R. 5 W.

Height of dam, 68 feet.

Bench mark, stone monument at each end.

Altitude of drainage basin ranges from 6,000 to 8,000 feet.

Area of reservoir, about 2,800 acres.

Approximate capacity of reservoir, 63,000 acre-feet.

A natural spillway exists about one-half mile north of west end of dam and is marked by two stone monuments.

Plenty of rock for construction at site.

A few houses are found within this site.

Water would be used in the valley of the Rio Grande.

Lands segregated for reservoir.

				Acres.
SW. ¼ SW. ¼ Sec.	15,	T. 3 N.,	R. 5 W.	40
SW. ¼	16	3	5	160
S. ½ SE. ¼	16	3	5	80
NW. ¼ SE. ¼	16	3	5	40
W. ½ NW. ¼	16	3	5	80
SE. ¼	17	3	5	160
E. ½ NE. ¼	17	3	5	80
NE. ¼	20	3	5	160
E. ½ NW. ¼	20	3	5	80
E. ½ SE. ¼	20	3	5	80
NW. ¼ SE. ¼	20	3	5	40
All	21	3	5	640
SW. ¼	22	3	5	160
W. ½ NW. ¼	22	3	5	80
W. ½ SE. ¼	22	3	5	80
SE. ¼ SE. ¼	22	3	5	40
SE. ¼ SW. ¼	26	3	5	40
W. ½ SW. ¼	26	3	5	80
SW. ¼ NW. ¼	26	3	5	40
W. ½	27	3	5	320
SE. ¼	27	3	5	160

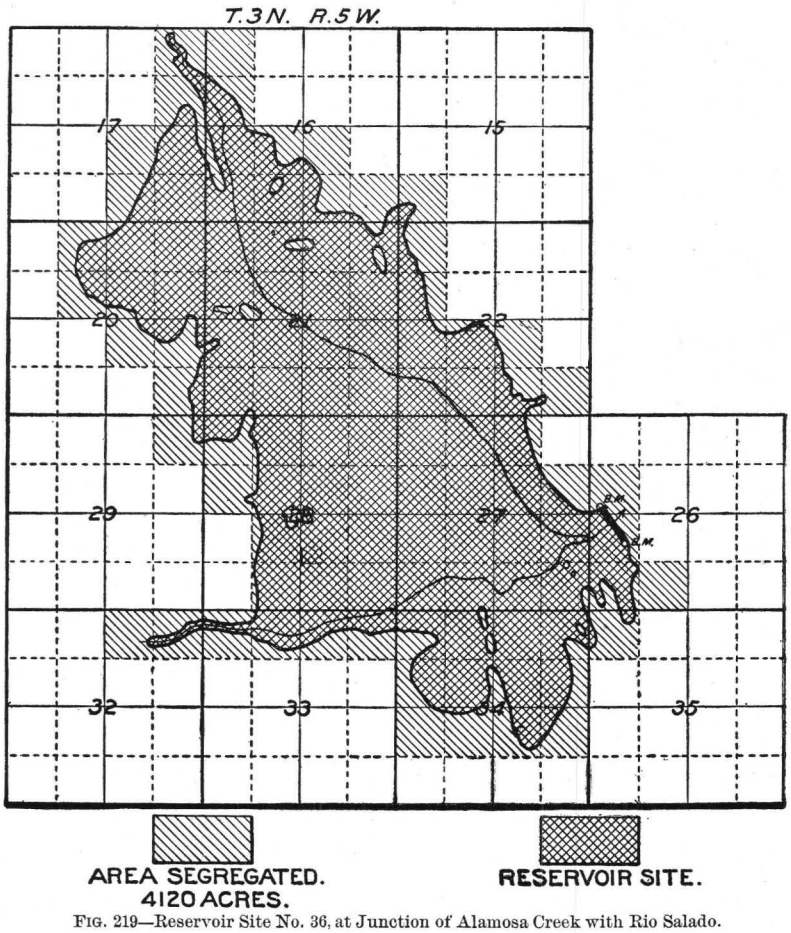


FIG. 219—Reservoir Site No. 36, at Junction of Alamosa Creek with Rio Salado.

					Acres.
W. ½ NE. ¼	Sec. 27,	T. 3 N.,	R. 5 W		80
SE. ¼ NE. ¼	27	3	5		40
E. ½	28	3	5		320
NW. ¼	28	3	5		160
E. ½ SW. ¼	28	3	5		80
NE. ¼ NE. ¼	29	3	5		40
N. ½ NE. ¼	32	3	5		80
N. ½ NW. ¼	33	3	5		80
N. ½ NE. ¼	33	3	5		80
N. ½	34	3	5		320
N. ½ SE. ¼	34	3	5		80
N. ½ SW. ¼	34	3	5		80
NW. ¼ NW. ¼	35	3	5		40
Area segregated					4,120

Action affecting titles to lands above segregated has been taken as follows:

					Acres.
S. ½ NE. ¼	Sec. 27,	T. 3 N.,	R. 5 W	(homestead)	80
N. ½ SE. ¼	27	3	5	(homestead)	80
Total					160

Reservoir Site No. 37.

Is situated on Ojo Caliente Indian Reservation, Socorro County, New Mexico.
Drainage basin mostly without timber.
Dam at entrance of narrow gorge about one-half mile below the Hot Springs.
Height of dam 125 feet.
Stone monument at each end.

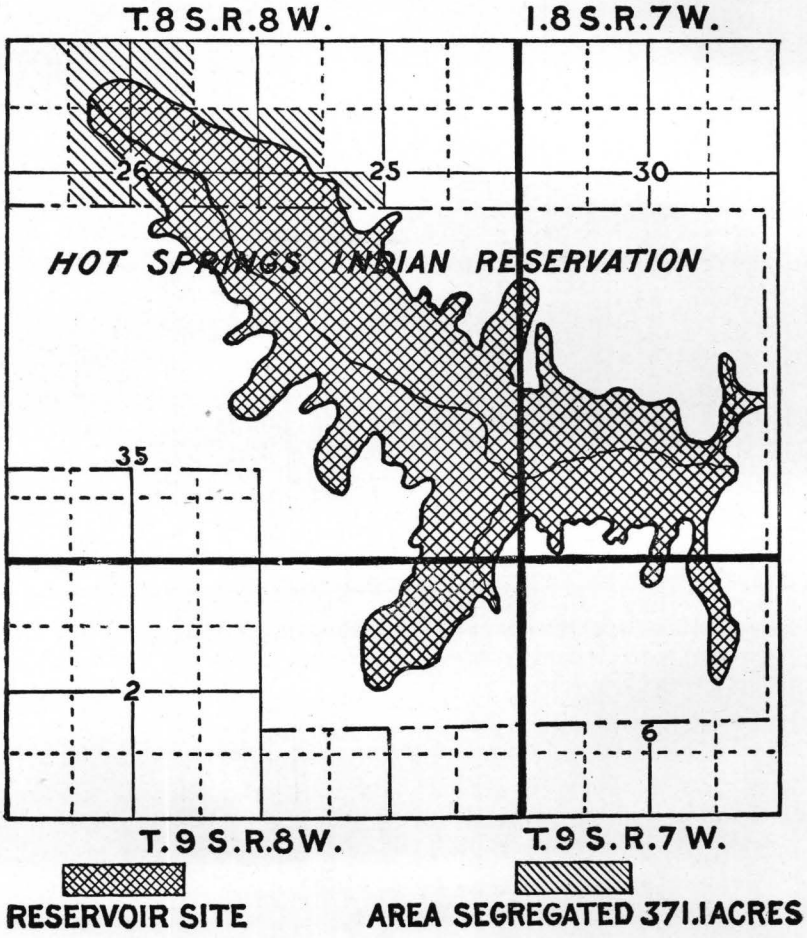


Fig. 220.—Reservoir Site No. 37, mostly on Hot Springs Indian Reservation.

Altitude of drainage basin from 6,000 to 7,000 feet.
Area of reservoir 1,185 acres.
Approximate capacity of reservoir 59,000 acre-feet.
Material for construction at site.
An Indian village and several houses are found within this site.
Water would be used in valley of Rio Grande.

Lands segregated.

					Acres.
SW. ¼ NW. ¼ Sec.	25,	T. 8 S.,	R. 8 W.		40·00
Lot 4	25	8	8		22·98
Lot 3	25	8	8		22·92
S. ½ NE ¼	26	8	8		80·00
NW. ¼ NE. ¼	26	8	8	S	40·00
E. ½ NW ¼	26	8	8		80·00
Lot 1	26	8	8		22·96
Lot 2	26	8	8		22·89
Area segregated					371·75

Remainder of reservoir on Hot Springs Indian Reservation.

Action affecting titles to lands segregated for Reservoir Site No. 37 has been taken as follows:

					Acres.
NW. ¼ NE. ¼ Sec.	26,	T. 8 S.,	R. 8 W.	(homestead, 1882)	40·00
E. ½ NW. ¼	26	8	8	(homestead, 1882)	80·00
S. ½ NE. ¼	26	8	8	(homestead, 1882)	80·00
Lot 1	26	8	8	(homestead, 1882)	22·96
Lot 2	26	8	8	(homestead, 1882)	22·89
Total					245·85

Reservoir Site No. 38.

Is situated on the Rio Grande, in Socorro and Sierra counties, New Mexico.

Drainage basin includes all of Rio Grande basin north of latitude 33° 30′.

Dam in NW. ¼ Sec. 17, T. 11 S., R. 3 W.

Height of dam, 80 feet.

Stone monument at each end.

Area of reservoir, about 5,540 acres.

Approximate capacity of reservoir, 175,000 acre-feet.

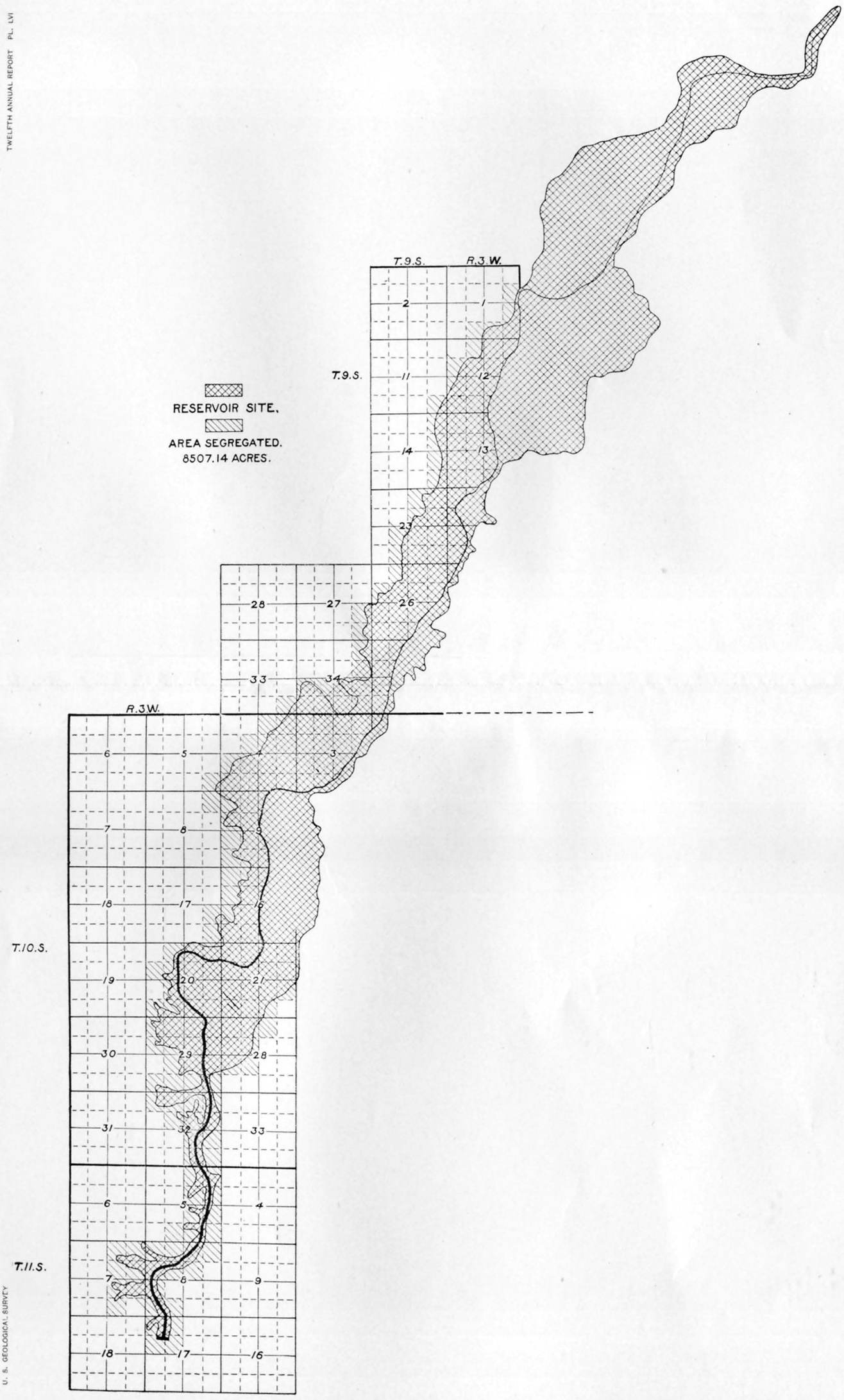
The villages of San José, San Albino, and Cantarecio, as well as a great many other houses, are situated within this site.

Water would be used in lower Rio Grande Valley.

Land segregated. (*See* Pl. LVI.)

				Acres.
SE. ¼ NE. ¼ Sec.	1,	T. 9 S.,	R. 3 W.	40·00
NE. ¼ SE. ¼	1	9	3	40·00
SW. ¼ SE. ¼	1	9	3	40·00
Lot 5	1	9	3	35·70
SE. ¼ SW. ¼	1	9	3	40·00
SE. ¼ SE. ¼	11	9	3	40·00
NW. ¼ NE. ¼	12	9	3	40·00
Lot 1	12	9	3	24·15
Lot 2	12	9	3	37·15
E. ½ NW. ¼	12	9	3	80·00
SW. ¼	12	9	3	160·00
Lot 4	12	9	3	46·05
Lot 3	12	9	3	37·75
SW. ¼ NW. ¼	12	9	3	40·00
NW. ¼	13	8	3	160·00
Lot 1	13	9	3	38·10
Lot 2	13	9	3	9·50

				Acres.
W. ½ SW. ¼ Sec.	13,	T. 9 S.,	R. 3 W.	80·00
Lot 3	13	9	3	39·00
Lot 4	13	9	3	26·50
E. ½ NE. ¼	14	9	3	80·00
E. ½ SE. ¼	14	9	3	80·00
NE. ¼	23	9	3	160·00
E. ½ SW. ¼	23	9	3	80·00
N. ½ SE. ¼	23	9	3	80·00
Lot 1	23	9	3	24·00
Lot 2	23	9	3	38·90
W. ½ NW. ¼	24	9	3	80·00
Lot 1	24	9	3	14·50
Lot 2	24	9	3	15·10
NW. ¼ SW. ¼	24	9	3	40·00
Lot 4	24	9	3	26·35
Lot 3	24	9	3	14·00
Lot 1	25	9	3	9·94
E. ½ NW. ¼	26	9	3	80·00
SW. ¼ NE. ¼	26	9	3	40·00
Lot 1	26	9	3	35·80
Lot 2	26	9	3	7·50
W. ½ SE. ¼	26	9	3	80·00
Lot 3	26	9	3	36·70
Lot 4	26	9	3	30·15
SW. ¼ NW. ¼	26	9	3	40·00
SW. ¼	26	9	3	160·00
E. ½ SE. ¼	27	9	3	80·00
SE. ¼ SE. ¼	33	9	3	40·00
SW. ¼	34	9	3	160·00
E. ½ NE. ¼	34	9	3	80·00
SE. ¼	34	9	3	160·00
W. ½ NW. ¼	35	9	3	80·00
NE. ¼ NW. ¼	35	9	3	40·00
Lot 1	35	9	3	26·11
Lot 2	35	9	3	32·30
Lot 3	35	9	3	65·00
Lot 4	35	9	3	39·10
Lot 5	35	9	3	31·50
Lot 1	2	10	3	2·76
Lot 1	3	10	3	21·43
Lot 2	3	10	3	27·97
Lot 3	3	10	3	39·27
W. ½ NW. ¼	3	10	3	80·00
Lot 4	3	10	3	22·24
Lot 5	3	10	3	5·97
Lot 6	3	10	3	31·08
Lot 1	4	10	3	40·10
Lot 2	4	10	3	40·30
Lot 5	4	10	3	39.06
Lot 6	4	10	3	16·66
SE. ¼ NE. ¼	4	10	3	40·00
SE. ¼ NW. ¼	4	10	3	40·00
W. ½ SW. ¼	4	10	3	80·00
Lot 7	4	10	3	27·85
Lot 8	4	10	3	19·00



RESERVOIR SITE, NEW MEXICO, NO. 38.

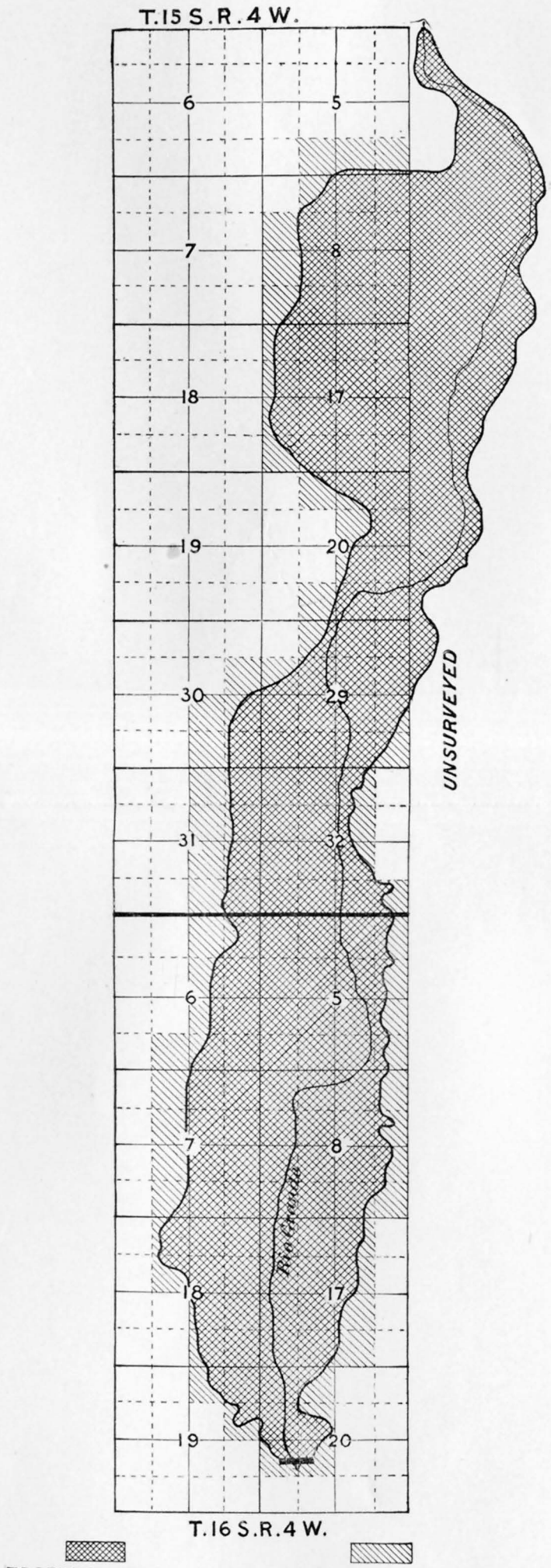
				Acres.
SE. ¼ SE. ¼	Sec. 5,	T. 10 S.,	R. 3 W	40·00
NE. ¼ NE. ½	8	10	3	40·00
W. ½ NW. ¼	9	10	3	80·00
W. ½ SW. ¼	9	10	3	80·00
Lot 1	9	10	3	34·24
Lot 2	9	10	3	3·40
Lot 3	9	10	3	39·70
Lot 4	9	10	3	33·70
Lot 5	9	10	3	39·90
Lot 6	9	10	3	10·80
Lot 7	9	10	3	1·29
Lot 1	10	10	3	2·36
Lot 1	15	10	3	22·03
Lot 2	15	10	3	22·10
Lot 3	15	10	3	22·18
Lot 4	15	10	3	22·25
NW. ¼	16	10	3	160·00
SW. ¼	16	10	3	160·00
S. ½ NE. ¼	16	10	3	80·00
SE. ¼	16	10	3	160·00
Lot 2	16	10	3	36·39
Lot 1	16	10	3	33·37
E. ½ SE. ¼	17	10	3	80·00
NE. ¼	20	10	3	160·00
SE. ¼	20	10	3	160·00
E. ½ NW. ¼	20	10	3	80·00
SW. ¼ NW. ¼	20	10	3	40·00
E. ½ SW. ¼	20	10	3	80·00
SW. ¼ SW. ¼	20	10	3	40·00
NE. ¼	21	10	3	160·00
NW. ¼	21	10	3	160·00
SW. ¼	21	10	3	160·00
W. ½ SE. ¼	21	10	3	80·00
NE. ¼ SE. ¼	21	10	3	40·00
NW ¼	28	10	3	160·00
NW. ¼ NE. ¼	28	10	3	40·00
N. ½ SW. ¼	28	10	3	80·00
NE. ¼	29	10	3	160·00
SE. ¼	29	10	3	160·00
NW. ¼	29	10	3	160·00
NE. ½ SW. ¼	29	10	3	40·00
S. ½ SW. ¼	29	10	3	80·00
NE. ¼	32	10	3	160·00
SE. ¼	32	10	3	160·00
E. ½ NW. ¼	32	10	3	80·00
NW. ¼ NW. ¼	32	10	3	40·00
S. ½ NE. ¼	5	11	3	80·00
Lot 1	5	11	3	43·10
Lot 2	5	11	3	43·30
SE. ¼	5	11	3	160·00
SE. ¼ SW. ¼	5	11	3	40·00
NE. ¼	7	11	3	160·00
N. ½ SE. ¼	7	11	3	80·00
SW. ¼ SE. ¼	7	11	3	40·00
W. ½ NE. ¼	8	11	3	80·00
NE. ¼ NE. ¼	8	11	3	40·00

					Acres.
NW. ¼	Sec. 8,	T. 11	S.,	R. 3 W	160·00
SE. ¼ SW. ¼	8	11		3	40·00
W. ½ SW. ¼	8	11		3	80·00
NW. ¼	17	11		3	160·00
Area segregated					8,547·14

Action affecting titles to lands segregated for Reservoir Site No. 38 has been taken as follows:

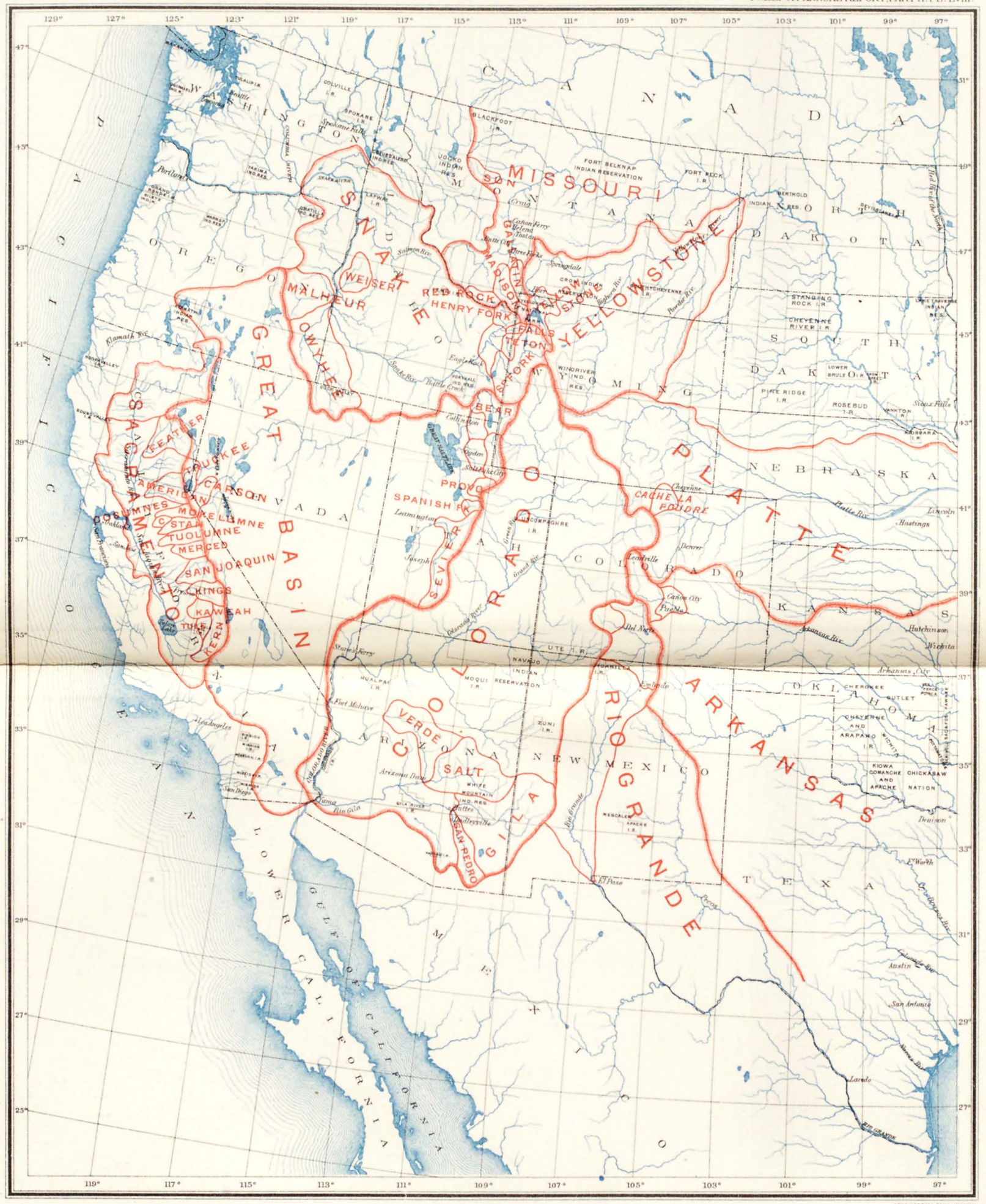
						Acres.
SE. ¼ NE. ¼	Sec. 1,	T. 9	S.,	R. 3 W.	(preemption, 1888)	40·00
NE. ¼ SE. ¼	1	9		3	(homestead, 1883)	40·00
SW. ¼ SE. ¼	1	9		3	(homestead, 1883)	40·00
Lot 5	1	9		3	(homestead, 1883)	35·70
NW. ¼ NE. ¼	12	9		3	(homestead, 1883)	40·00
Lot 1	12	9		3	(homestead, 1883)	24·15
Lot 2	12	9		3	(homestead, 1883)	37·15
E. ½ NW. ¼	12	9		3	(homestead, 1883)	80·00
SW. ¼	12	9		3	(homestead, 1883)	160·00
Lot 4	12	9		3	(homestead, 1884)	46·50
E. ½ NW. ¼	13	9		3	(homestead, 1883)	80·00
Lot 1	13	9		3	(homestead, 1883)	38·10
Lot 2	13	9		3	(homestead, 1883)	9·50
SW. ¼ NW. ¼	13	9		3	(homestead, 1883)	40·00
NW. ¼ NW. ¼	13	9		3	(homestead, 1887)	40·00
W. ½ SW. ¼	13	9		3	(homestead, 1883)	80·00
Lot 3	13	9		3	(homestead, 1883)	39·00
Lot 4	13	9		3	(homestead, 1883)	26·50
E. ½ NE. ¼	14	9		3	(homestead, 1887)	80·00
NE. ¼ SE. ¼	14	9		3	(homestead, 1883)	40·00
SE. ¼ SE. ¼	14	9		3	(homestead, 1885)	40·00
NE. ¼ NE. ¼	23	9		3	(homestead, 1883)	40·00
S. ½ NE. ¼	23	9		3	(preemption, 1883)	80·00
E. ½ SW. ¼	23	9		3	(preemption, 1885)	80·00
N. ½ SE. ¼	23	9		3	(preemption, 1885)	80·00
Lot 1	23	9		3	(preemption, 1883)	24·00
Lot 2	23	9		3	(preemption, 1883)	38·90
NW. ¼ NW. ¼	24	9		3	(homestead, 1883)	40·00
Lot 1	24	9		3	(homestead, 1883)	14·50
SW. ¼ NW. ¼	24	9		3	(preemption, 1883)	40·00
Lot 2	24	9		3	(preemption, 1883)	15·10
NW. ¼ SW. ¼	24	9		3	(preemption, 1883)	40·00
Lot 4	24	9		3	(preemption, 1883)	26·35
Lot 1	25	9		3	(preemption, 1884)	9·94
E. ½ NW. ¼	26	9		3	(preemption, 1883)	80·00
SW. ¼ NE. ¼	26	9		3	(preemption, 1883)	40·00
Lot 1	26	9		3	(preemption, 1883)	35·80
Lot 2	26	9		3	(preemption, 1883)	7·50
W. ½ SE. ¼	26	9		3	(preemption, 1884)	80·00
Lot 3	26	9		3	(preemption, 1883)	36·70
Lot 4	26	9		3	(preemption, 1884)	30·15
SW. ¼	26	9		3	(preemption, 1884)	160·00
SE. ¼ SE. ¼	34	9		3	(preemption, 1883)	40·00
W. ½ NW. ¼	35	9		3	(preemption, 1884)	80·00
NE. ¼ NW. ¼	35	9		3	(preemption, 1884)	40·00
Lot 2	35	9		3	(preemption, 1884)	32·30
Lot 3	35	9		3	(preemption, 1883)	6·50

					Acres.
Lot 4	Sec. 35,	T. 9 S.,	R. 3 W.	(preemption, 1883)	39·10
Lot 5	35	9	3	(preemption, 1883)	31·50
W. ½ NW. ¼	3	10	3	(desert land, 1886)	80·00
Lot 4	3	10	3	(desert land, 1886)	22·24
Lot 5	3	10	3	(desert land, 1886)	5·97
Lot 6	3	10	3	(desert land, 1886)	31·08
Lot 7	4	10	3	(preemption, 1884)	27·85
Lot 8	4	10	3	(preemption, 1884)	19·00
Lot 1	9	10	3	(preemption, 1884)	34·24
Lot 2	9	10	3	(preemption, 1884)	3·40
Lot 3	9	10	3	(preemption, 1884)	39·70
Lot 4	9	10	3	(homestead, 1888)	33·70
Lot 5	9	10	3	(homestead, 1888)	39·90
Lot 6	9	10	3	(homestead, 1888)	10·80
Lot 2	16	10	3	(homestead, 1884)	36·39
E. ½ NW. ¼	16	10	3	(homestead, 1884)	80·00
NE. ¼ SW. ¼	16	10	3	(homestead, 1884)	40·00
S. ½ NE. ¼	16	10	3	(homestead, 1884)	80·00
N. ½ SE. ¼	16	10	3	(homestead, 1884)	80·00
SE. ¼ SE. ¼	16	10	3	(homestead, 1884)	40·00
SW. ¼ SE. ¼	16	10	3	(homestead, 1884)	40·00
S. ½ SW. ¼	16	10	3	(homestead, 1884)	80·00
N. ½ NE. ¼	20	10	3	(homestead, Aug. 9, 1890)	80·00
SE. ¼ NE. ¼	20	10	3	(homestead, Aug. 9, 1890)	40·00
W. ½ SE. ¼	20	10	3	(homestead, 1884)	80·00
SW. ¼ NW. ¼	20	10	3	(homestead, 1884)	40·00
SE. ¼ NW. ¼	20	10	3	(homestead, 1884)	40·00
E. ½ SW. ¼	20	10	3	(homestead, 1884)	80·00
E. ½ SE. ¼	20	10	3	(homestead, 1884)	80·00
NE. ¼ NW. ¼	21	10	3	(homestead, 1884)	40·00
W. ½ NE. ¼	21	10	3	(homestead, 1884)	80·00
NW. ¼ NW. ¼	21	10	3	(homestead, 1884)	40·00
SE. ¼ NW. ¼	21	10	3	(homestead, 1884)	40·00
NE. ¼ SE. ¼	21	10	3	(homestead, 1884)	40·00
W. ½ SW. ¼	21	10	3	(homestead, 1884)	80·00
SW. ¼ NW. ¼	21	10	3	(homestead, 1890)	40·00
NW. ¼ NW. ¼	28	10	3	(homestead, 1884)	40·00
NE. ¼	29	10	3	(homestead, 1884)	160·00
NE. ¼ SE. ¼	29	10	3	(homestead, 1884)	40·00
E. ½ NW. ¼	29	10	3	(homestead, 1884)	80·00
W. ½ SE. ¼	29	10	3	(homestead, 1890)	80·00
NE. ¼ SW. ¼	29	10	3	(homestead, 1890)	40·00
SE. ¼ SE. ¼	29	10	3	(homestead, 1884)	40·00
N. ½ NE. ¼	32	10	3	(homestead, 1884)	80·00
SE. ¼ NE. ¼	32	10	3	(homestead, 1884)	40·00
E. ½ SE. ¼	32	10	3	(homestead, 1884)	80·00
W. ½ SE. ¼	32	10	3	(homestead, 1885)	80·00
Lot 1	5	11	3	(homestead, 1884)	43·10
SE. ¼ NE. ¼	5	11	3	(homestead, 1884)	40·00
W. ½ NE. ¼	8	11	3	(homestead, 1885)	80·00
E. ½ NW. ¼	8	11	3	(homestead, 1885)	80·00
SE. ¼ SW. ¼	8	11	3	(homestead, 1886)	40·00
E. ½ NW. ¼	17	11	3	(preemption, 1886)	80·00
W. ½ NW. ¼	17	11	3	(preemption, 1886)	80·00
					5,152·31



RESERVOIR SITE, NEW MEXICO, NO. 39.

RESERVOIR SITE AREA SEGREGATED 6857.33 ACRES



INDEX MAP OF RIVER MEASUREMENTS.

Showing the relative location of the drainage basins and the principal places at which gauge readings have been made.

by

F. H. NEWELL

Scale.

100 0 100 200 300 400 500 600 Miles.

GEO. S. HARRIS & SON, LITH. BOSTON

Action affecting titles to lands segregated for Reservoir Site No. 39 has been taken, as follows:

					Acres.
SE. ¼ SW. ¼ Sec.	5,	T. 15 S.,	R. 4 W.	(preemption, 1883)	40
SE. ¼ SE. ¼	5	15	4	(preemption, 1883)	40
E. ½ NE. ¼	8	15	4	(preemption, 1883)	80
E. ½ NW. ¼	8	15	4	(preemption, 1883)	80
SW. ¼ NW. ¼					40
SW. ¼	8	15	4	(preemption, 1883)	160
N. ½ NW. ¼	17	15	4	(preemption, 1883)	80
W. ½ NE. ¼	17	15	4	(preemption, 1883)	80
NW. ¼ SE. ¼	17	15	4	(preemption, 1883)	40
NE. ¼ SW. ¼	17	15	4	(preemption, 1883)	40
SW. ¼ SW. ¼	17	15	4	(preemption, 1883)	40
W. ½ SE. ¼	30	15	4	(preemption, 1884)	80
NW. ¼ NE. ¼	31	15	4	(preemption, 1884)	40
SW. ¼ NE. ¼	31	15	4	(homestead, 1885)	40
W. ½ SE. ¼	31	15	4	(homestead, 1885)	80
NW. ¼ NE. ¼	6	16	4	(homestead, 1885)	40
W. ½ SE. ¼	6	16	4	(desert, 1883)	80
SE. ¼ SW. ¼	6	16	4	(desert, 1883)	40
NE. ¼ NW. ¼	7	16	4	(desert, 1883)	40
SE. ¼ NW. ¼	18	16	4	(desert, 1888)	40
					1,200

NEVADA.

RESERVOIR SITES NUMBERED 1 AND 2.

Reservoir Site No. 1.

Known as Lower Truckee No. 1. On the Truckee River, about 5 miles above Wadsworth, in Washoe and Storey Counties, Nevada.

The drainage basin includes all of Tahoe, Independence, and Donner Lakes, in all about 1,000 square miles. On nearly the whole area the snow fall is very heavy and the spring flow of all streams very large. In dry seasons the water of the Truckee in summer is nearly all used for irrigation above the reservoir site. Elevation of the drainage basin ranges from 4,200 to 10,800 feet.

The dam site is in NW. ¼ of Sec. 20, T. 20 N., R. 23 E.

Height of proposed dam, 50 feet.

Bench mark on a stone marked U. S. G. S. B. M. at north end of dam, at an altitude above sea level of about 4,250 feet.

Top contour level with bench mark.

Area inclosed, about 400 acres.

Approximate content of reservoir, 7,500 acre-feet.

A limited amount of cottonwood can be cut along the river near the site for dam building. Building stone of a poor quality in abundance.

Reservoir site partly settled.

Irrigable lands on both sides of the Truckee River all the way to Pyramid Peak.

Recommended for segregation in letter dated February 27, 1891.

Lands segregated for reservoir.

					Acres.
S. ½ NW. ¼	Sec. 20,	T. 20 N.,	R. 23 E		80
N. ½ S. ½	19	20	23		160
S. ½ N. ½	19	20	23		160
NE. ¼	24	20	23		160
SE. ¼ NW. ¼	24	20	23		40
SW. ¼	24	20	22		160
N. ½ SE. ¼	24	20	22		80
W. ½ W. ½	25	20	22		160
Area segregated					1,000

Action affecting titles to lands segregated for Reservoir Site No. 1 has been taken, as follows:

					Acres.
W. ½ W. ½	Sec. 25,	T. 20 N.,	R. 22 E.	(patented, C. P. R. R., June, 1886)	160
S. ½ N. ½	19	20	23	(patented, C. P. R. R., June, 1886)	160
SW. ¼ NW. ¼	20	20	23	(desert, Feb., 1885)	40
					360

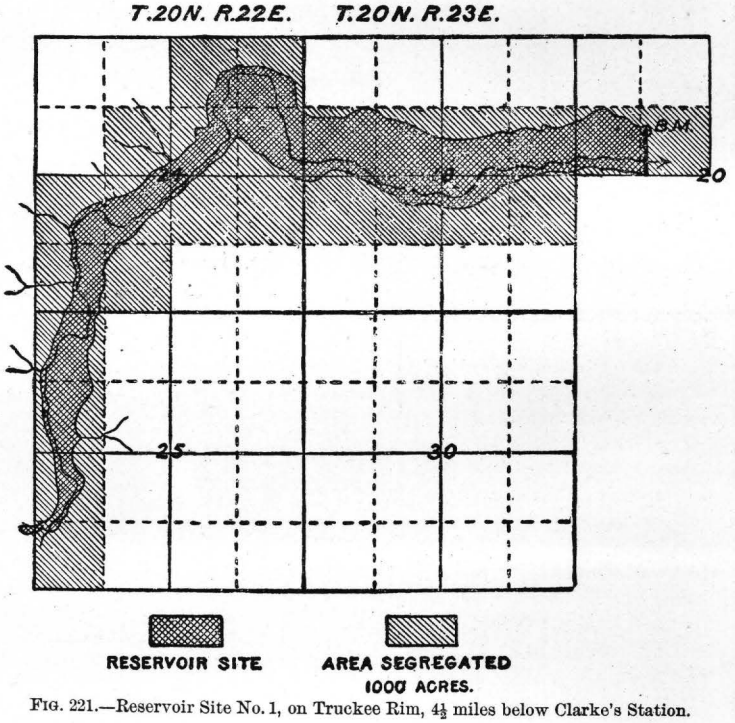


FIG. 221.—Reservoir Site No. 1, on Truckee Rim, 4½ miles below Clarke's Station.

RESERVOIR SITE NO. 2.

Known as Lower Truckee No. 2. On the Truckee River, about 10 miles above Wadsworth, in Washoe and Storey Counties, Nevada.

The drainage basin includes all that of the Truckee River above the site, about 1,000 square miles in area. A reservoir on this site or Site No. 1, would seriously interfere with the present location of the C. P. R. R. Elevation and water supply the same as for Site No. 1.

Height of dam, 60 feet.

Bench mark on a stone marked U. S. G. S. B. M. at south end of dam.

Approximate elevation, 4,300 feet.

Top contour level with bench mark.

Top contour incloses an area of 395 acres.

Approximate content of reservoir, 7,400 acre-feet.

A poor quality of stone and a scanty supply of cottonwood timber for building purposes in vicinity of dam site.

Partly settled.

Irrigable lands on both sides of the Truckee River for 20 miles below the site.

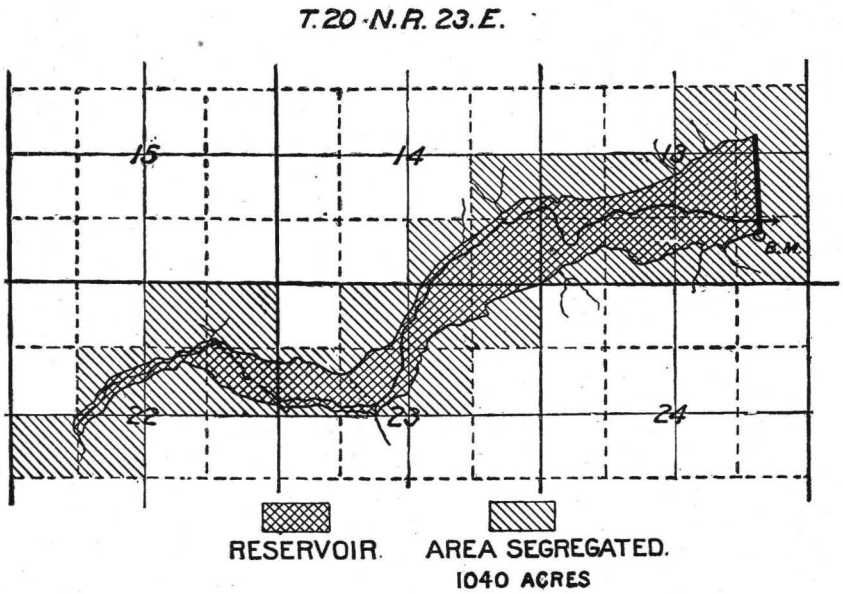


FIG. 222.—Reservoir Site No. 2, on Truckee Rim, 4 miles west of Wadsworth.

Recommended for segregation in letter dated February 27, 1891.

Lands segregated for reservoir.

					Acres.
S. ½ SE. ¼	Sec. 14,	T. 20 N.,	R. 23 E.		80
NE. ¼ SE. ¼	14	20	23		40
SW. ¼	13	20	23		160
SE. ¼	13	20	23		160
S. ½ NE. ¼	13	20	23		80
N. ½ NE. ¼	23	20	23		80
SW. ¼ NE. ¼	23	20	23		40
S. ½ NW. ¼	23	20	23		80
NE. ¼ NW. ¼	23	20	23		40
NE. ¼	22	20	23		160
NE. ¼ SW. ¼	22	20	23		40
S. ½ SW. ¼	22	20	23		80
Area segregated					1,040

Action affecting the titles to lands segregated for Reservoir Site No. 2 has been taken, as follows:

					Acres
S. ½	Sec. 13,	T. 20 N.,	R. 23 E.	(patented, C. P. R. R., June, 1886)	320
E. ½ SE. ¼	14	20	23	(selected by the State, August, 1872) .	120
SW. ¼ SE. ¼	14	20	23		
S. ½ NE. ¼	22	20	23	(selected by the State, August, 1872) ..	80
N. ½ NE. ¼	23	20	23	(patented, C. P. R. R., June, 1886).....	80
SW. ¼ NE. ¼	23	20	23	(patented, C. P. R. R., June, 1886).....	40
S. ½ NW. ¼	23	20	23	(patented, C. P. R. R., June, 1886).....	80
NE. ¼ NW. ¼	23	20	23	(patented, C. P. R. R., June, 1886).....	40
					760

HYDROGRAPHY OF THE ARID REGIONS.

BY

F. H. NEWELL.

CONTENTS.

	Page.
Hydrographic measurements and irrigation	219
The arid regions	219
Hydrographic data	221
Deficiency of water	221
Increase of water duty	223
Water storage	224
Relative amount of flood waters	227
Time of floods	228
Intensity of floods	230
Rainfall and river flow	230
Points of maximum utility	231
Classification of drainage basins	232
Humidity and irrigation	234
Evaporation observations	234
Results of stream measurements	235
Upper Missouri and Yellowstone Basins	236
Platte Basin	238
Arkansas Basin	240
Rio Grande Basin	240
Topography and elevations	240
Annual and monthly rainfall	243
The Colorado district of the Rio Grande	245
San Luis Valley	247
Irrigation practice	248
The Taos district of the Rio Grande	251
Tres Piedras Mesa	256
Embudo gauging station	257
Espanola Valley	258
The Chama district	261
Santa Fe district	269
Albuquerque district	270
Tributaries below the Chama	273
Santa Fe and adjacent streams	273
Jemez River	274
Puerco River	275
Résumé of water supply	277
Mesas along the Rio Grande	278
Mesilla Valley	279
Gypsum Plains district	281
Pecos River	282
General topography	282
Climate and water supply	283
Upper tributaries	284

Page.

Rio Grande Basin—Continued.
Pecos River—Continued.
Lower tributaries in New Mexico 286
Agriculture along the Pecos 287
Irrigation works on the Pecos 288
Colorado River drainage basin 290
The Gila Basin 292
Topography and altitudes 292
Agricultural lands 295
Duty of water 296
Water storage 298
Rainfall 299
Upper Gila district 302
San Pedro district 303
Middle Gila district 305
Verde district 309
Upper Salt district 310
Lower Salt district 311
Lower Gila district 314
Agua Fria and Hassayampa districts 315
Santa Cruz district 315
Sacramento and San Joaquin basins 316
Kern River 319
Tule River 319
Kaweah River 320
Kings River 320
San Joaquin River 321
Merced River 322
Tuolumne River 322
Mokelumne River 323
Lower San Joaquin River 323
The Great Basin 324
Truckee River 324
Carson River 325
Salt Lake Basin 325
Bear River 325
Bear Lake 327
Lower Bear River 329
Cache Valley 330
Ogden and Weber Rivers 334
Utah Lake drainage 334
Sevier River 339
Snake River drainage 344
Discharge tables 345

ILLUSTRATIONS.

		Page.
PL. LVIII.	Index map of river measurements	222
LIX.	Diagram of monthly river flow and rainfall	226
LX.	Diagram of daily discharge of the West Gallatin River and Red Rock Creek, Montana	228
LXI.	Diagram of daily discharge of the Madison River, Montana	230
LXII.	Diagram of daily discharge of the Missouri River, Montana	232
LXIII.	Diagram of daily discharge of the Sun River, Montana	234
LXIV.	Diagram of daily discharge of the Yellowstone River, Montana	236
LXV.	Diagram of daily discharge of the Cache la Poudre, Colorado, 1884 to 1891	238
LXVI.	Diagram of daily discharge of the upper tributaries of the Arkansas River, Colorado, 1890	240
LXVII.	Diagram of daily discharge of the Arkansas River at Canyon City, Colorado, 1888 to 1891	242
LXVIII.	Map of the Rio Grande and Pecos basins	244
LXIX.	Earth columns near station at Embudo, New Mexico	246
LXX.	Diagram of monthly rainfall in the Rio Grande Basin	248
LXXI.	Diagram of daily discharge of the Rio Grande at Del Norte, Colorado	250
LXXII.	Diagram of daily discharge of the Rio Grande at Embudo, New Mexico	256
LXXIII.	Diagram of daily discharge of the Rio Grande at El Paso, Texas	280
LXXIV.	Diagram of gauge height of the Colorado River at Yuma, Arizona, 1880 to 1891	290
LXXV.	Map of the Gila Basin, Arizona	292
LXXVI.	Diagram of monthly rainfall in the Gila Basin, Arizona	300
LXXVII.	View of the Hassayampa Reservoir, Arizona	302
LXXVIII.	Diagram of daily discharge of the Gila River, Arizona	306
LXXIX.	Diagram of daily discharge of the Salt River, Arizona	308
LXXX.	Diagram of daily discharge of the Kern River, California, 1879 to 1882	310
LXXXI.	Diagram of daily discharge of the Kaweah River, California, 1879 to 1882	312
LXXXII.	Diagram of daily gauge height of the Kings River, California, 1880 to 1891	314
LXXXIII.	Diagram of daily discharge of the upper San Joaquin River, California, 1879 to 1882	316
LXXXIV.	Diagram of daily gauge height of the upper San Joaquin River, California, 1880 to 1891	318
LXXXV.	Diagram of daily discharge of the Merced River, California, 1879 to 1882	320

Page.

PL. LXXXVI. Diagram of daily discharge of the Tuolumne River, California, 1879 to 1882 322
LXXXVII. Diagram of daily discharge of the Mokelumne River, California, 1879 to 1882 322
LXXXVIII. Diagram of daily gauge height of the lower San Joaquin River, California, 1880 to 1891 322
LXXXIX. Diagram of daily discharge of the Truckee and Little Truckee Rivers at Boca, California, and of Prosser Creek 324
XC. Diagram of daily discharge of the Truckee River at Vista, Nevada 324
XCI. Diagram of daily discharge of the Carson River at Empire, Nevada, and of the East and West forks of the Carson 324
XCII. Map of the Bear River drainage basin 326
XCIII. View of the Bear River Canyon, Utah 328
XCIV. Diagram of daily discharge of the Bear River at Battle Creek, Idaho 330
XCV. Diagram of daily discharge of the Bear River at Collinston, Utah 332
XCVI. Diagram of daily discharge of the Ogden River, Utah 336
XCVII. Diagram of daily discharge of the Weber River, Utah 336
XCVIII. Diagram of daily discharge of the American Fork and Spanish Fork rivers, Utah 338
XCIX. Diagram of daily discharge of the Provo River, Utah 340
C. Diagram of daily discharge of the Sevier River, Utah 342
CI. Diagram of daily discharge of Henry Fork, Idaho 344
CII. Diagram of daily discharge of the Falls and Teton rivers, Idaho 344
CIII. Diagram of daily discharge of the Snake River, at Eagle Rock, Idaho 344
CIV. Diagram of daily discharge of the Owyhee River, Oregon 344
CV. Diagram of daily discharge of the Malheur River, Oregon 344
CVI. Diagram of daily discharge of the Weiser River, Idaho 344
FIG. 223. Diagram of annual rainfall in the Rio Grande Basin 244
224. Diagram illustrating sediment measurements at Embudo, New Mexico 258
225. An acequia at Roswell, New Mexico 289
226. Diagram of annual rainfall in the Gila Basin 300
227. Diagram of the daily gauge height of the Tule River, California, 1879 and 1880 319
228. Diagram of daily gauge height of the Tuolumne River, California, 1890 and 1891 322
229. Diagram of fluctuations of Utah Lake 336

HYDROGRAPHY OF THE ARID REGIONS.

By F. H. Newell.

HYDROGRAPHIC MEASUREMENTS AND IRRIGATION.

The hydrographic investigations of the Geological Survey consist of measurements of the water flowing in the rivers or stored in the lakes of the United States, and, as far as possible, of a study of the laws which govern the distribution and fluctuation of the water supply. The greater part of these investigations are made in the western half of the United States, where flowing water possesses the greatest value and importance. In that part of the country the results of this work, besides being of scientific value, have direct practical application to irrigation and to the problems arising from the deficiency of water for agriculture and other needs of man, for upon the correct solution of these problems is dependent the growth and prosperity of this great division of the United States.

In the eastern portion of the country hydrographic investigations are confined mainly to considerations of the flood discharge of rivers, for here the water supply is usually ample for all needs, and public interest is drawn to such subjects only through an excess of water so great as to be destructive. In the western part of the United States, however, the amount of water at low stages is the object of chief solicitude, and all the fluctuations are watched with care, for agricultural success or failure follows the prevalence of high or low water.

THE ARID REGIONS.

Over a large portion, perhaps one-half, of the continent of North America the rainfall is too small to support those forms of vegetation upon which man depends mainly for his supply of food. This great area, marked by a scanty plant life, lies in a general north and south direction, beginning in high latitudes, where the low temperature forbids the growth of many species of plant life, and continues through the United States and into Mexico till cut off by the belt of tropical rains. The eastern border of this region of droughts is usually taken for convenience as coinciding with the one-hundredth meridian, and from this as the eastern limit it extends to the mountain ranges bordering the Pacific Ocean. This aridity of climate has a fundamental influence

upon the appearance of the country and upon the occupation of its inhabitants. There is perhaps no natural classification under which will fall more groups of facts than that of the division of the United States into these two great regions, the humid and the arid, for in them many of the political and social customs, as well as agriculture, must be radically different.

In this vast area, containing great deposits of mineral wealth, and embracing agricultural land as rich as any on the globe, since the supply of moisture is too small for the needs of man, the examination of all features which modify the water supply and the acquisition of knowledge of its present distribution and character have been recognized as being of great importance, for it is acknowledged that, although the water supply is at best scanty, its future use and efficiency can be greatly increased by a more intelligent utilization of the amount at present available.

There is thus no investigation which bears more fundamentally upon the complete development of the resources of this great region than this careful examination and a recording of facts which are now known, together with a study of the influences which may lead to a more thorough and economical employment of the waters. With our present information a report on these facts can not claim to be complete, but it is rather an introduction to the subject, which, while revealing the deficiency of our knowledge, demonstrates the great necessity of more careful and continued observations in the same line.

The cause of the aridity of this vast area is traceable primarily to the general circulation of the atmosphere and to the shape and relief of the continent. This is perhaps best put by Ferrel in his "Popular Treatise on the Winds," page 183, in which he states:

> If the whole surface of the earth were that of the ocean, or any smooth homogeneous surface, the calm belts, the rain belt, and the dry zones would extend without interruption entirely around the globe with the same regularity which is observed upon the oceans, and everywhere the same climatic conditions would exist on the same parallels of latitude. But on account of the influence of mountain ranges in deflecting the currents of the general circulation of the atmosphere great diversities of climate are found in different places on the same parallels.

It is thus on account of the topographic features of the continent, of the elevation and distribution of the mountain masses, that this arid land stretches in its general longitudinal direction instead of crossing the continent from west to east. Thus a full knowledge of the climate, and especially of the distribution of the rainfall not only in restricted localities but on the continent as a whole, is largely dependent upon a correct understanding and representation of the general topographic features, for it is these which both in a broad and also in a local way are primary factors among causes which make a country inhabitable and prosperous. Therefore, in this discussion of the hydrography of the arid lands, considerable space has been devoted to descriptions of topographic features and local peculiarities, in order that all possible light might be cast upon seeming anomalies.

HYDROGRAPHIC DATA.

Upon navigable rivers in the United States measurements and other examinations have been and are being made under the direction of the Chief of Engineers, U. S. Army, all efforts being directed toward an improvement of navigation, the physical and geological problems receiving less consideration. The character of the work is thus entirely different in scope and results from that undertaken by the Geological Survey; but many of the details, especially of measurements of floods, are of great value in the physical investigations carried on by the latter.

Beyond the field work of these two organizations of the General Government a large amount of hydrographic information has been collected at various times, and many measurements of flowing waters have been made by engineers in the employ of the States, municipalities, or corporations, and this data, much of which is unpublished, would, if all could be brought together, prove of great value. For example, the state engineering department of California has published data concerning the principal rivers of that state; the State engineers of Colorado have done a similar work on a smaller scale; the northern transcontinental survey also acquired many facts in Montana, Idaho, and adjoining States, and various exploring parties in all parts of the West have occasionally gauged streams and estimated discharges. The results of many of these measurements will be discussed later, in connection with descriptions of the various drainage basins.

The data collected from the sources just mentioned have been reduced to common units and arranged in form convenient for making comparisons, and as many results as can be obtained at this time have been thus brought together and republished in condensed form, with brief explanatory remarks. On the index map, Pl. LVIII, is shown the location of the principal drainage basins and the points at which the gaugings referred to in subsequent discussions were made.

During the year ending June 30, 1891, the Geological Survey received reports of the daily gauge height of many rivers of the West at points where gauging stations were previously established and discharge measurements made, and by this means the daily mean discharge at these several localities has been computed. These discharges afford a comparison with those obtained in previous years, and add greatly to the knowledge of the régime of these rivers. On subsequent pages the results of these computations, are given and on the accompanying plates the daily discharges for various stations are shown in graphic form. In connection with these, the data obtained from other sources have been introduced in geographical order.

DEFICIENCY OF WATER.

As to the practical bearings of these investigations it is sufficient to state that the area cultivated by irrigation in most drainage basins of the arid region is far larger than can be covered by the present water

supply, and each year the crops upon thousands of acres in various localities are injured or lost for lack of water at critical times. Besides this, there is a still greater acreage which can be reached by canal systems constructed or projected, including bodies of land as good as that now under cultivation and sometimes better, and in addition to these irrigated and irrigable lands there are in many parts of the arid region plains of arable land so vast that by no possibility can they ever be brought under irrigation. Thus as a whole the water supply can never be conserved too carefully, for there will always be fertile lands in excess of that supply.

With greater economy in the use of the present available water, a greater acreage each year can be successfully cultivated, but there will soon be a limit to the slow growth in this manner, for under ordinary circumstances it will happen that each year the amount of land successfully cultivated must fluctuate with the variations of water in the rivers; in years of large flow, the farmers will be prosperous, while, when droughts occur, a certain portion of the crops will be lost, if dependence is placed wholly upon the unregulated flow of the streams.

There are, however, as above mentioned, floods at irregular intervals bringing with them great quantities of water. It has occurred to thousands of individuals, on seeing on the one hand rich soil lying barren for lack of moisture and on the other destructive torrents, that by the proper conservation of these floods, by saving the waste waters in times of need, not only will the farmer be able to raise all his crops, but, in addition, great tracts of land now unproductive may be made sources of wealth to the community. It is only a question of time, it may be five years or fifty, when dams will be built to hold back this flood water, but the building of these will proceed slowly, for the conditions of success in such enterprises are entirely different from those pertaining to other irrigation projects.

There can be nothing of an experimental, temporary nature in designing storage works as there is in the case of diversion dams in rivers or of canal works. They can not be essentially changed or modified, and the washing away of one is not a matter of loss to the owners alone, as with canal headworks, but may involve the destruction of lives and property in distant localities. There are in the history of the last few years too many examples of this to call for further comment, and it is now generally recognized that not only must large sums of money be expended to construct these storage dams securely and permanently, but that a rigid inspection must be made by competent authorities.

Before any steps can be made toward the construction of such dams their builders must have ample and accurate information on which to base conclusive estimates as to the success of the enterprise. They must know, among other things, not only that the reservoir thus created will be of ample size, but that it has a reliable and sufficient water supply and that it will not be exposed to floods which can in any combination of circumstances tear it down.

In most of the drainage basins where the typography is such that the floods are sudden and of short duration, the actual amount of water discharged by rivers is in general greatly overestimated, and before any notable reservoir can be made the question arises as to whether there is enough water to fill it. Our information on this point, though it is one which deeply concerns these basins, is unfortunately meager. The importance of the case, however, justifies a careful examination of the known facts and their publication. It is hoped that a discussion of these data may serve, perhaps, as a foundation for a protracted examination in the future, when there is a more general appreciation of the fact that the permanent agricultural growth of this land must await the completion of a long series of such careful observations.

INCREASE OF WATER DUTY.

Every improvement which tends to greater economy in the use of the present water supply adds ultimately to the acreage which can be cultivated. Water is wastefully used in many instances, there being a lack of economy in the methods of conducting it to the fields and in applying it to the soil. There are no inducements toward economy and no unity of action by which economy can be enforced. Each canal company or association of canal-owners is content if sufficient water can be procured to cover its own claim, regardless of the possible rights of others. In a case where a company sells water there is rarely any attempt to enforce economy, or inducement held out to users of the water to save it or make it cover the greatest possible extent of land.

The common method of irrigating, especially when used on alfalfa and other forage crops and the small grains, is that of flooding, the water being caused to spread over the ground to an average depth of 2 to 3 inches or more. For other crops it is allowed to run along the furrows until the ground between each two furrows is saturated. For fruit trees or vineyards small trenches are plowed or dug leading from the lateral or small distributing ditch to each tree, the water being allowed to settle around the roots of the tree or vine.

Experience, however, is gradually teaching the farmer that better success can often be obtained with small amounts of water intelligently applied than with greater, and also that as irrigation extends less and less water is required on many soils, this being due perhaps to a general raising of the moisture in the ground or to a clogging of many points of escape. The result is that less water per acre is used and needed on the older lands than on the newer.

The area of land which can be irrigated by a given quantity of water is known for convenience as "the duty of the water." The unit in general use is the second-foot, or cubic foot per second, that is, a quantity of water equaling a stream 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot every second. From what has been said, it is obvious that the duty of water varies much, being greater on

old land than on new, and differing with the soils, as well as the skill and customs of the irrigators.

There are unfortunately no reliable or detailed measurements to show what the actual water duty is. A number of estimates have been made, none of which agree very closely. Powell[1] in his first book on the arid lands gave the average water duty in Utah, under good conditions, as reaching 100 acres to the second-foot. The average of a number of estimates of the amount actually used in Utah, under ordinary conditions and with little skill, was a trifle over two-thirds of this, or about 70 acres. In Wyoming and Idaho, where water was plentiful, land new, and irrigators unskilled, the duty was from 30 to 40 acres only. In Arizona and California calculations have been made that with care a second-foot can be made to cover 120 acres, or even more.

Another way of expressing the duty of water is in acre-feet—the quantity of water covering an acre 1 foot in depth—1 acre-foot thus being equivalent to 43,560 cubic feet. Thus a water duty of $1\frac{1}{2}$ acre-feet to the acre means that during the course of the irrigating season a quantity of water has been applied equal to a depth of $1\frac{1}{2}$ feet over the ground. Some such arbitrarily selected duty of water is taken in all discussions as to the utility of water-storage systems, in order to compute the relation between their capacity and efficiency.

It is evident that the duty of water will depend considerably upon the point at which water is measured. If, for example, water is measured when entering the field where used, a higher duty will result than is found when the water is measured at the head of the canal, for in the latter case a certain quantity is lost by seepage and evaporation before it can reach the land on which it is to be employed. Further, a still less duty is shown if the water is measured in the river before entering the canals, unless, as is frequently the case, a certain amount returns to the river by seepage, to be used over again by land below.

WATER STORAGE.

Water storage for purposes of agriculture is comparatively new to the Arid Regions of the West, and is practiced to a small extent relatively to the whole area needing it. In order then to obtain certain definite ideas concerning relative costs and values, it would be useful to compare this with water storage as practiced in many parts of the country for municipal supply. The greater number of cities of the United States own or control reservoirs for holding the water, either for purposes of clearing it or as a safeguard against accident.

One of the most important conceptions in connection with a comparison between municipal supply and that for agricultural purposes is the vastly greater quantities needed and the less value of water for the latter use. The amount which is used in irrigation is so much greater than

[1] Reports on the lands of the Arid Region of the United States, J. W. Powell, 2d ed., 1879, p. 84.

that needed by a city that it is difficult at first to comprehend the difference, and many persons have been disappointed in their attempts at storage by failing to take into account in their original estimates the losses and waste which necessarily take place in connection with the free use of the water for agriculture.

If it is assumed that 100 gallons per day is ample for each inhabitant of a small city, and, on the other hand, 1 acre foot is sufficient to irrigate 1 acre, a comparison can be made between the relative values of these two water supplies. One acre-foot equals 43,560 cubic feet, or about 326,000 gallons. Neglecting in both cases losses from evaporation, this 326,000 gallons on the above basis would supply 9 persons with water for a year. In other words, 1 acre-foot of stored water would either irrigate 1 acre, or, if carried to a city, would supply 9 persons, and 1,000 acre-feet would water 1,000 acres or supply a city of 9,000 inhabitants; but now if we compare the relative value of the property concerned the difference is at once apparent. The value of the irrigated land, at a liberal estimate, can not ordinarily be placed over $50 per acre, while the valuation of city property, taking the average for the United States for this number of inhabitants, would be about $5,000,000; that is to say, the property which must bear the expense of storing water is in the case of agriculture $50,000, and in the case of the city, needing the same amount, one hundred times as great, or $5,000,000. Taking these facts alone into consideration, it would seem that the city can afford to pay a vastly greater sum for storage, and can make use of opportunities for storage which are far too expensive for rural districts.

There are many minor considerations which modify the above comparison, but it is sufficient to demonstrate the general fact that for agricultural success water storage must be very cheap and of enormous capacity. The farmer can not afford to take the same chances of success or to repair injuries to the same extent that a city can, so that far greater caution, engineering skill, and foresight must be employed than in the case of our ordinary municipal supplies.

In preliminary discussions of water storage for purposes of irrigation one of the most important facts to be borne in mind is that success does not depend directly upon the quantity, distribution, or fluctuations of the rainfall. A full and exact knowledge of this subject is of course important and valuable as affording collateral data, but since the amount of water flowing in the stream is remotely affected by variations in rainfall, these data can not be depended upon primarily. Comparing the rainfall and the snowfall, it may be said that precipitation in the form of snow is of greater importance than the rain to irrigation schemes, for the useful floods of most rivers are due rather to melting snow than to rainstorms. The time of the year at which snow falls, whether early or late in winter, and the temperature of early spring, have great influence upon the quantity and intensity of floods. This is seen on the various plates of discharge referred to in the following pages. By comparing

one with another it will be noted that melting snow furnishes the water necessary for great spring floods, this quantity being increased or diminished day by day as the temperature rises or falls, so much so that in cases where the river gauging station is near the headwaters of a stream the diagram of river discharges to a certain extent would serve as the diagram of fluctuations of temperature.

Pl. LIX has been prepared to show, in condensed and generalized form, the lack of coincidence between the average discharge and the mean annual rainfall for each month of the year in four widely separated basins. In each of the four diagrams on this plate the dotted line represents the mean annual rainfall, and the solid line the average height or discharge of the river. The months of the year are shown by vertical spaces, and horizontal lines give the height of water or quantity of discharge and also the depth of rain.

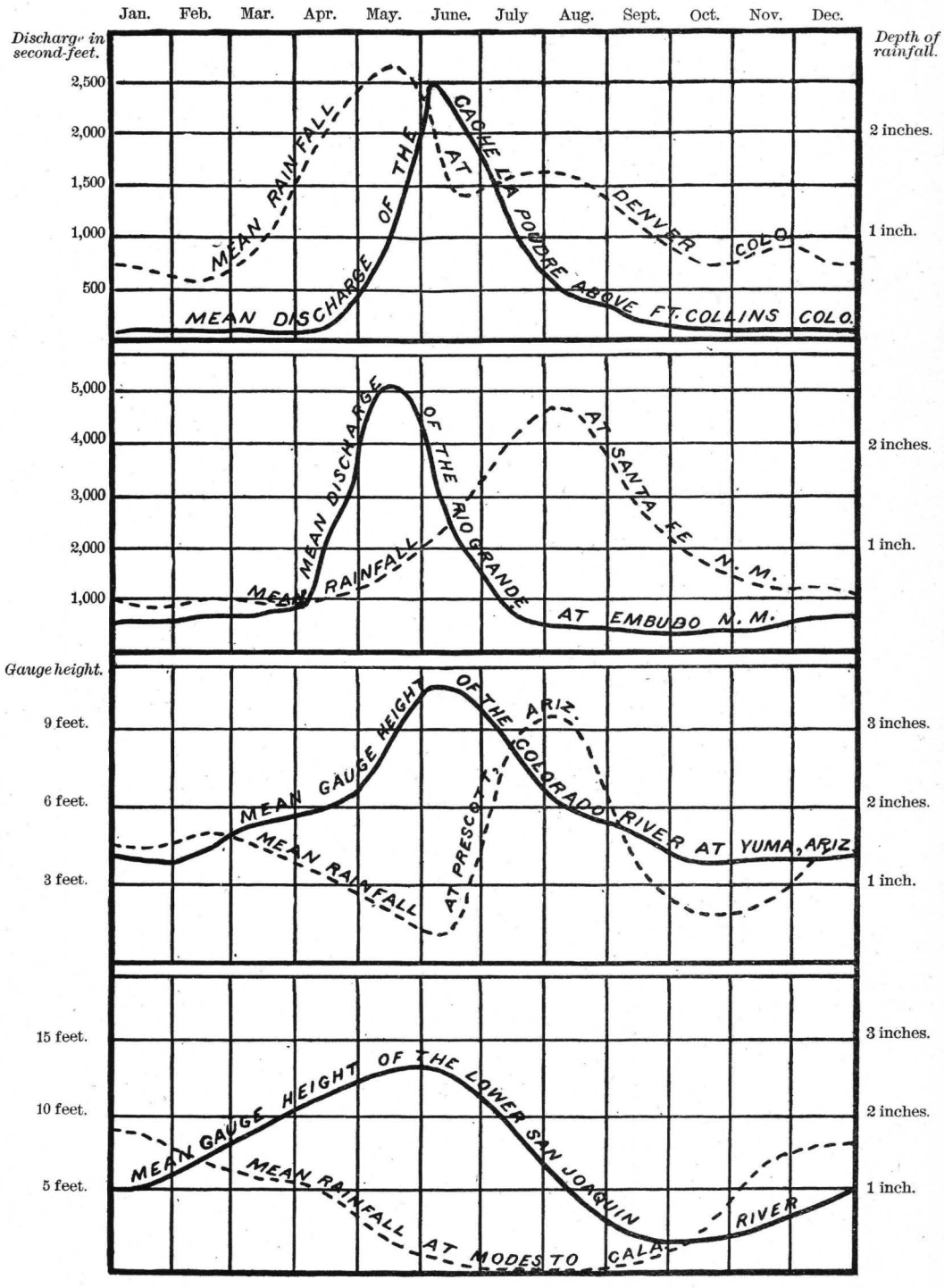
In the upper diagram the mean discharge of the Cache la Poudre, above Fort Collins, for all years during which measurements have been made, is compared with the mean rainfall at Denver, Colorado, the assumption being made that rainfall at this station follows as a general rule the fluctuations within the basin of the Cache la Poudre. It will be seen that the maximum amount of rainfall is in May, while the maximum river flow is in the early part of June. The rainfall in June decreases, and then increases slightly in July and August.

On the second diagram the mean discharge of the Rio Grande at Embudo, New Mexico, is compared with the mean annual rainfall at Santa Fe, although it is probable that the rainfall in the upper part of this basin has a habit intermediate between that at Denver and at Santa Fe. The river at this point reaches its maximum discharge earlier in the year than does the Cache la Poudre, and the rainfall, on the other hand, has its maximum in the early part of August.

In the third diagram the mean gauge height of the Colorado River at Yuma, Arizona, is shown in connection with the rainfall at Prescott, Arizona. The maximum river height is reached in the early part of June at the time of minimum rainfall in the basin, the maximum rainfall occurring about two months later, and usually causing little if any fluctuation in the height of the river.

The lowest diagram on the plate shows the average height of the lower San Joaquin River in conjunction with the mean rainfall at Modesto, California. Here the maximum discharge occurs at about the same time as that of Cache la Poudre Creek and of the Colorado River, while the maximum rainfall is about the first of January.

These four dotted lines of rainfall typify fairly well the distribution of rainfall in the arid region; on the east the maximum occurring in the summer, on the south the period of minimum rain occurring in May and June, and followed by heavy rain in July and August, at the time of the greatest droughts in California. The rivers, however, excepting in the case of those depending wholly upon local storms, have their regular spring floods independent of the distribution of rain.



AVERAGE MONTHLY RIVER FLOW AND RAINFALL.

RELATIVE AMOUNT OF FLOOD WATERS.

In any discussion of hydrographic data, and especially its bearing on water conservation, one of the facts of primary importance is the relation between the amount of water carried in floods and in low stages; in short, whether the river discharges in flood an amount greater by many times than that discharged during the remainder of the year, or whether the increase is comparatively small. For instance, taking a practical illustration, along most of the rivers of the West, as previously stated, is an area of land greater than can be irrigated during the latter part of the crop season, and with an unregulated flow the area of land to be cultivated is governed by the low-water discharge of the river; and furthermore, all of this low water has in most cases been long ago appropriated. To bring more land under cultivation it is essential, after practicing economy of the waters now available, to store some of the flood waters, and hold these until later in the season for use in time of need.

The question of primary importance, then, is the amount of flood water relative to the ordinary discharge—whether it is sufficiently great to insure the success of storage works, and in time repay the cost of their construction by permanence of supply; or, on the other hand, whether the floods are so small in amount or irregular in occurrence as to be of doubtful value. It is really upon the flood waters that the greatest dependence for storage must be placed, for in many parts of the country the low-water discharge being appropriated and used during the most important season of the year, little reliance can be had upon this low-water flow during the remaining seasons.

After the irrigating season is over, the amount of water flowing in the streams in the interval between that time and the beginning of the floods is usually small. In some parts of the country, especially in the south, the irrigating season extends practically throughout the year, and the water is used on the small grains, trees, and gardens, or for saturating the ground for the purpose of raising forage plants, when not otherwise needed. In many places, too, where the irrigating season is short, and extends only from four to six months, the water supply after the end of the irrigating season and between that time and the beginning of the floods is so small, or of such an uncertain character, as to be of doubtful value for storage purposes, the evaporation in many cases being sufficient to prevent an accumulation of water in any large storage basin. In short, then, it is to the amount and certainty of the flood waters that attention must be given in considerations of storage.

The relation between the quantity in flood and in low water is shown graphically upon the discharge diagrams or hydrographs of the various rivers, and it is instructive to compare these. The most conspicuous feature is the difference in character between the floods in rivers which receive their main water supply from melting snow and in rivers which depend wholly or in great part upon the rain fall. In the first case, as

shown by the hydrographs in the Upper Missouri basin, the flood is seen to consist of a gradual continuous rise, and to increase in quantity until a maximum is reached, followed by an almost equally continuous decline. In the latter case, for example in the Gila basin, the floods are of an exceedingly irregular character, coming at any stage of the river and passing off rapidly, the river falling immediately again to low stage.

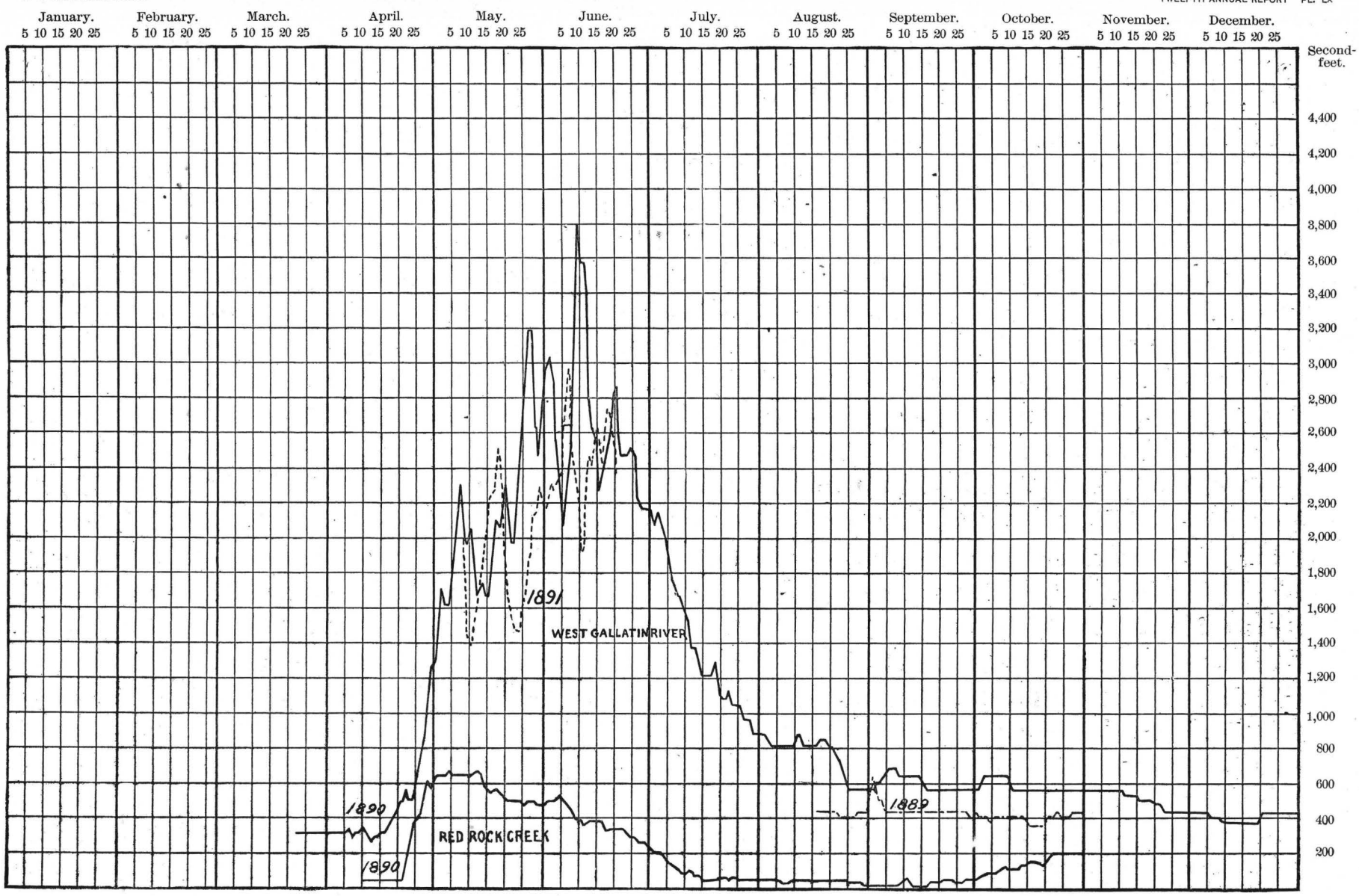
The following table is given in order to exhibit in concise manner the relation between the mean discharge and the quantity of water carried in floods during the years in which measurements have been made. In the column at the right is the quotient, obtained by dividing the maximum discharge by the average quantity flowing in the stream. For example, in the case of the first river on the list, the West Gallatin, the maximum flood reached a quantity four and five-tenths times the average annual discharge:

River.	Flood increase.	River.	Flood increase.
West Gallatin	4·5	Bear at Battle Creek	3·9
Madison	3·2	Bear at Collinston	3·2
Missouri	3·6	Ogden	3·4
Sun	5·9	Weber	5·4
Yellowstone	4·4	Provo	2·3
Cache la Poudre	1·8	Spanish Fork	6·6
Arkansas	5·3	Sevier	4·0
Rio Grande at Del Norte	4·7	Henry Fork of Snake	4·4
Rio Grande at Embudo	6·1	Falls River	3·7
Rio Grande at El Paso	11·1	Teton	4·3
Gila	12·6	Snake at Eagle Rock	5·3
Salt	100·0	Owyhee	6·8
East Carson	4·4	Malheur	6·3
West Carson	6·2	Weiser	6·8

On looking down the list, it will be seen at a glance that on most of the rivers the flood has been from four to five times the volume of the average flow for the year. The most notable exceptions, however, are in the case of the Rio Grande at El Paso, the Gila, and the Salt, where the measured floods were over eleven or twelve times the average flow, and on the Salt River one hundred times, this latter case being that of the great flood of February, 1891. It is probable that if the measurements were continued for a period sufficiently long a far greater flood increase would be noted on some of the other streams. The three instances just noted, however, stand out clearly as illustrations of the wide fluctuations of the rain-fed rivers of the south.

TIME OF FLOODS.

The fact of secondary importance to that of the quantity of the floods for storage is the time at which they occur and the relation between the duration of high water and the time of growing crops. On most of the rivers of the West floods occur in the spring and diminish in early summer. On some rivers they occur earlier and on others later, depending largely upon the altitude of the catchment basin. There is usually ample water at the time the crops are planted,



DAILY DISCHARGE OF THE WEST GALLATIN RIVER AND OF RED ROCK CREEK, MONTANA.

so that there is no trouble in giving a first watering to all the land cultivated, but toward the end of the season, when the crops are maturing, the supply in the river diminishes, and often a portion of the crop is lost from lack of water at the critical time.

As a rule it may be said that the later the floods occur the better for the success of crops and of storage schemes, for in the latter case the shorter is the time during which the water is held and the less will be the loss from evaporation. On the other hand, the earlier in the season the floods occur the less water will be available for crops and the greater will be the loss by evaporation.

The time is fast approaching when a large part of the flood water, excepting perhaps in a few great rivers like those of the Colorado drainage, will be held by storage from the early months of the year to July and August. In fact, much of this flood water is now needed, for the area of tilled land in many parts of the arid region is too great for the present supply in ordinary seasons, and unless some unusual storms occur, valuable areas of crops are lost. Besides these areas tilled, there are the tracts of fertile land so vast that the amount under cultivation shrinks into insignificance.

Comparing, therefore, the rivers in their adaptability for supplying storage reservoirs as regards the time of flood, it will be seen that the most favorable instances are afforded by the streams of the northern basins bounded by lofty mountains, as, for example, those of the upper Missouri and Arkansas basins, while, on the other hand, the streams draining the basins of less altitude are less favorable from this standpoint.

In strong contrast to the rivers flowing into the Missouri in regard to the time of flood are those of southern or lower basins, as, for example, the Gila and Salt, or the Malheur and Owyhee in Oregon. As will be seen at a glance at the diagrams for the Gila basin, the time of floods is very uncertain, and while, as a general rule, the floods are more apt to occur in certain months, yet they cannot be relied upon as in the case of most northern rivers. Water storage in these rain-fed rivers, therefore, becomes more a matter of chance, and it is not possible to estimate within as narrow limits as in the case of the snow-fed streams the probable amount of water to be obtained each year.

A comparison with the habits of the rivers outside of the arid region, as, for example, the Ohio or the Upper Mississippi, shows strongly the difference in the effect of the rainstorms, and illustrates the influence of topography and climate upon the discharge of a stream. On one extreme, that of the rivers in Arizona, the rain falls upon hard earth or barren rocks and slopes, which allow the water to flow off immediately. There is little or no vegetation to check or retain the water, and it rushes down the canyons and unites in the rivers, forming sudden floods. On the other extreme are the rivers of the humid region, rising in forested areas, where erosion has to a great extent cut down the higher moun-

tains into rolling hills now covered with vegetation. The rain is held for a time, at least, by the soil, and slowly finds its way to the river, and the flood rises gently and diminishes so gradually that the effect of a heavy rain may be felt for days or weeks.

INTENSITY OF FLOODS.

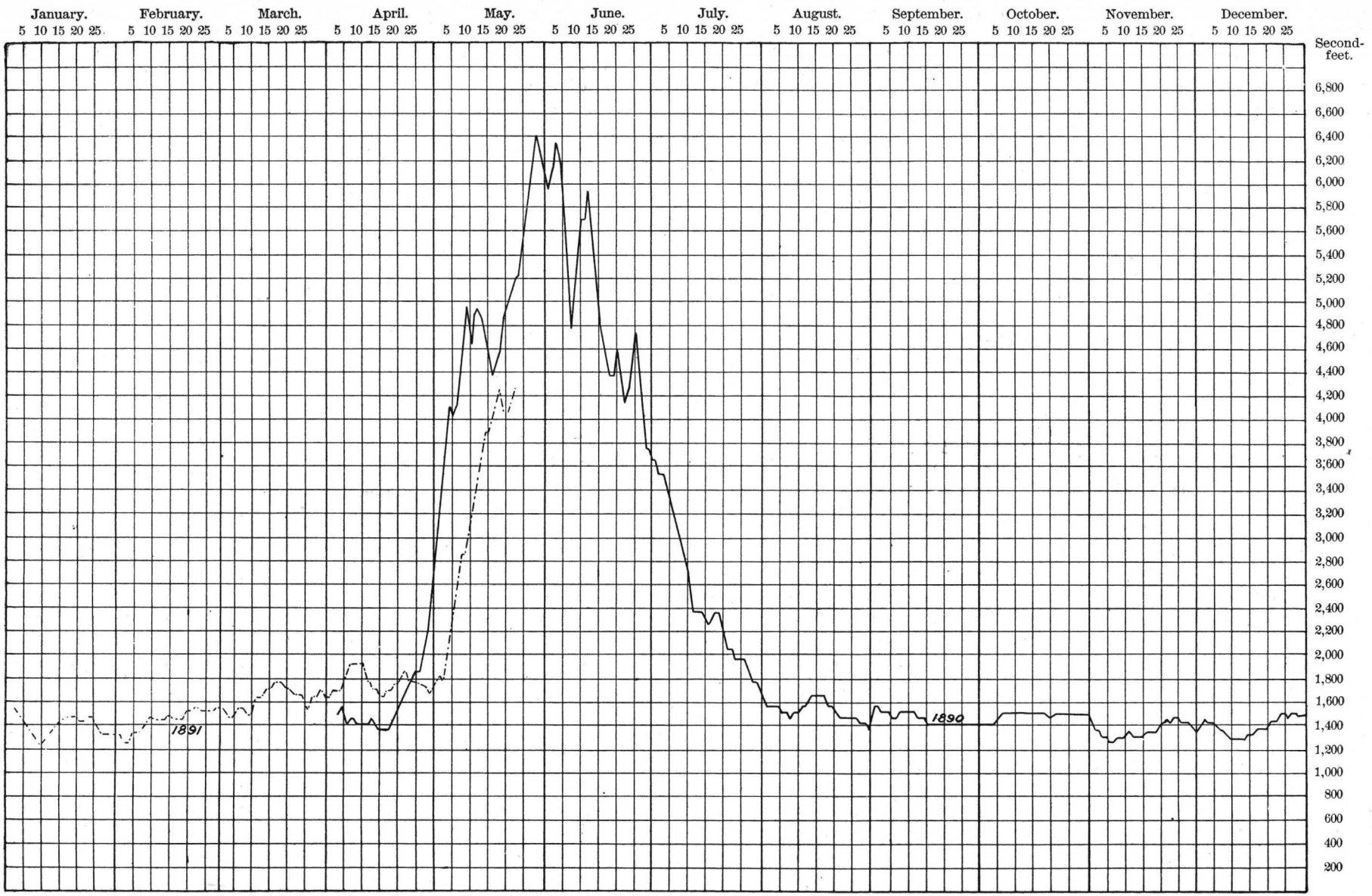
The intesity of floods—that is, the relation between the quantity of water and the time during which the flood occurs—is involved in the two points above mentioned. It follows as a matter of course that on those rivers on which floods occur suddenly the rate of increase of water will be greatest and its destructive effects most apparent. In proportioning storage works and canals for diversion of flood waters, intensity, as well as quantity of flood, plays an important part, for, on the one hand, structures must be designed to withstand the sudden impetus of floods, and, on the other, diversion channels or waste weirs must be made of extraordinary size to provide for the passage of enormous quantities of water in a few hours. It is apparent that structures to withstand the onset of floods, shown diagrammatically on many of the following plates, must be proportioned and executed in a manner which, to a person seeing only the low water, must seem extravagant.

One fact particularly characteristic of the regions of intense floods is that river channels in size and general appearance bear very little apparent relation to the average daily discharge of streams which flow in them. In humid regions from inspection of a river channel an engineer can, in general, form a valid opinion as to the average amount of water which flows in it and the probable extent of the floods, but in the arid region, especially in the basins of lost rivers, the size of channel is entirely out of proportion to the amount of water which ordinarily flows in it, due to the extremely erratic conditions which prevail. For years or decades there may be a mere rill or at places no water in sight in the natural drainage lines, when, by a sudden storm or local "cloud-burst," vast quantities of water will be precipitated, carving in a few hours a channel of capacity for a navigable river. Thus it is that long observations are required to determine what may be the average flow of streams of this class and the quantity of water, if any, which can be depended upon from year to year.

RAINFALL AND RIVER FLOW.

The amount of water flowing in the river each day does not depend directly upon the rainfall of the preceding days, but upon many modifying conditions, and a storm, although widespread and reported at all stations, may not show itself by greatly increasing the amount of water passing any given point on the river. On the other hand, a storm so local that it is not reported by observers may cause a decided increase in the amount of water available, or even a destructive flood.

In examining the depth of run-off—that is, the quantity of water dis-



DAILY DISCHARGE OF THE MADISON RIVER AT RED BLUFF, MONTANA.

charged equivalent to a certain depth over any given basin—it will usually be seen that the larger the area the less is the relative amount discharged, and this is especially the case in those parts of the country where evaporation is notably greater than rainfall. The rivers increase in size to a certain point as they flow down the broad sandy channels, and then decrease, excepting in times of unusual floods. Even in those parts of the country where rainfall is great and evaporation of less importance this general law seems to hold good, namely, that the rivers do not increase in volume in direct proportion to the area drained, but that the ratio of discharge to area is, in a general way, decreasing from the headwaters toward the outlet. This fact must be borne in mind in these comparisons, and due allowance made for the point on the river's course at which measurements are made.

POINTS OF MAXIMUM UTILITY.

There is a general similarity among the rivers under discussion in that they rise in great mountains and flow as torrents through narrow valleys, gorges, and canyons, entering finally upon plains of vast extent and with nearly level surfaces. On account of the great altitude the sources of the river are usually in a cold and an inhospitable region where great bodies of snow accumulate during the winter, and the frosts, which occur perhaps every month of the summer, render agriculture entirely out of the question. Below this upper region are often valleys which, though still of considerable altitude, are suitable for grazing, and in which a few of the hardier crops can be raised. Here also is found the most valuable timber, and the climate, though rigorous, is favorable for habitation, so that settlers, if forced from the lower regions from lack of water or other causes, find here place for homes and opportunities for earning a livelihood. These valleys also are most favorably situated for storage reservoirs, many of glacial origin seeming to be thus designed by nature.

Farther down, beyond the canyons, stretch the wide, open valleys, and out beyond these the rich alluvial soil of the plains. It is here at these lower altitudes with a warm, sunny climate that agriculture is most successful, and here a given amount of water properly used will raise crops of the greatest value. In these places, near the foot of mountains, the water flows in well defined channels with high confining banks. Farther out upon the plains, however, the character of the river and its channel change. The silt deposited by the diminished velocity chokes the bed of the river, and the water spreads over a great expanse of sands, dividing and subdividing into numerous shallow streams whose united width may be more than a mile, but whose depth at ordinary stages is scarcely over a foot. In these sands enormous quantities of water disappear by seepage and evaporation, until finally, in seasons of low water, the channel becomes almost if not completely dry. The conveyance, therefore, of water through this channel to land far out

on the plain involves a wasting of the greater portion in order that a small part may reach the desired locality.

From the above considerations alone it will be seen that the point from which water can be used to the greatest advantage is that at which the stream begins to change in character, to lose its well defined channel and sink in the sand of the bed, for at this point the river is carrying its maximum amount of water. The land here is usually as fertile as any on the plains, while the opportunities for canal building in the gently sloping edges of the plains are most favorable both for taking out the water at the smallest cost and for covering the largest extent of land.

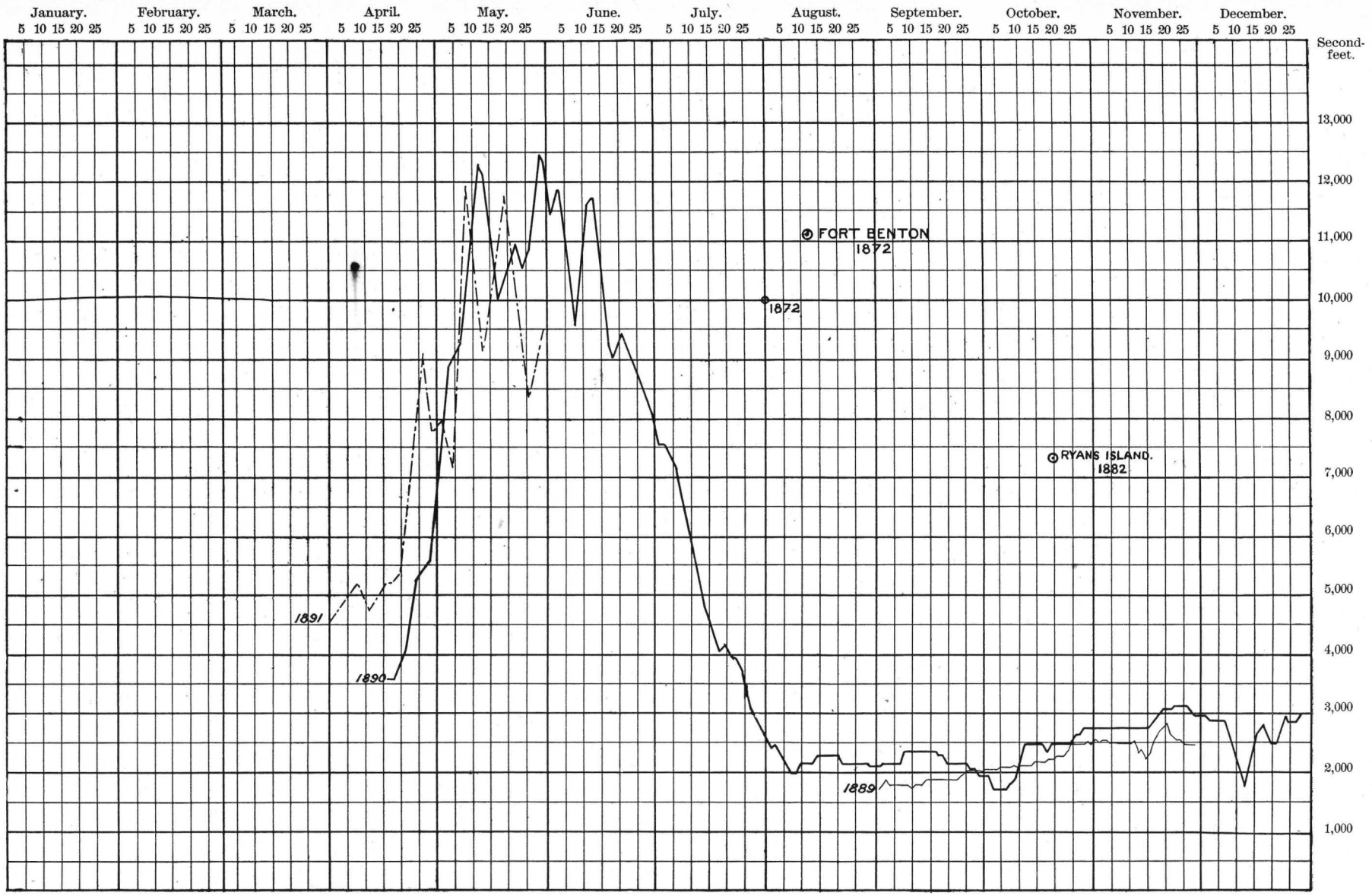
If the water is diverted far above this point it is used with less economy and, on account of the altitude, the crops raised are of less value, while below this point on the open plain the wastage of water required for its conveyance in sandy channels results in loss, which is in general proportional to the distance to be covered. The chief interest, therefore, centers on the examination and measurement of the streams as they leave the canyons, and, secondary to this, on similar work in the upper valleys, where the great storage sites are found.

CLASSIFICATION OF DRAINAGE BASINS.

Hydrographic basins are divided by Powell into three classes, viz: Headwater districts, river trunk districts, and lost stream districts. The headwater districts include the sources of the river in the high mountains, including thus the torrential portion, and also the land used for farming immediately adjoining the river where it leaves the mountains. In a large river system this is the most important and most interesting portion of its course, from the standpoint of irrigation. Each large perennial tributary of the river thus becomes a district by itself, and can be considered independently in any discussion of the hydrography of the region.

The river trunk district includes the great area through which the main stream flows, but from which the stream receives little or no water. This vast area, in fact, instead of contributing to the flow, leads only to its dissipation, for, in passing through the wide valleys or plains which constitute this portion, much of the water is lost by seepage and evaporation. The trunk stream district can not be considered by itself, but must be governed largely by the conditions existing in all of the headwater districts, and it is only after the problems connected with the headwaters have been satisfactorily settled that the main stream can be treated in the best manner.

The third class of basin, which in the west is one of the most important and perhaps most easily controlled, is that of the lost river. In this the circulation of waters is complete within itself, that is, the water coming from the atmosphere in the form of rain or snow gathers on the mountain slopes and flows in torrents to the plains, where it again dis-



DAILY DISCHARGE OF THE MISSOURI RIVER AT CRAIG, MONTANA.

appears, finally returning to the air by evaporation. Thus each basin can be considered independently, since the proper utilization of its waters does not effect any other basin except in the most remote manner.

All these classes of basins are represented in many of the great river systems, in the Arkansas, the Rio Grande, the Gila, and others, each embracing within its scope many minor basins, some tributary to the river and others entirely lost. Each of these subbasins constitutes a unit, and, while the lost river basin may be considered as an independent unit, the others are factors, upon the proper application of which depends the final solution of the problem as to the best manner of utilizing the water supply. Each one must be carefully studied in turn, its limits clearly defined, and all the characteristics known. Within each of these basins the problems of water supply are to be studied for the whole area, as each part is intimately connected with every other, and whatever affects one locality influences the rest. A storage work built on a minor tributary, since it tends to diminish the water at one time and increase it at another, is of importance to the majority of inhabitants of that particular basin. Considering all the subbasins, the influence of one upon the other varies with their character. For example, the headwater basins, as a whole, must be considered in connection with works of improvement on the trunk-stream basins, while, on the contrary, the lost-stream basins, being units which stand entirely independent of the rest of the country, need less consideration, excepting as they may influence the wealth and population in a general way.

The headwater and lost-stream districts are easily recognized, being plainly marked by nature and separated from each other by mountain ranges or lower divides shown by the topographic maps. The main-stream districts, however, are not so clearly delimited, for the lines bounding them are somewhat arbitrary in their nature, so that careful study must be given to the conditions which govern them.

The lost rivers, though found scattered throughout the west in nearly all of the large drainage basins, are most numerous and in fact are distinctive of the great interior basin. Within this area not a drop of water escapes to the sea; the rain descending upon the mountain flows for a time in streams, then finally passes into the air again, is carried by the wind, which perhaps striking against some great escarpment is deflected upward and the moisture again precipitated enters upon a new round of river life, this round being repeated again and again, the individual molecule of water perhaps passing through innumerable changes of condition, until finally it travels out of the basin to be replaced by moisture which is continually entering, mainly from the Pacific side. In this round of existence a portion of the moisture is caught and held for an indefinite time in the sands or gravels of the river bottoms which are saturated by percolation from the running streams. These layers of porous material form reservoirs from which wells and springs are supplied, the amount of water delivered by these wells and

springs being in a general way proportional to the extent and permeability of the sands and gravels.

HUMIDITY AND IRRIGATION.

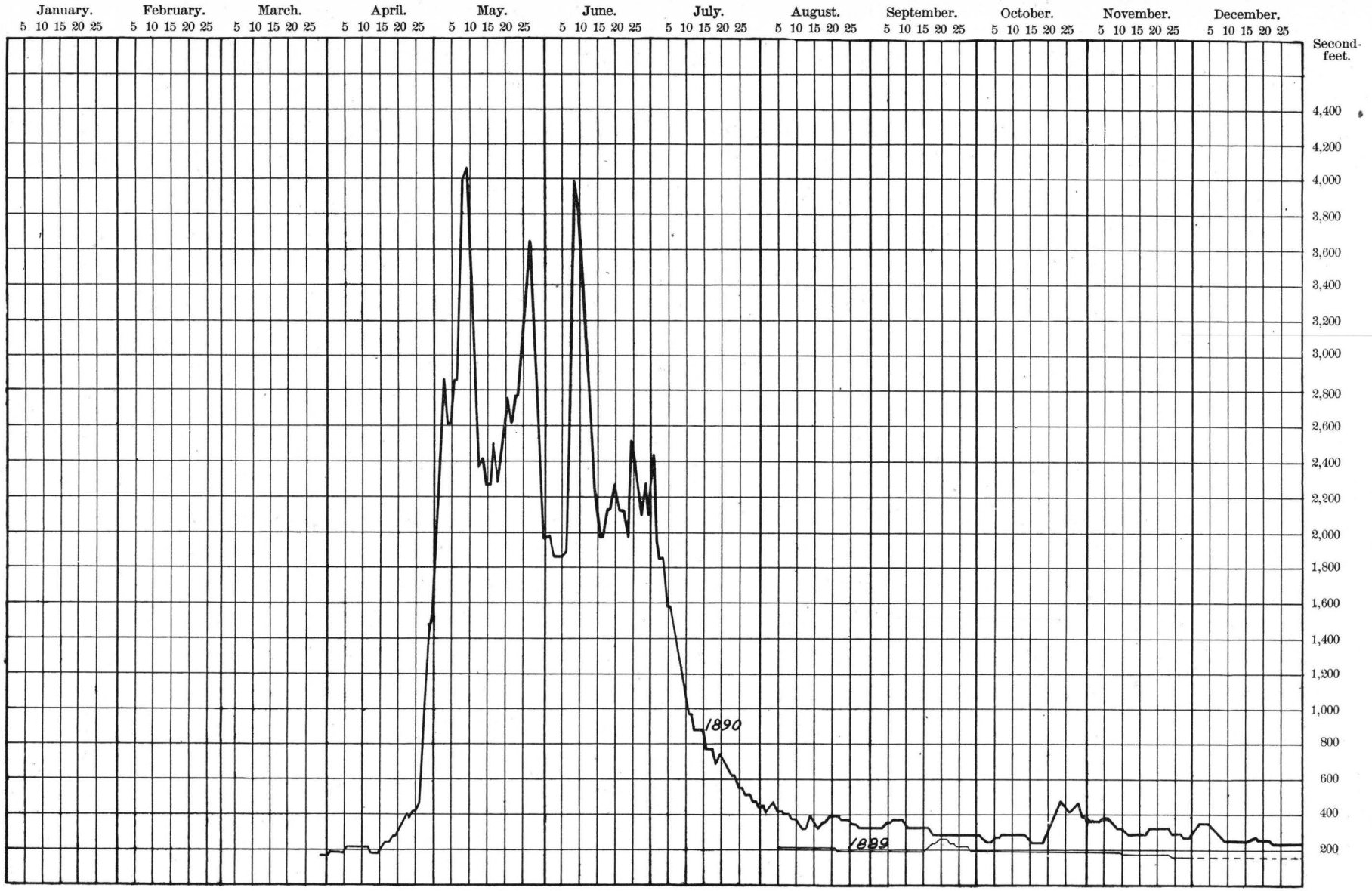
There is a popular belief that by spreading the water on the surface of the ground through irrigation the rainfall is increased by the addition of this water to the air through evaporation. There is no question that evaporation from the soil, especially from large tracts of cultivated land, must tend to lower the temperature near the surface and make the air far more humid, so that, as far as the feelings or sensations of man go, irrigation and consequent evaporation may tend to modify the temperature and make it better adapted for the comfort of man in the immediate vicinity of his operations. But, as for modifying the climate as a whole or bringing about such changes as will cause an increased rainfall, it is doubtful if these operations can have the slightest influence, especially if the relative bulk of water contained in the air is compared with that which is added to the ground and escapes by evaporation, to increase the amount and percentage of that already there.

In this connection it is interesting to note that inland lakes, with their vast bodies of water continually adding moisture to the air, increase the rainfall only to a slight extent, if any, around their borders. If these vast stretches of water do not have a decided and perceptible influence upon the rainfall of a country, it seems hardly possible that the smaller scattered areas of earth moistened by irrigation, in extent hardly 1 per cent of the entire area of any one county, can have any measurable influence upon the distribution of rain. The benefits to be derived are, however, not dependent upon increasing the humidity of the atmosphere as a whole, but only of that minute fraction of it which happens to be in immediate contact with the parts of the earth's surface utilized by man.

In short, in all water conservation, the first efforts should be directed toward making the largest use of the present available moisture, preventing losses by evaporation not only in the flowing water, but in the fields, by means of proper tilling and by sheltering the soil, and after that by increasing the available supply by storing floods, and by making use of other sources which require engineering skill and the investment of capital.

EVAPORATION OBSERVATIONS.

The evaporation observations described in the previous annual report have been continued in the same manner at Fort Douglas, the military post near Salt Lake City, Utah, at Fort Bliss, about a mile above El Paso, Tex., and also at Tempe, Ariz. The results obtained at these three places, together with those of previous years, are given in the following table.



DAILY DISCHARGE OF THE SUN RIVER 18 MILES ABOVE AUGUSTA, MONTANA.

Monthly totals of evaporation from large pans.

Months.	Fort Douglas, Utah.			Fort Bliss, Texas.			Tempe, Arizona.		
	1889.	1890.	1891.	1889.	1890.	1891.	1889.	1890.	1891.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	.....	.....	.....	.....	2·0	2·7	.....	.....	3·9
February	.....	.....	.....	.....	2·0	2·9	.....	.....	3·6
March	.....	.....	.....	.....	7·0	5·5	.....	.....	3·7
April	.....	3·7	3·2	.....	7·3	7·4	.....	5·8	4·2
May	.....	4·1	4·8	10·9	10·8	.....	.....	5·5	.....
June	.....	5·1	5·2	10·7	11·7	.....	.....	5·6	.....
July	.....	7·6	7·6	9·6	9·6	.....	13·7	6·6	.....
August	10·5	6·5	6·5	11·4	7·6	.....	14·1	11·5	.....
September	5·7	4·6	5·2	9·2	.....	.....	11·0	5·8	.....
October	4·9	2·1	2·5	6·8	.....	.....	6·4	5·2	.....
November	1·0	1·2	1·4	4·6	3·7	.....	4·4	4·6	.....
December	.....	.....	.....	2·9	3·0	.....	.....	3·2	.....

RESULTS OF STREAM MEASUREMENTS.

In the following pages the data for the various drainage basins are presented in geographical order, beginning at the headwaters of the Missiouri and continuing southward, taking in turn the Yellowstone, Platte, Arkansas, Rio Grande, and Colorado River basins, then the San Joaquin and Sacramento, the Interior Basin, and finally the Snake drainage. In each of these the order of arrangement is from the headwaters toward the mouth. In the case of the Rio Grande, Gila, and Salt Lake basins a description of the topography and its relation to the water supply is given with some degree of minuteness.

Descriptions of the gauging stations, and the results of the measurements in these basins up to June 1890, have been published in the Eleventh Annual Report of the Director of the U. S. Geological Survey, Part II, together with comments upon the local topography and climate. Since the time of that publication readings of gauge height have been maintained at the principal localities mentioned in that report, enabling computations to be made of the daily mean discharge at those places, thus affording opportunity for comparison of the amount of water flowing in the years 1889 and 1890.

The daily discharges of the streams measured in these basins are shown in diagrammatic form on the accompanying plates. The irregular lines indicate by their position the amount of water flowing on each day of the years given. The days are indicated by the spaces from left to right, in general each fifth day of the month being designated by a vertical line. The amount of water flowing on intermediate days can be ascertained by dividing these spaces by the eye into fifths. In the case of the months having thirty-one days the space from the twenty-fifth day to the first of the next month is proportionally wider than the others, and in the case of the last three days in February proportionally narrower.

The height of the curved line above the base indicates the average amount of water in cubic feet per second flowing on the particular day considered. Thus these diagrams show not only the amount of water on any given date, but also the amount relative to that of the whole year or series of years, and to that of other rivers. The average

monthly discharges, or at least such as have not been published in the previous report, are given in condensed form at the conclusion of this paper.

UPPER MISSOURI AND YELLOWSTONE.

On Pl. LX the discharges for the West Gallatin, southwest of Bozeman, Montana, and for Red Rock Creek, a tributary of the Jefferson, are given together, since the discharge of the latter is so small that it does not interfere with the clearness of the diagram. The discharges of the West Gallatin during September and October of 1889 are given, being indicated by a line of dots and dashes. This discharge, as can be seen, was nearly 200 second-feet less than in the succeeding year. The measurements in 1891, beginning in the early part of May, show a less discharge than that of 1890.

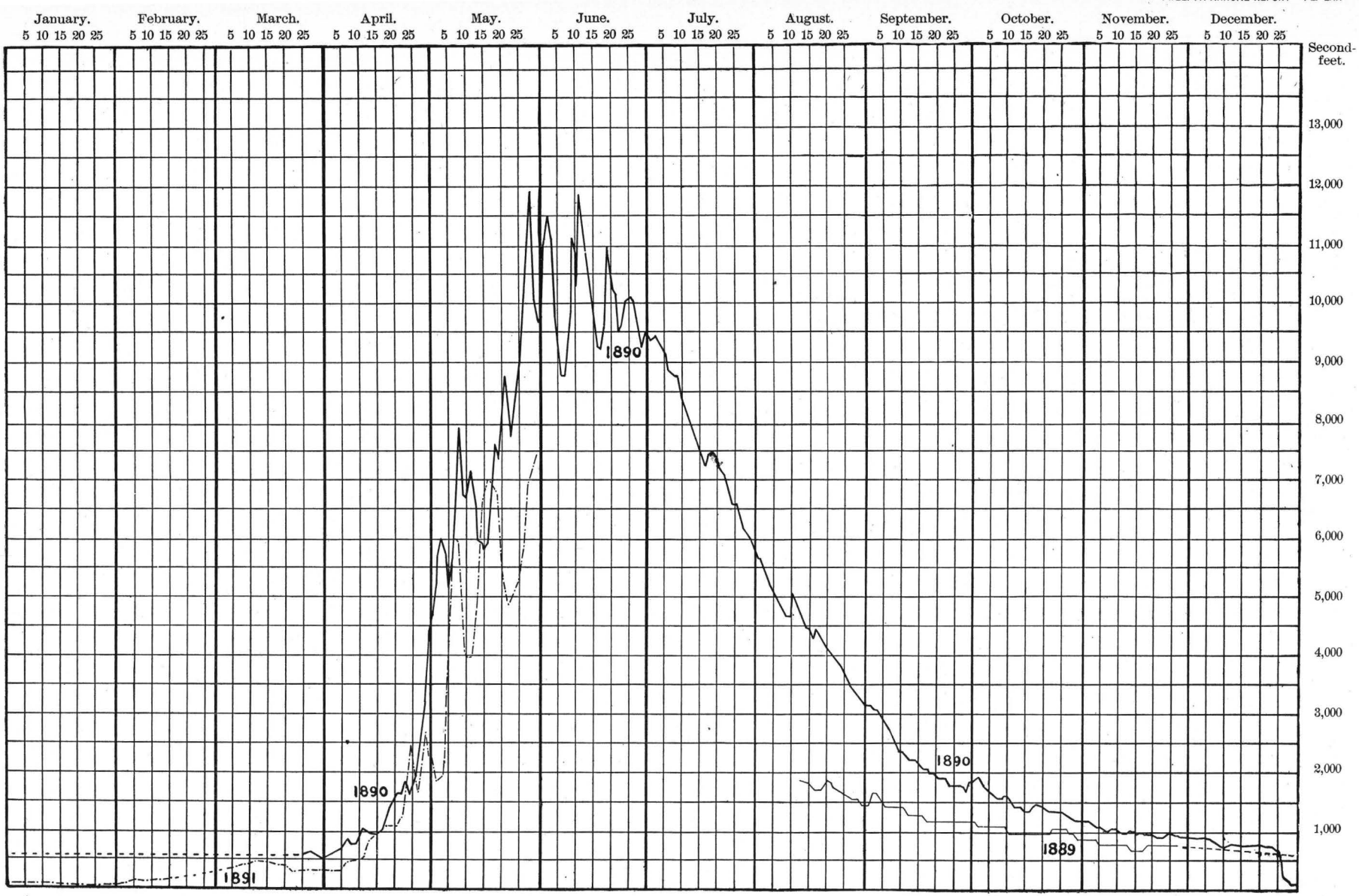
The discharge of the Madison, near Red Bluff, Montana, is shown on Pl. LXI, the most noticeable feature being the comparative regularity of the small oscillations during all the months of the year excepting those of the spring floods. The discharge of 1891, as in the case of the other rivers, is decidedly less than 1890.

The amount of water in the Missouri River at Craig, as shown on Pl. LXII, is in 1891 nearly equal to that of 1890, the lower discharge of the tributaries, however, being noticeable even in the case of the main stream. The relative location of these stations can be seen on the small map, Pl. LVIII, which also gives in a general way the relative size of the areas drained.

The discharge of the Sun River above Augusta, Montana, is shown on Pl. LXIII. A record has been kept of only one flood season, that of 1890, and therefore comparisons can not be made. It is probable, however, that this series of measurements represents fairly well the ordinary behavior of the river. The low water of the fall of 1889 is shown on the diagram, it being in amount decidedly less than that of 1890.

It is interesting to compare the results given on the diagrams and in the tables with those obtained in other years. The earliest recorded gaugings were made in 1872 by Thomas P. Roberts, assistant engineer on the Union Pacific Railroad.[1] He found that the Gallatin was flowing in the latter part of July, 1872, at the rate of 2,090 second-feet, the Madison 2,670 second-feet, and the Jefferson 3,778, making in all 8,538 second-feet. According to Roberts's judgment, the lowest water of September and October was about 6,600 second-feet, and the highest in the middle or last of May, 33,300 second-feet, both amounts being, however, far greater than obtained by later measurements. On July 31, 1872, the measured discharge at a point 71 miles below the Three Forks was 10,000 second feet, and on August 12, at Fort Benton, 11,132

[1] Report of a Reconnoissance of the Missouri River in 1872, by Thomas P. Roberts, assistant engineer Union Pacific Railroad. Printed for the use of the Engineer Department, U. S. Army, 1875.



DAILY DISCHARGE OF THE YELLOWSTONE RIVER AT HORR, MONTANA.

second-feet,[1] the amount of these discharges relative to the results obtained by recent measurements being shown on Pl. LXII.

In 1882 gaugings were made by the Engineer Corps, U. S. Army, at Stubbs Ferry, 73 miles below the Three Forks, and 12 miles from Helena, and of the three principal tributaries entering below Stubbs Ferry. The discharge at this place was, at a stage of 0·5 feet, 3,770 second-feet; of the Dearborn, at high water in the Missouri, 622 second-feet; of Deep Creek, at 2·75 stage of Missouri, 1,800 second-feet, and of the Sun River, at 3·05 feet in Missouri, 4,270 second-feet. The total discharge of the Missouri just below the mouth of the Sun River, or about 50 miles above Fort Benton, was, for a stage of 3·05 feet, 19,425 second-feet.[2]

In 1878 a gauging was made at Dauphin Rapids, 95 miles below Fort Benton and about 12 miles below Judith River. The discharge was 11,062 second-feet[3] from a drainage area of 39,247 square miles.[4] It was estimated that the mean daily discharge in 1879 was 13,530 second-feet, and in 1880 was 18,151 second-feet. Comparing this with the mean annual rainfall in these years, which was assumed to be 15·80 inches and 16·88 inches, respectively, in the basin, the run-off was computed to be 30 per cent of the rainfall in 1879, and 37 per cent in 1880,[5] or a depth of 4·67 inches and 6·30 inches in these respective years.

On October 20, 1882, a measurement was made at Ryan Island, 72 miles below the above-mentioned locality, and about 30 miles above the mouth of the Musselshell River, the drainage area being estimated to be 39,965 square miles. The discharge was 7,305 second-feet at a stage of 0·87 foot above low water of 1874.[6]

In the fall of 1890 a few stream measurements were made by Mr. G. A. Marr, assistant engineer of the Missouri River Commission, while carrying on careful leveling from Three Forks to Fort Benton, Montana. These gaugings, although considered approximate merely, are given in connection with other data, because they afford material for further study. The first of these is the measurement of July 28, 1890, made above the Three Forks, when it was found that the Gallatin discharged 730 second-feet and the three streams—the Gallatin, Madison, and Jefferson—aggregated 2,863 second-feet. The second measurement was on August 6, 1890, on the Missouri, just below Gallatin, the total discharge being 2,460 second-feet, and the third on September 18, 1890, near Canyon Ferry, giving 2,682 second-feet.

The daily discharge of the Yellowstone River below the National Park is given in graphic form on Pl. LXV. The measurements were made about 6 miles below the town of Cinnabar, at Horr, a station described in a previous report. As shown on this plate, the discharge for 1891 is similar to that for 1890, but is, in general, a little less.

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[1] Report of a reconnoissance of the Missouri River, etc., p. 54.
[2] Annual Report of the Chief of Engineers, U. S. Army, 1883, p. 1340.
[3] Ibid., 1878, p. 699.
[4] Ibid., 1883, p. 1353.
[5] Ibid., p. 1353, et seq.
[6] Ibid., p. 1354.

Many of the tributaries of the Yellowstone, especially those heading in Wyoming, are of great importance in irrigation, their waters in the summer being entirely diverted upon the fertile lands along the valleys. The State engineer of Wyoming, under authority of recent legislation, has gauged some of these streams for the purpose, primarily, of obtaining information by which to determine the rights of the various canals and ditches claiming the waters. In this manner a body of data is being acquired concerning these tributaries, which, however, has not as yet been published. For example, a permanent gauging station has been established on Clear Creek, near Buffalo, Wyoming, this stream, a tributary of Powder River, supplying water for a part of one of the most important agricultural areas in the State. In the annual report of the State engineer for 1890 it is stated that, upon explaining to some of the public-spirited citizens of that vicinity the importance of a gauging station and the inability of the engineer to establish it on account of the lack of appropriation from the State, the citizens immediately volunteered to assist in the work, and an arrangement was made by which they undertook the construction of a weir. Pending the completion of the weir, a temporary gauging station was established, and daily readings are taken of the discharge of the stream.

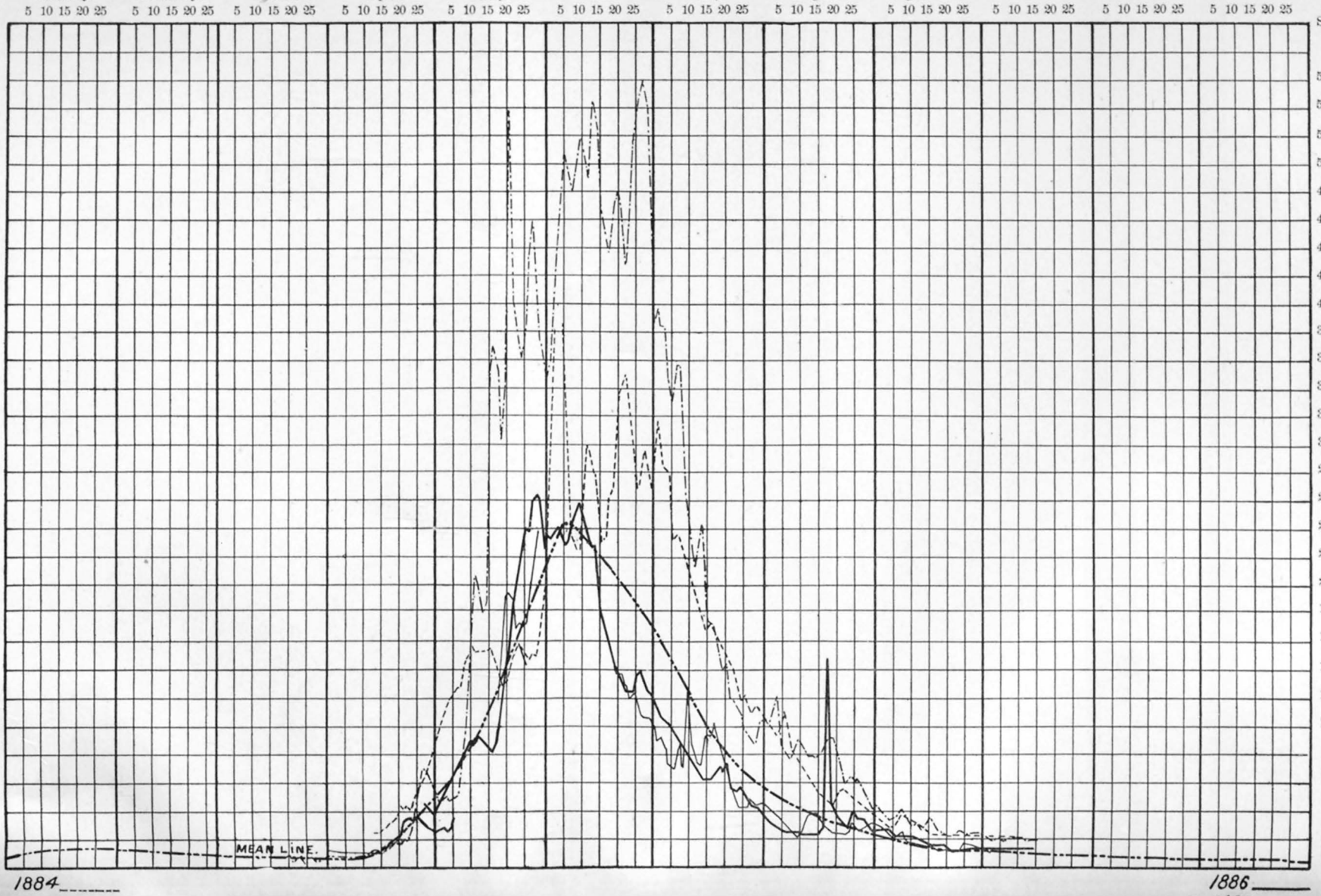
The discharge of the Yellowstone was measured in August, 1879, at the mouth of the Big Horn, at a stage of 1·70 feet above low water of 1878, giving for the Big Horn 5,865 second-feet, for the upper Yellowstone 7,471 second-feet, and total discharge below the Big Horn 13,336 second-feet. At Fort Keogh, 100 miles by river below the Big Horn, the discharge in September, 1878, was 14,462 second-feet, in October, 1879, was 6,505 second-feet, and in 1883, at about the same stage, 6,015 second-feet. At Wolf Rapids, 50 miles below, in September, 1878, gaugings gave 11,235 second-feet, and at Diamond Island, 100 miles by river below Wolf Rapids, in October, 1878, the discharge was 8,155 second feet.[1]

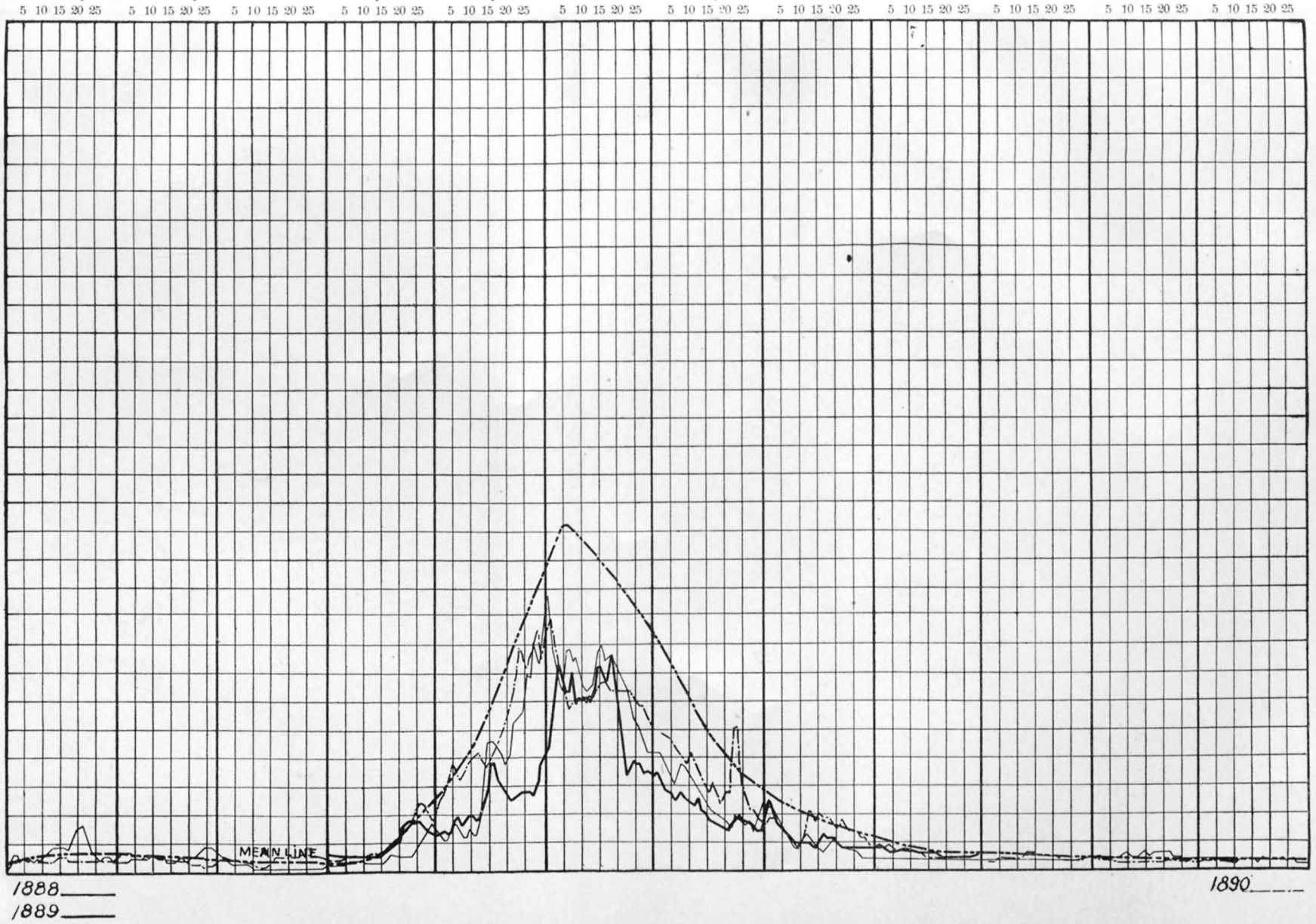
The total drainage area of the Yellowstone is 69,683 square miles, and of the Missouri, above the mouth of the Yellowstone, 95,093 square miles. The data for the total discharge of the Upper Missouri and Yellowstone are not sufficiently extended to enable exact comparisons to be made, but from inspection of the foregoing it appears that the quantity of water in the two streams is about equal.

PLATTE BASIN.

The most important series of measurements in this drainage basin are those being made on the Cache la Poudre, about 12 miles above Fort Collins, Colorado. These have been fully described in the previous report, and the results given up to June 30, 1890. The diagrams on Pl. LXV show graphically the daily discharges up to the present time and afford a means of comparing one year with another.

[1] Annual Report of the Chief of Engineers, U. S. Army, 1880, p. 1476, and 1883, p. 1342.





DAILY DISCHARGE OF THE CACHE LA POUDRE 12 MILES ABOVE FORT COLLINS, COLORADO, 1884 TO 1891.

For clearness these data have been placed on two diagrams, the discharges for 1884, 1885, 1886, and 1887 being placed on one page, and those for 1888, 1889, and 1890 on the other. In addition to these discharges for individual years, the line showing the average daily discharge has been plotted on both diagrams. This curve shown by heavy dots and dashes has been obtained by combining the results for each year since the beginning of the observations. The discharges for 1884 and 1885 come far above this line, while those for 1886 and 1887 agree with it fairly well. During the years succeeding these, however, the flood discharge does not at any time reach this line, showing the great diminution in flow for the last three years.

The fluctuations and uses of the waters of the Cache la Poudre are discussed by Prof. L. G. Carpenter in the annual reports of the Colorado State Agricultural College at Fort Collins.[1] Other measurements of flowing water have been made at various points in the Platte basin, these, however, being mainly disconnected and fragmentary. Mr. Henry Gannett, in the Hayden[2] report for 1876, gives the results of a number made on tributaries heading near the continental divide. The State engineer of Wyoming has also made a number of gaugings of the Laramie and other rivers, and has established gauging stations, the results of which promise to be of value.

A permanent station on the Laramie was established in December, 1888, at Woods, near the southwestern corner of Albany County, about 30 miles above Laramie City. During the following winter and up to April 1, 1889, the discharge was approximately 112 second-feet. The maximum for the year, 1,620 second-feet, occurred in June, falling from this to a minimum of 43 second-feet in September. A smaller quantity of water was discharged in that year than ever before known, the maximum in some seasons being over 6,000 second-feet.

The North Platte was gauged by Mr. A. M. Van Auken, civil engineer, near Fort Laramie, Wyoming, in 1887, 1888, and 1889, and also near the Wyoming-Nebraska line during the low stages of 1890, the velocities in each instance being obtained by means of floats. The results are not considered by him to be more than approximations, but as such they have their value, and with this qualification they are herewith given. It is believed by Mr. Van Auken that these figures will give a fair idea of the discharge of the stream, and that the results are more accurate for the smaller discharges than for the larger.

[1] The State Agricultural College of the State of Colorado. Third annual report of the agricultural experiement station, 1890. Fort Collins, Colo., p. 58.

[2] Tenth Annual Report of the U. S. Geol. and Geog. Survey of the Territories, F. V. Hayden, 1876, pp. 323–326.

North Platte River.

Month.	Discharge.			Month.	Discharge.		
	Max.	Min.	Mean.		Max.	Min.	Mean.
1887.	*Sec. f.*	*Sec. f.*	*Sec. f.*	1889—Continued.	*Sec. f.*	*Sec. f.*	*Sec. f.*
May	8,240	3,520	5,255	June	10,260	5,170	8,240
June	10,140	7,680	8,995	July	6,080	4,240	5,506
July	7,680	3,640	5,676	August	4,290	3,220	3,498
August	3,720	3,380	3,560	September	3,240	2,580	2,892
1888.				October	3,210	2,430	2,859
May	4,510	3,780	3,991	November 1 to 15	3,960	2,370	3,205
June 1 to 21	6,490	3,920	5,671	1890.			
July 11 to 31	6,060	4,280	4,711	March	3,400	3,180	3,316
August	5,180	3,900	4,341	April	3,720	3,200	3,457
September	3,920	3,430	3,822	May	6,970	3,840	5,151
October 1 to 22	3,920	3,110	3,517	June	10,240	8,180	8,682
1889.				July	7,960	5,120	6,469
April	3,438	2,970	3,208	August	5,425	3,380	4,160
May	8,120	2,960	4,216	September 1 to 6	3,680	3,440	3,560

ARKANSAS BASIN.

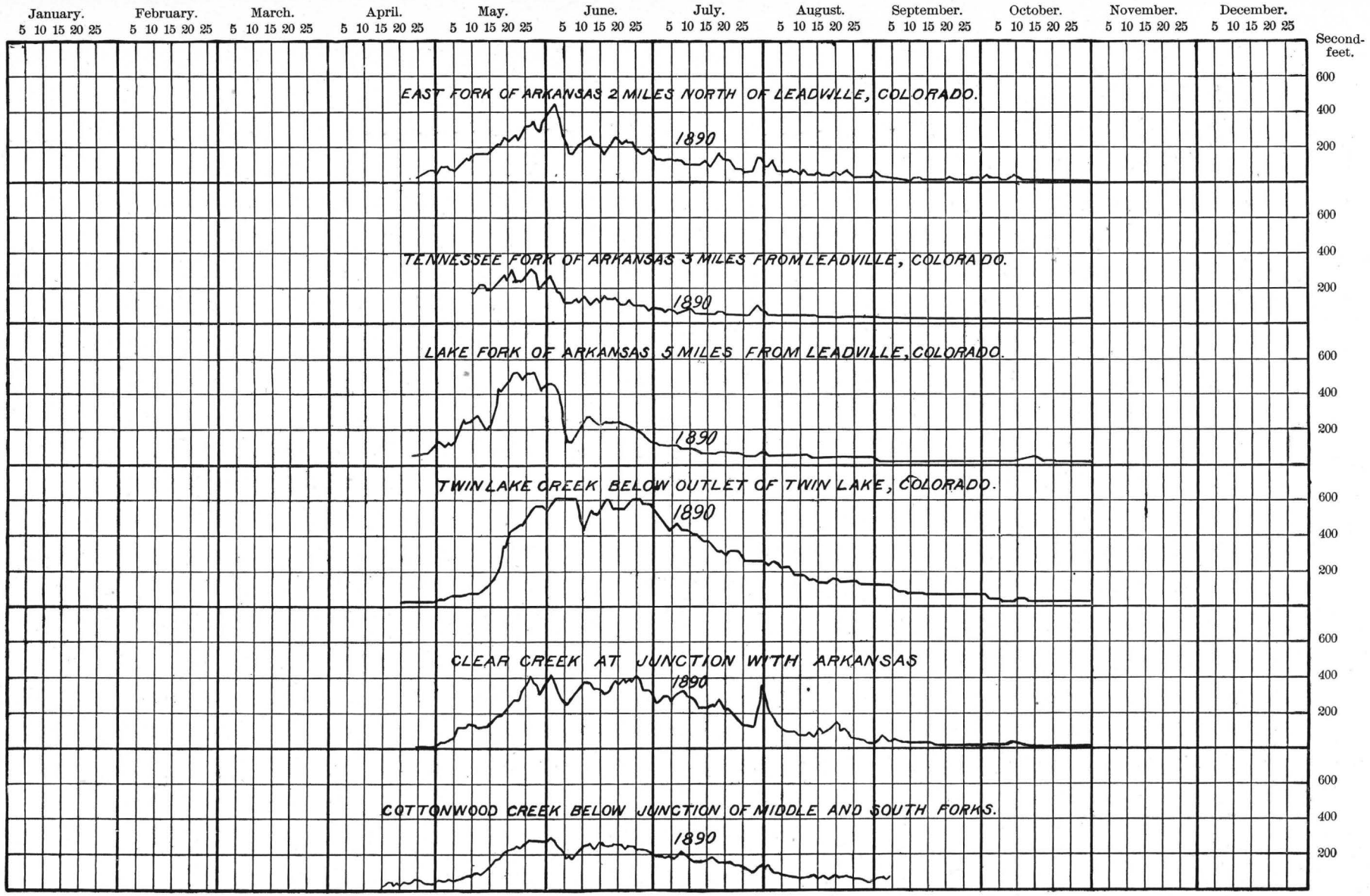
The gauging stations in this basin were described in the last annual report of this Survey, to which reference should be made for details regarding the measurements up to that time. The results of these measurements and computations of discharge for the upper tributaries of the Arkansas are given on Pl. LXVI, and for the Canyon City station on Pl. LXVII. Referring to this plate, it will be seen that the most notable fact is the increased discharge during the spring of 1891. This is also brought out by the table of monthly discharges given on page 349. No measurements have been made of the discharge at stations on the lower Arkansas since 1889. The gauge heights at these stations have been published in diagrammatic form in comparison with the rainfall in the basin in the previous annual report. (Pl. LXXI, Eleventh Ann. Rep. U. S. Geol. Survey, part II.)

RIO GRANDE BASIN.

TOPOGRAPHY AND ELEVATIONS.

A study of the hydrography of the Rio Grande Basin, Pl. LXVIII, and of its facilities for water conservation offers some of the most interesting problems undertaken by the Geological Survey. This is due not only to the large extent of area covered by this basin, but also to the wide difference in topography and character of soil and climate. The matter is further complicated by the relation of political divisions, State and county lines, to the basin as a whole.

This discussion of the Rio Grande Basin, including the subbasin of the Pecos, its largest tributary, is confined to that portion lying within the State of Colorado and the Territory of New Mexico, the part in Texas possessing a smaller interest in this connection. The total area in these three political divisions above the junction of the Pecos with the Rio Grande is, approximately, 145,200 square miles. Not all of the area embraced within the limits of this great topographic basin contributes water to the river, but on the contrary, there are extensive



DAILY DISCHARGE OF THE UPPER TRIBUTARIES OF THE ARKANSAS RIVER, 1890.

tracts, as in the case of all the southern basins of the arid region, from which there is no outflow. The total area north of the Texas-New Mexico line, including the lost river basins, is 89,100 square miles, and that portion in Colorado included in the above measurement is 7,527 square miles.

The largest part of the water flowing in the Rio Grande comes from the mountains of Rio Grande and Conejos Counties, Colorado, and also, though to a less degree, from the mountains in Costilla County. The river reaches its maximum, considering all seasons of the year, at a point not far from its headwaters, for after flowing through the San Luis Park and entering New Mexico the various tributaries, though draining large areas, do not contribute a notable amount to the stream excepting in times of floods, and on the other hand there is a constant loss by evaporation and artificial diversions.

The Rio Grande Basin is a long, narrow strip of country, the perennial supply of water coming principally from a comparatively small area of about 2,000 square miles of lofty mountains. The greater part of the remaining catchment contributes water only in times of flood, that is, in the months of May and June, while during the rest of the year the waters falling within this area or coming from melting snows do not reach the trunk stream, but are evaporated or sink into the sands. In addition to the areas contributing a perennial supply of water and a spasmodic supply, there is a vast area of lost river basins from which, as mentioned before, no water comes at any time, but which from topographic features may be included within this great catchment basin.

The following descriptions of these topographic features and the character of the water supply of the subbasins embraced within the Rio Grande drainage system were taken from reports made at various times by assistants who were engaged in water measurements or preliminary examinations for reservoir sites. Among these were Messrs. L. D. Hopson, G. T. Quinby, R. S. Tarr, W. W. Follett, and H. M. Dyar. In order to condense and unify this material and combine it with data from all sources, the individual reports have not been designated, but they have been inserted as needed in geographical order.

The Rio Grande rises in southwestern Colorado (Pl. LXVIII), flows easterly for a time as a mountain stream, and finally enters the San Luis Valley about 80 miles below its source. In this valley it receives from the north the waters of the Saguache and San Luis rivers by seepage, if at all; from the west, near the lower end of the valley, the Alamosa, La Jara, Conejos, and San Antonio rivers; and from the east the Trinchera, Culebra, and Rio Costilla. About 4 miles north of the Colorado State line it enters a long canyon locally known as the Rio Grande Canyon.

The general slope of the valley is still toward the south, the river descending, however, more rapidly than does the surface of the country.

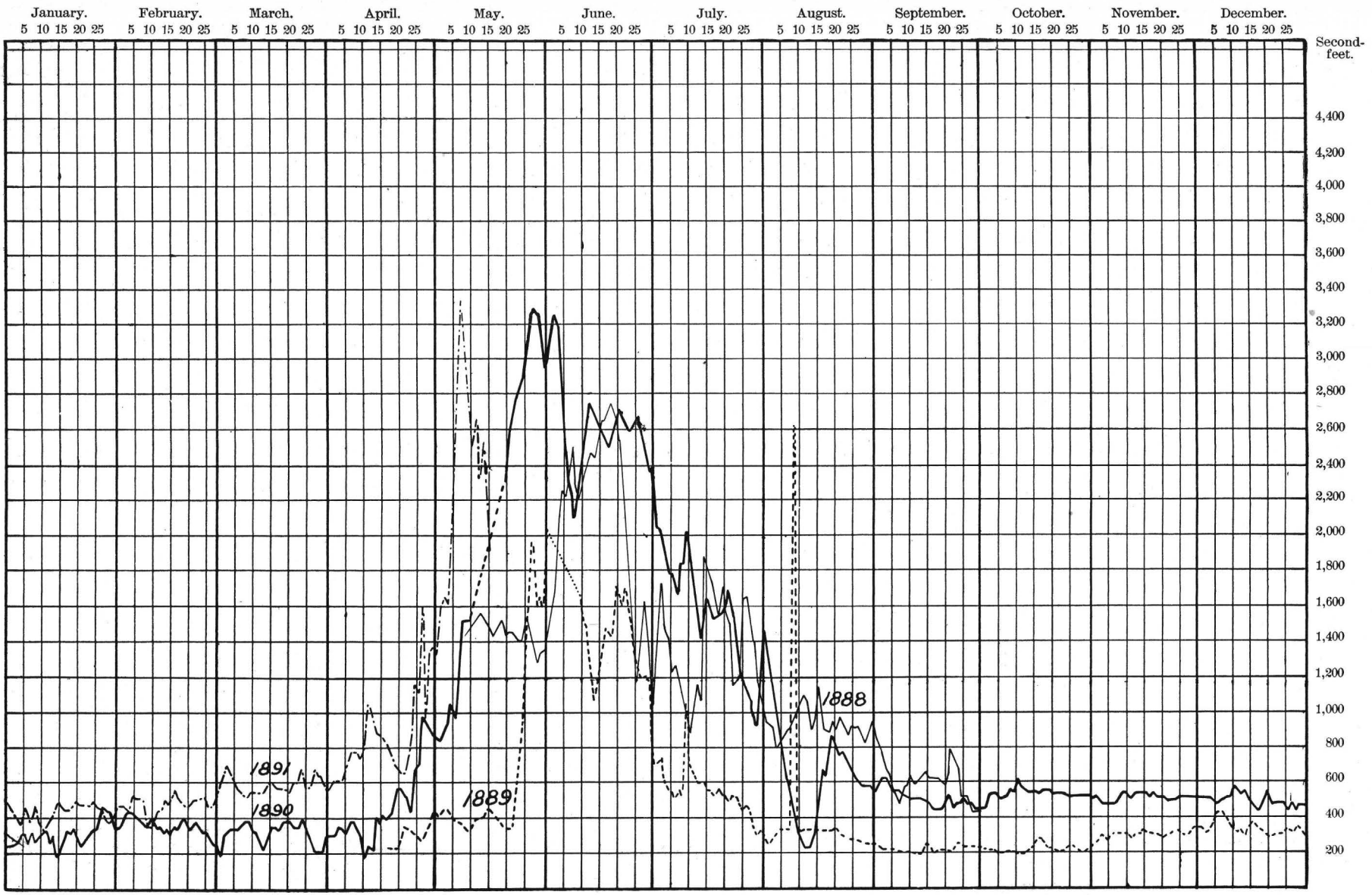
This canyon is 300 or 400 feet deep in places, appearing from above as a gash in an otherwise level mesa. Its southern end is 3 miles below Embudo, New Mexico, where the walls open and the river enters the Espanola Valley. While in the canyon above Embudo the river receives from the east Taos River, Embudo Creek, and other small streams, and in the Espanola Valley it is increased by the Chama flowing in from the west and by a number of streams from the east.

At the lower end of Espanola Valley the river passes through White Rock Canyon, a gorge in a range of hills stretching from the Jemez to the Santa Fe Mountains. From Pena Blanca near the lower end of this canyon nearly to Socorro the river flows in a valley from 1 to 3 miles wide, bounded on each side by mesas from 300 to 600 feet above the river. About 20 miles below Pena Blanca the Jemez enters from the west, and 60 miles or more below Albuquerque the Puerco comes in from the same side. Below these streams the Rio Grande has no tributaries of note until the Pecos is reached, about 400 miles by river below El Paso.

At and below Socorro the valley contracts until it becomes too narrow for agriculture, but from San Antonio to San Marcial the valley is from 1 to 2 miles wide. Below San Marcial the river swings to the westward around the Fra Cristobal and Caballos Mountains, which lie along the west edge of the Jornada del Muerto, the valley from San Marcial to Rincon being narrow, low, and marshy. At Rincon the river enters a canyon which extends to Fort Selden, a distance of 15 miles. The Mesilla Valley, the most fertile valley of New Mexico, begins below Fort Selden and extends to the pass above El Paso, a distance of over 50 miles. Above El Paso the banks of the river again assume the canyon like character for three miles, and the river passing this enters the Ysleta Valley, a fine grape and fruit producing country.

From this brief description of the river it will be seen that outside of the Mesilla Valley there are no large valleys in New Mexico along the Rio Grande or along any of its smaller tributaries, the valleys of the main river being generally narrow, seldom reaching a width of over two miles, and alternating with long canyons or gorges. The water of the stream, especially in the central and southern part of New Mexico, is heavily loaded with silt, and this is deposited to a certain extent in each of these valleys, forming broad alluvial plains. The channel of the river through these valleys is usually choked by sandbars, and in times of low water the stream divides into a number of minor channels, and apparently a large percentage of the water is lost in these great deposits of fine material.

The canyons above these valleys are not cut into hard, indurated rocks, but in many cases are bordered by steep walls of comparatively soft, friable sandstones, alternating with conglomerates or beds of clay, the whole series, in the northern part of the territory at least, being capped by a vesicular lava. The fall through these canyons being great,



DAILY DISCHARGE OF THE ARKANSAS RIVER AT CANYON CITY, COLORADO. 1888 TO 1891.

the down-cutting is rapid, and thus the waters are supplied constantly with fresh detritus, part of which is deposited in turn in the valley below.

Pl. LXIX gives a view characteristic of these canyon walls, showing the soft crumbling sandstones and the fantastic shapes into which they are carved by the rain and frost. This view was taken near the Embudo railroad station and in the vicinity of the point at which river gaugings had been made. The height of the cliffs from the bottom to the upper pinnacles shown in the picture is 500 or 600 feet, the total depth of the canyon at this point being about 1,000 feet. The sandstone crumbles readily under the hand, the only exception being in the case of a few thin bands, apparently containing a little lime, their superior hardness enabling them to resist erosion and thus stand out, as shown in the photograph. Such carvings of soft rock could, of course, exist only in an arid region, where the rainfall is too slight to erode rapidly or to encourage the growth of vegetation.

On Pl. LXVIII is given a contoured map of the basin, including on the east the drainage of the Pecos and on the southwest that of the Mimbres, although the latter river belongs to the class of lost rivers and even in times of flood does not contribute to the Rio Grande, but to the river system in Mexico west of the Rio Grande. On this map the contours show the elevation for each thousand feet above the sea, and the increase of height is further shown by the depth of tint, the highest mountains being heavily tinted. The great mountain ranges in the northern part of the basin, which furnish the principal supply of water, are thus clearly shown, and on the south the broad desert plains are seen, together with their relation to the river and to the dividing ridges of mountains. This map is of necessity generalized to a large extent, from the fact that topographic surveys have not been carried on over a large part of the area.

ANNUAL AND MONTHLY RAINFALL.

The annual rainfall, as measured in various parts of the Rio Grande basin, is shown graphically on Fig. 223, the stations selected being those in or near the basin and for which there was the longest record. Ten stations are represented on this diagram, the depth of rain at each being shown by the height of the black blocks or steps above each base line. Each year during which observations were made is represented by one of these blocks or steps, the blank spaces showing either that no observations were taken or else that they were not continuous throughout the year. The horizontal lines give the depth in inches and the vertical lines divide the five-year periods, so that wherever the observations are complete there are five of these black steps or blocks between two vertical lines. The years are shown by the figures at the top of the diagram, 1860–1864 signifying that the observations on these years whenever made are to be found in that space. Most of the obser-

vations, however, begin about 1870 and continue with more or less interruption until 1889.

This diagram serves to show the great irregularity in the measured rainfall and the range in total depth for any one place, and demonstrates how difficult it is to draw general conclusions. The most marked feature is the extraordinary rainfall reported at Fort Garland in the years 1870, 1871, and 1872. It is highly probable, however, that this report is an error, although the individual observations of the storms in these years do not seem to indicate it. In the lower left-hand corner the rainfall at two widely separated stations is given, that for Fort Selden for the years 1867 to 1876, inclusive, and that for Deming from 1883, continuing through that decade.

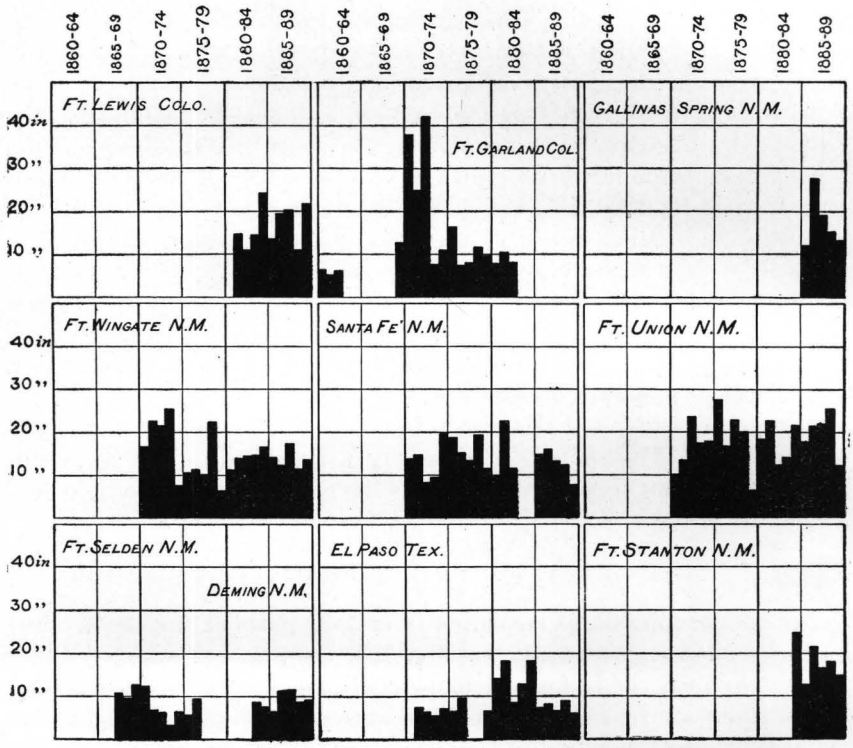
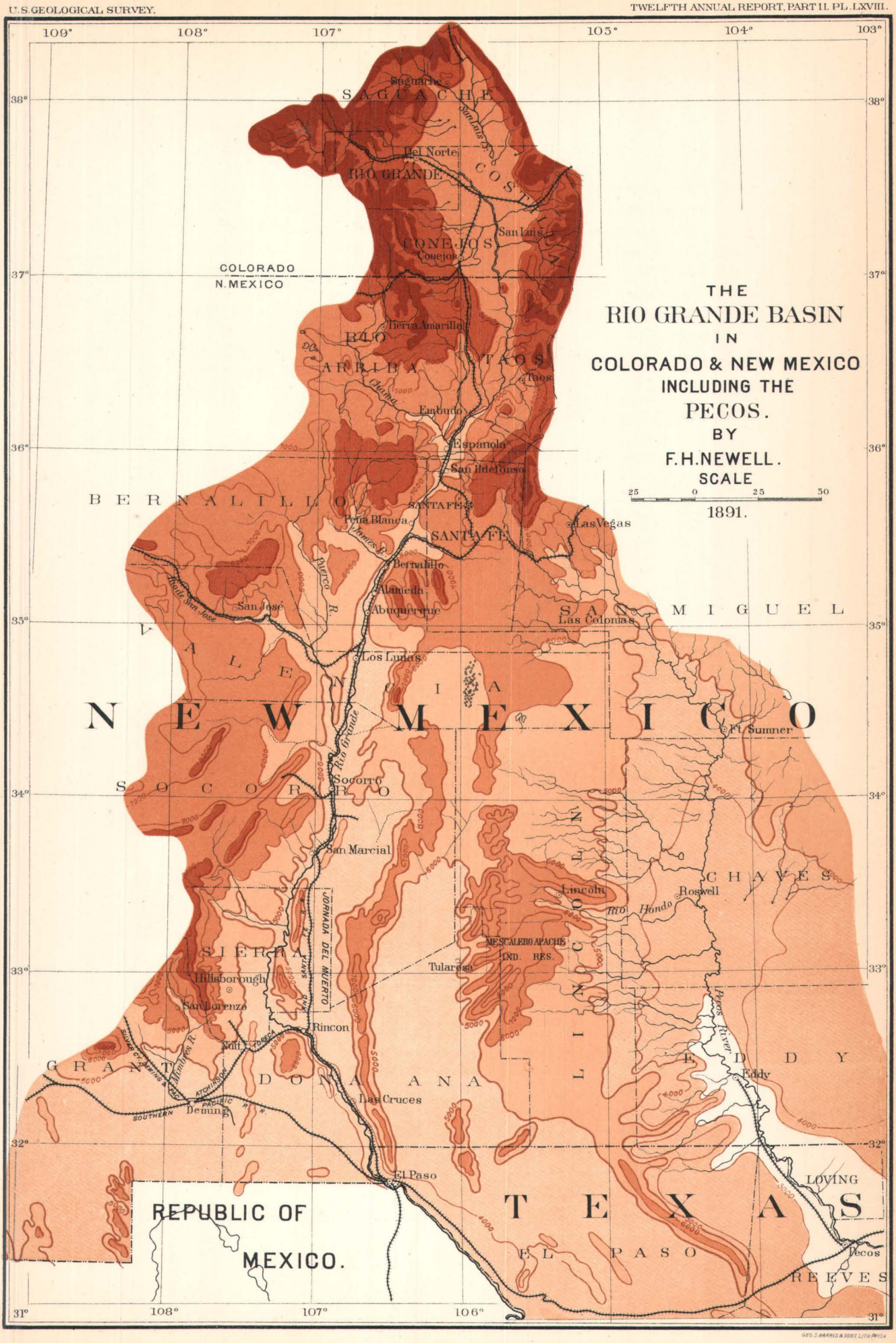


FIG. 223.—Diagram of annual rainfall in the Rio Grande Basin.

The rainfall at Fort Wingate, one of the longest of the series of measurements, shows the character of the fluctuations in this basin, in two instances years of great rainfall being immediately followed by years of drought. The Santa Fe record is broken, the years 1883 and 1884 being lost, and the El Paso record is also deficient in the years 1877 and 1878; otherwise these give a long and instructive series of observations, showing that the rainfall at most stations in the northern part of the basin seldom falls below 10 inches and rarely rises above 20. In the


THE
RIO GRANDE BASIN
IN
COLORADO & NEW MEXICO
INCLUDING THE
PECOS.
BY
F.H.NEWELL.
SCALE
25 0 25 50
1891.
109° 108° 107° 105° 104° 103°
38° 37° 36° 35° 34° 33° 32° 31°
SAGUACHE
RIO GRANDE
CONEJOS
COLORADO
N.MEXICO
RIO ARRIBA
TAOS
BERNALILLO
SANTA FE
VALENCIA
SAN MIGUEL
SOCORRO
GRANT
DONA ANA
SIERRA
LINCOLN
CHAVES
EDDY
LOVING
REEVES
EL PASO
TEXAS
REPUBLIC OF
MEXICO.
NEW MEXICO
Del Norte
San Luis
Conejos
Tierra Amarilla
Taos
Embudo
Española
San Ildefonso
Pena Blanca
Las Vegas
Bernalillo
Alameda
Albuquerque
San José
Las Colonias
Los Lunas
Socorro
San Marcial
Lincoln
Roswell
Ft. Sumner
Rio Hondo
Tularosa
MESCALERO APACHE IND. RES.
Hillsborough
San Lorenzo
Rincon
Las Cruces
Deming
El Paso
Eddy
Pecos
Rio Grande
Rio Puerco
Rio Chama
Rio San Jose
Jornada del Muerto
Pecos River
Animas R.
Gila R.
Santa Fe R.
Mimbres R.
Silver City, Deming & Pacific R.R.
Atchison, Topeka & Santa Fe R.R.
Southern Pacific R.R.
GEO. S. HARRIS & SONS, LITH. PHILA.

southern part of the basin, however, the rainfall apparently fluctuates for the most part below 10 inches a year, at long intervals rising above this.

The distribution of the rain by months throughout the year at various stations in the Rio Grande basin is shown on Pl. LXX, the height of the small black pillars showing the mean depth of rainfall at the various stations named for a period of from 12 to 15 years. This diagram does not exhibit the rainfall in any one year, but shows the average distribution at these points. The most noticeable feature is the excessive rainfall at all stations in July, and especially in August, and the diminished amount in the early and late months of the year.

The basin of the Rio Grande can readily be divided into a number of parts, belonging to one or another of the three classes of drainage districts—headwaters, trunk-stream, or lost rivers. These are usually sharply distinguished by peculiar topographic features, and are well recognized in common usage. In the descriptions of the hydrography of these, given in the following pages, the order of succession is taken in general from the headwaters down, taking first the district in the State of Colorado, including the source of the river, the San Luis Park and the lost river basins to the north, then the Taos district and the adjoining areas, and in succession the Espanola Valley, the Chama district, the Santa Fe district, the Albuquerque Valley, the tributaries below the Chama, and the Mesilla Valley. After these descriptions of the main Rio Grande drainage, that of the Pecos in New Mexico is given, condensed from a report by R. S. Tarr, and finally the lost river basins between the Rio Grande and Pecos are briefly mentioned.

THE COLORADO DISTRICT OF THE RIO GRANDE.

The headwater district of the Rio Grande Basin, embracing the San Luis Valley, surpasses all other subdivisions in extent of irrigation and permanence of water supply, and is of the first importance in any consideration of the conservation of the waters. The general elevation of the cultivated land of this division is from 7,500 to 7,700 feet or over. The central plain is bounded by high mountains of 9,000 to over 13,000 feet in elevation on all sides, excepting on the south, where the valley opens into New Mexico. The southern boundary of this district may be taken as coincident with the State line of Colorado, for on the south the topographic features do not sharply divide this district from the adjoining portions of the Rio Grande Basin.

The great division of the river basin includes 45 square miles in San Juan County, 615 square miles in Hinsdale County, 2,520 square miles in Saguache County, 1,170 square miles in Rio Grande County, and all of Costilla County—1,720 square miles, and of Conejos County 1,200 square miles—in all an area of 7,270 square miles. The total area of the comparatively level lands of the valley is 2,400 square miles, and of the high mountains4, 870 square miles. Most, if not all, of the water must

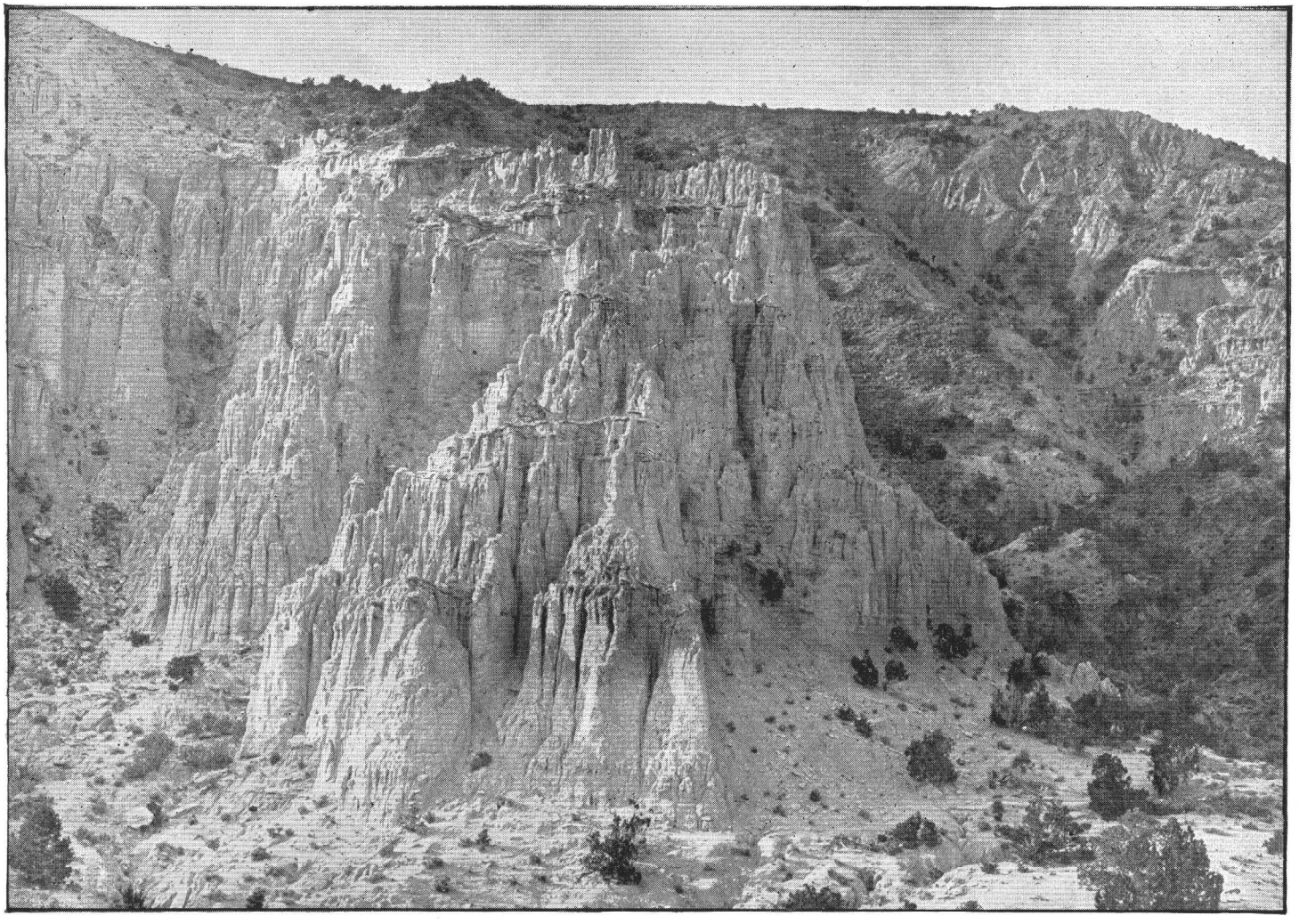
be derived from this latter area, namely, of these higher mountains, for the rain which falls upon the valley itself does not add perceptibly to the available supply of water.

From the high mountains which surround this division come innumerable small streams, some of which unite into creeks of notable size, while others sink, gradually disappearing into the porous soil of the valley bottom. The Rio Grande rises in the extreme western prolongation of this drainage area, and flows in a general easterly course, receiving a number of these small streams on its way. Shortly after entering the valley proper, or park, as it is sometimes called, near the town of Del Norte, it begins to take a general southwesterly course, which finally changes to the south. Beyond Del Norte are few streams contributing water to the river throughout the year: so that, taking the year as a whole, the maximum amount of water in the river is to be found comparatively near the head of the river, and probably not far from Del Norte.

In its headwaters the Rio Grande is a torrential stream, but after leaving Wagon Wheel Gap it gradually loses its steep descent, and beyond Del Norte has a very light grade, becomes sinuous, and often divides into several channels, especially in floods. There is constant tendency to shift the channel and to cut off the loops, and thus great trouble and expense are occasioned to the owners of canals, in the attempt to preserve the headworks and prevent the river from washing them out or leaving them.

The gauging station of the Geological Survey is at a point about 3 miles above Del Norte, thus obtaining the discharge of the river above the headworks of most of the canals, so that the measurements given in the accompanying tables may be taken as showing the maximum flow of the river at the point between the torrential portion and the sinuous plain portion. The discharge for nearly two years is shown on Pl. LXXI, by the examination of which the relation between the floods of 1890 and 1891 can be seen at a glance. In 1891 during the early months the water was high, and there was promise of a large flood. This culminated, however, in the first week in May, and then declined rapidly, reaching its lowest point at the time when on the previous year the water was highest. The dotted line in July, August, and September gives the approximate discharge for 1889, the measured discharge for the rest of that year being shown by the fine line.

The greater portion of the catchment area of this division does not contribute water to the Rio Grande; thus there are two subdivisions—that of the perennial drainage of the Rio Grande and the lost river drainage. The entire northern or northeastern part of this division in Colorado belongs to the class of lost rivers, since the waters of the streams do not penetrate across the broad San Luis Park, but gradually disappear into the gravelly soil—as, for example, the Saguache Creek—or flow into the San Luis lakes, from which they escape by evaporation, leaving the bed dry for a part of the year.



EARTH COLUMNS AT EMBUDO, NEW MEXICO.

Although a large per cent of the drainage from the mountains surrounding the park is lost by evaporation, a small amount penetrates the soil and fills the porous strata. The extensive irrigation which is practiced in the central parts of the plain also adds water, and thus the unconsolidated sands and gravels are completely saturated. These waters gradually rising in the earth tend to create swamps, and already certain areas of valuable land have been ruined. Systems of drainage must be constructed in many places to take away this injurious excess of water.

It has been found possible to recover some of this water by means of wells, and on the lower grounds a large number ot artesian wells of small diameter and of depth from 70 to 200 feet or more have been put down, giving an excellent supply for domestic purposes and for watering stock.

SAN LUIS VALLEY.

The San Luis Park or valley proper comprises the lower lands or central part of the basin, and consists of the broad extent of nearly level land, the soil being probably of lacustrine origin. Large irrigating systems take water from the Rio Grande and carry it both north and south into these rich and level bottom lands, while smaller canals and ditches owned by farmers are to be found around the edge of the valley, utilizing the water of the smaller streams.

This valley is far the largest on the Rio Grande, being nearly 70 miles long and 40 miles wide, the vast extent of unbroken land surpassing in area the total of the agricultural land along the river in New Mexico. The surface slopes from both sides away from the river, the stream flowing upon a low, broad ridge and the valley bottom as a whole falls gently toward the south, parallel to the river.

Although the altitude of the lands of the valley bottom is high, yet the climate is not too severe for agriculture. The snowfall is generally too light to insure the success of winter wheat, and disappears rapidly toward spring. The soil of the valley varies greatly, some of it being a sandy adobe, and in other places a coarse gravel. There is often a sandy loam from 8 to 15 inches thick overlying this coarse gravel. In the northwestern part of the valley, and also to a less extent throughout the park, are low swampy places known as "sinks," in which large quantities of alkali have accumulated. The adjacent land is usually a pure adobe, which, under the action of the heat, has become baked and cracked. The irrigators state that this land after cultivation becomes the easiest to till and requires the least water.

The extent of arable land is so great that the unregulated water supply is insufficient for all demands. The larger canals taking water from the Rio Grande claim many times the volume of water flowing in that stream, and have been involved in protracted and expensive lawsuits concerning their respective rights. In the same way the irrigators

owning ditches taking water from the smaller streams, having need for more water than is available at all times, are frequently involved in quarrels, and require the intervention of the water commissioners.

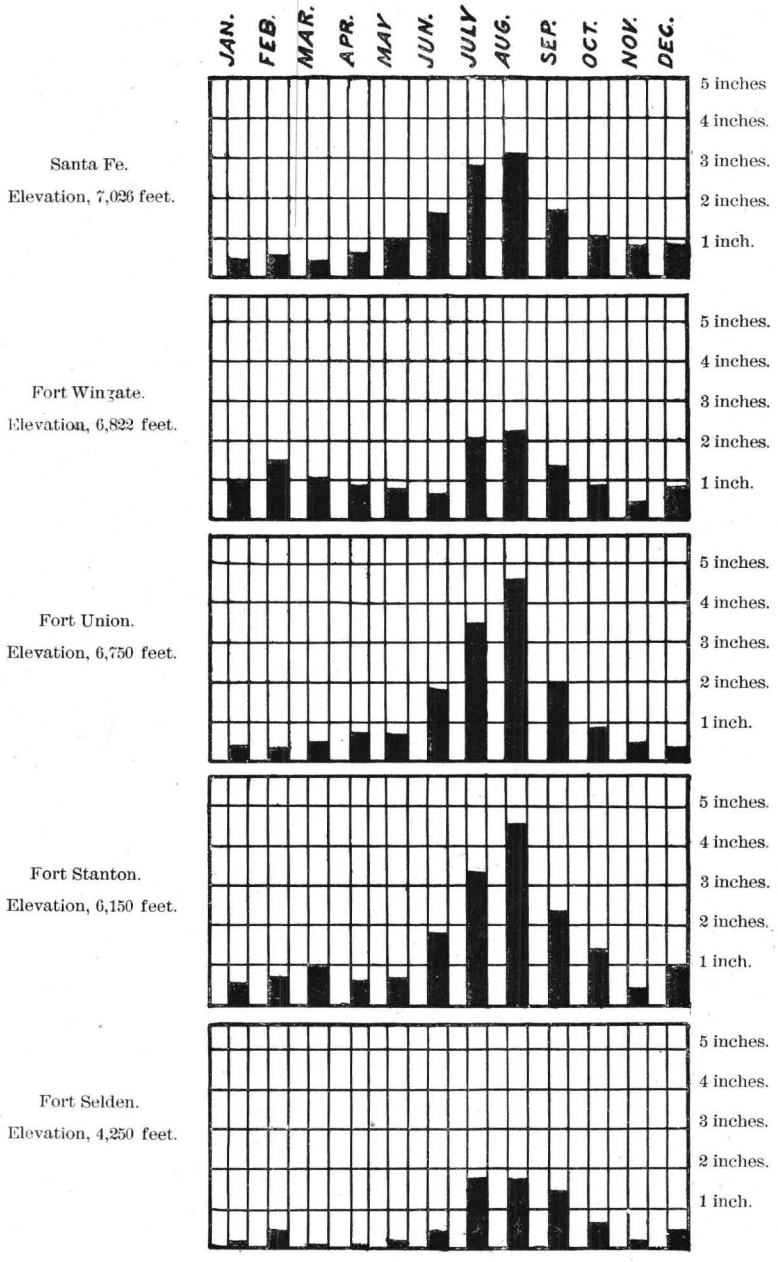
The principal crops raised are the cereals, grasses, and other forage plants. The altitude of the farming lands in the valley being so great, from 7,500 to 7,700 feet, the prevailing opinion has been that, on account of the shortness of the season, corn and similar crops would never prove successful to any extent. Alfalfa also has not succeeded in all places. Wheat, oats, barley, and the vegetables bear abundantly, and attain a growth which it is claimed, is rarely equaled in any other section of the country.

IRRIGATION PRACTICE.

The application of the water is accomplished by flooding, by running it in furrows, and by lateral seepage from the canals. For example, on one farm, rectangular in shape, the main ditch and its branch run on the west and north sides. From a point near the middle of the west side a branch of the main ditch runs diagonally to the southeast corner. Running out from the main ditch and branches at distances of from one-half to three-fourths of a mile apart are the main laterals. From these laterals at about every hundred feet the "acequias" or sub-laterals are taken out. In the case of both the laterals and acequias the general direction and number are controlled by the configuration of the ground.

If the ground is gently undulating, the acequias follow the contour, if not too sinuous, thus commanding the whole field, the irrigator alway keeping in mind the fact that the water should reach its destination in the shortest time possible with the greatest head. Small ridges several inches in height are made from the acequias to lead the water over the land. The gates having all been raised and the ditches filled, the irrigator walks along the acequia and cuts a small opening in the bank just below the ridge, allowing the water to flood the ground for some distance around. He then passes on making another opening just below, and so on throughout the field. When the ground has been flooded to a sufficient depth the openings are closed, and the water allowed to soak into the soil. The silt deposited from the turbid waters of the Rio Grande tends to enrich the ground and to prevent exhaustion of soil.

The furrow method consists simply in filling the nearly parallel furrows and allowing the water to seep laterally to the roots of the plants. The number of irrigations required to raise a crop seldom exceeds three, and is sometimes only two, depending largely upon the character of the season. Irrigation by lateral seepage from the ditches is commonly known to the farmers as subirrigation. On old land crops can be raised on the strips of ground 100 feet wide on each side of the canal, the only irrigation being the lateral seepage from the canal.



AVERAGE MONTHLY RAINFALL AT STATIONS IN THE RIO GRANDE BASIN IN NEW MEXICO.

Irrigation for grass and meadow lands begins about the 1st of May, and for grain and potatoes about a month later. After the hay is cut the ground is often given a second watering for aftermath. On meadow land three good floodings are required, except on the bottom or lowlands, where two are used. For grain there are three waterings on higher land and two on the lower land. Irrigation ends for grain and potatoes from the first to the middle of August.

In general, the larger canals in this valley are very wide and shallow, and are built for a considerable portion of their way in embankments raised slightly above the general level of the surrounding ground, allowing the water to be easily conducted out upon the fields. The loss by evaporation and seepage at such places is in consequence very great. The advantage, however, of this method of construction is that the cost of a shallow canal is usually less than of one having a deep cross section, and the banks are less liable to be destroyed. Wherever practicable, however, the canals have been partly in excavation and partly in embankment.

Almost without exception the head works of the canals, including gates, dams, flood weirs, etc., are constructed of wood, and are of a very temporary character. There are few boxes or devices employed in the valley for the absolute measurement of water, since the canal companies have not felt the necessity of accurately measuring the amount of water given to the consumer. With the increase of the number of canals and in sale of the water rights there is a prospect, however, of the general adoption of some form of measuring box or weir which measures water in statutory units.

The San Luis Valley comprises eight of the water districts of the State of Colorado, these districts being Nos. 20 to 27, inclusive. The administration of the water service of the canals lying in these districts is subject to the control of the water commissioners. The rules governing the service of the canals are enacted by the companies owning them. Many of the canals were built by irrigators, but the largest, as for example the Citizens', Del Norte, Empire, and San Luis canals, were constructed for the purpose of selling and renting water. They usually rent water for a term of from one to five years, the lessee signing an agreement binding himself to use the water for his own purposes only, not to let any of it run to waste, and to fulfill other requirements.

Some of the companies agree that whenever, through scarcity of water, due to neglect, they can not deliver the amount called for in the agreement, they will pay the damage caused thereby to the irrigator. The amount charged for the rental of water has been fixed by the companies, and generally varies from year to year. With the Citizens' and Del Norte canals the prices have ranged from 80 cents to $1 per statutory inch per year.

The farmers seem to prefer to pay a dollar or even more per statutory inch each year for the rental of water rather than buy a perpetual right

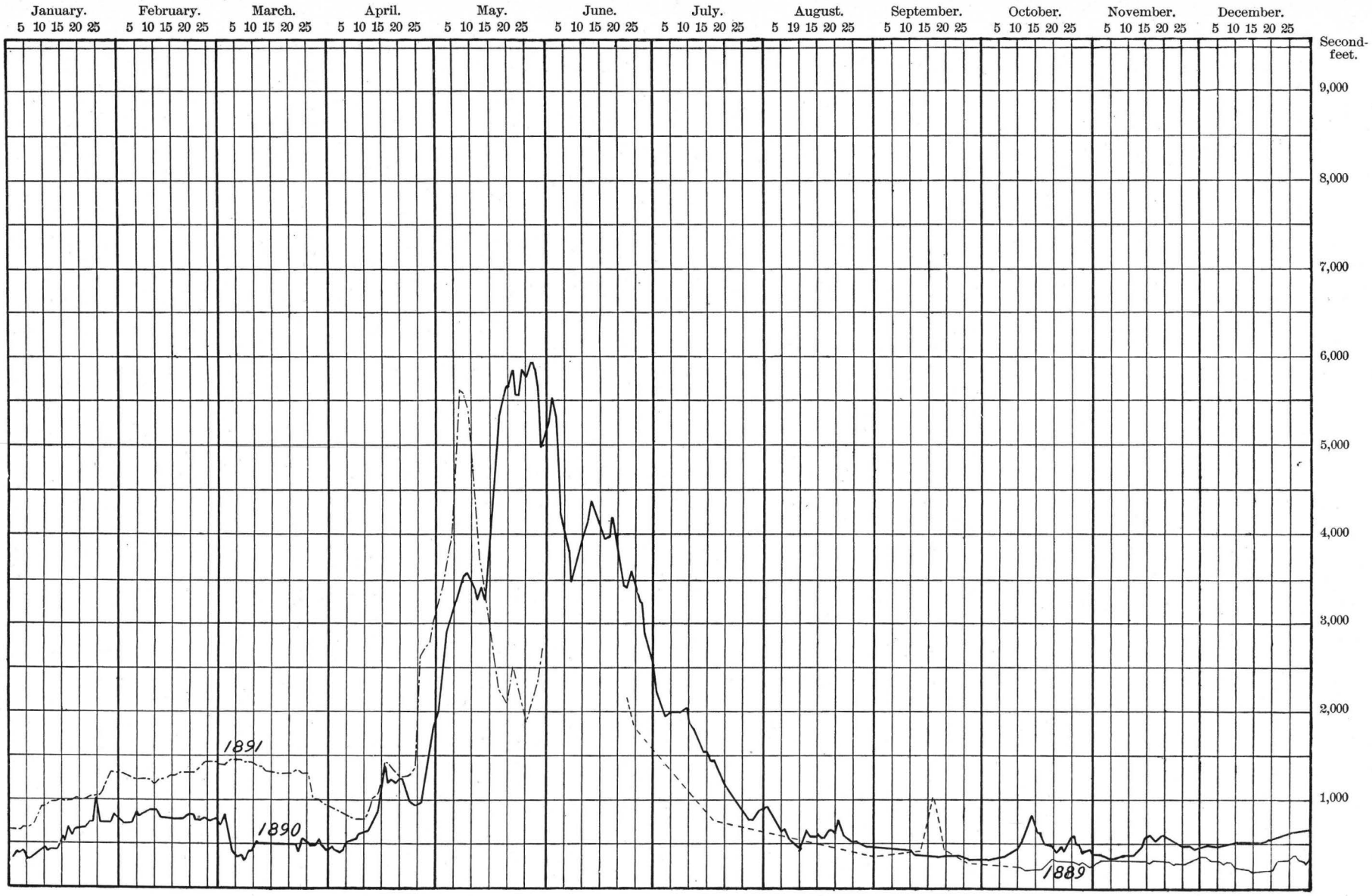
or agreement to irrigate perpetually a certain area of land. This is caused by poverty, by doubts as to the perpetuity of the right, or by fears that the company furnishing water will sell more than it is able to supply. The perpetual use of 1 inch of water has been sold for from $5 to $8, and in one case perpetual water rights for 160 acres sold for from $800 to $1,000, the rights in this case being considered to be the perpetual use of 2·88 cubic feet per second through the irrigating season. These rights are subject to an assessment each year, which the companies agree shall not exceed a specified amount, and it is further agreed by certain companies that, when three-fourths of the capacity of the canal has been sold, the management of it shall be placed in the hands of the water-users.

The duty of water in this valley has been a matter of considerable attention, but the results obtained have not been wholly satisfactory, on account of the fact that there were no devices in general use for the absolute measurement of water. In a small portion of the valley there is considered to be what is commonly known as a "standard" duty of water, viz: 1·44 cubic feet per second to 80 acres, or 1 cubic foot per second to 55·5 acres. The farmers taking water from the Del Norte and Citizens' canals buy or rent it on the basis of from $\frac{1}{2}$ to 1 statute inch for each acre. This latter figure gives the extremely low duty of only 35 or 40 acres per cubic foot.

In fact, the duty of water varies very widely, on account of the differences in the character of the soil, kind of crop, the length of time the land has been irrigated, and the intelligence of the irrigator. The seepage of water through different soils is so widely different that the irrigator can not in many cases estimate what portion of the water passing through the headgate on his lateral really reaches the field. To illustrate the difference of opinion or of practice, it may be well to cite the case of a manager of one of the great farms of the valley, who asserted that certain tracts required thirteen floodings, while others required only one, or possibly two, to produce the same result.

A few farmers who have been, perhaps, more careful in the use of water, and have considered the subject thoroughly, believe that 1 statutory inch is ample for 2 acres, and state that experience has shown that 80 inches of water purchased from a canal has not only watered 160 acres, but that there has been a surplus for use on other ground. Some of the canal companies in selling water by the acre calculate at the rate of $\frac{5}{8}$ of a miner's inch to the acre, or a duty of about 60 acres to the second-foot.

There is no doubt as to the increased duty of water from one year to another; everywhere this question, when asked, has been answered in the affirmative, and it was often stated that during the second year of cultivation the land required only about three-fourths as much water as during the first year. The duty continues to increase, but not as rapidly as at first, until the limit is reached, every portion of the ground



DAILY DISCHARGE OF THE RIO GRANDE AT DEL NORTE, COLORADO.

being thoroughly soaked. The results of this are easily observed, for in tracts of land that have been irrigated continuously for a number of years, the low portions of the field have turned into swamp. On land that has been irrigated for four years, it is asserted that on the fifth year a crop can easily be raised without any irrigation, except that from the seepage from the ditches.

THE TAOS DISTRICT OF THE RIO GRANDE.

South of the Colorado district, and immediately adjoining it, on the east side of the river, is a portion of the Rio Grande Basin, which may be called for convenience the Taos District, from the name of its principal valley. This division includes the streams flowing westerly from the group of mountains of which the Taos Range is of chief importance. The topography of this division is peculiar, and distinguishes it sharply from that of the San Luis Park to the north. The surface rocks consist largely of soft clays, sandstones, and gravels, underlaid by a broad sheet of lava, which appears on the sides of the canyons along the Rio Grande and its tributaries. These easily eroded deposits are deeply cut by occasional storms, and loose material is carried by every flood to the Rio Grande, causing its waters to be turbid and at times overloaded.

The streams leaving their mountain canyons flow for a time over this lava sheet with gentle current, depositing much of the material brought down from the heights and forming alluvial plains; then, as they approach the Rio Grande, they reach the point where the lava has been worn away, and with swift current flow rapidly downward into narrow canyons to join the main river.

The principal valleys in this division from north to south are the Cerros, Rio Colorado, San Cristobal, Arroyo Hondo, and Taos, which will be described in turn from north to south.

At Cerros there is no distinct valley or stream, but several small streams, viz, the Latir, Rito Primero, and Rito del Medio, are taken by ditches and brought into one channel, being caught just after they emerge from the Cerros Mountains. The combined flow does not exceed 20 second-feet. The amount of irrigable land is largely in excess of the present water supply, for a strip extending from the mountains to the Rio Grande, a width of some 8 miles and running parallel to the river for at least 15 miles, can easily be brought under ditch. The land to which water has been brought is scattered and irregular in outline, but there are estimated to be in all about 960 acres under ditch, and nearly all of this is farmed to a certain extent. By a proper system of storage, such as is possible on these mountain streams, the greater part of all this area might be brought under cultivation.

The first valley south of the Cerros region is that through which Colorado Creek flows. This valley is about 4 miles long and contains, it is estimated, about 1,800 acres adapted to irrigation, fully 1,500 acres of this land being under ditch; only a portion, however, is annually under

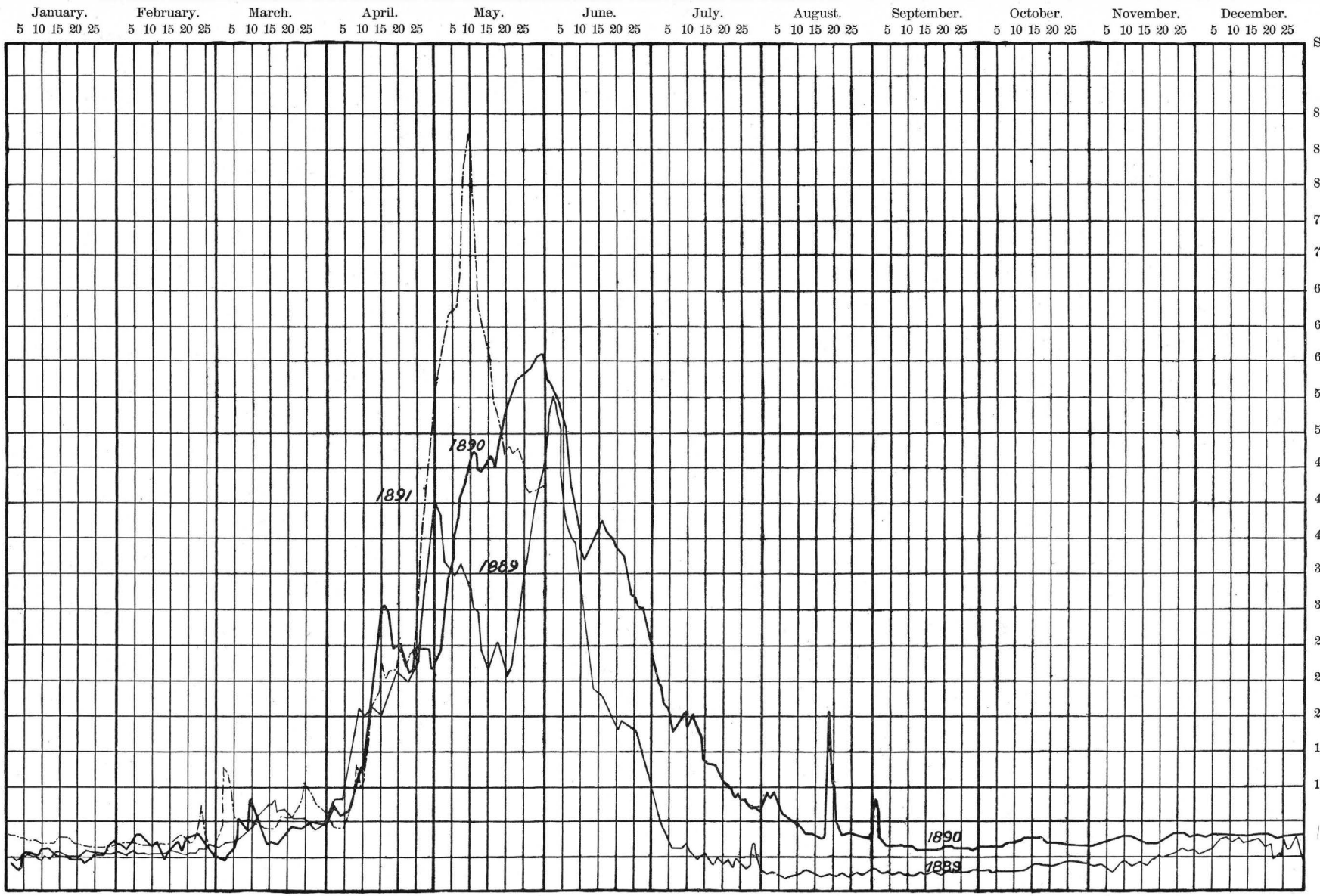
crop. The water supply is derived from two forks of the stream, which join above the place at which water is taken out. It is estimated that nearly half of the water of Colorado Creek is taken across a divide and carried to the mines at Elizabethtown. In the valley the stream was flowing at the rate of 23 second-feet early in March, 1889.

South of Colorado Creek and between it and the Arroyo Hondo is a tract of land 8 to 10 miles wide, extending from the mountains to the Rio Grande. The greater portion of this is covered with timber, heavy among the foothills but growing thinner away from the mountains. Several small creeks whose waters are used in irrigation cross this tract, the largest of these being the San Cristobal, the waters of which are used in a small valley containing about 1,800 acres of land. This is the smallest and least important of the valleys between the Rio Grande and the Taos Mountains, being occupied by a few ranches. The bench portion of the San Cristobal Valley, containing in all about 800 acres, may be considered as irrigable land; of this about 400 acres are under ditch, and the rest could be easily watered. Not more than 250 acres are actually tilled or used as hay fields. The stream is very small, and does not exceed 8 second-feet at ordinary stages, so that it is doubtful if more could be done with the present water supply.

The Arroyo Hondo is the next stream in order south of the San Cristobal. The valley through which it flows is from one-half to three-quarters of a mile wide for the distance of about 4 miles, then it contracts and again opens at short intervals. This valley is for the greater part of its course fully 500 feet below the general level of the surrounding country. The two main ditches which furnish water for the tilled land are taken out about one-half mile up in the canyon on opposite sides of the river. This stream, as measured on February 26, 1889, above these ditches, was flowing at the rate of 17 second-feet, and on November 5, 1890, at about 13 second-feet at a point below Frasier's Mill.

The land in the valley, in all from 1,200 to 1,500 acres, not including the gorge at its upper or the canyon at its lower end, may be classed as irrigable. The main ditches being taken out, one on each side, nearly all the land may be said to be under ditch. A great portion of this area is in crop, and yet it is claimed that but little over one-fourth of the total water supply is used.

South of the Arroyo Hondo is the principal valley of this division—the Taos Valley—surpassing all the others in water facilities and area of crops cultivated. The term "Taos Valley" is apt to give a false impression, for the true valley of the Taos Creek is but a shallow and rather narrow cut in the lava extending from the west side of the Rio Grande nearly to the mountains. The name is given, however, to the lava mesa, about 12 miles long from north to south and about 8 miles wide, lying between the Rio Grande and Taos Range, and having a large population, mostly Mexican. Water for irrigation is obtained



DAILY DISCHARGE OF THE RIO GRANDE AT EMBUDO, NEW MEXICO.

from Taos Creek and its branches, and from the Arroyo Hondo and Seco. The altitude, nearly 7,000 feet, is too high for many kinds of fruit, but large quantities of grain are raised.

The amount of land in the Taos Valley upon which water could be brought is very large, certainly as much as 50,000 acres, and probably even more. The most reliable information indicates about 15,000 acres actually under ditch. This acreage is difficult to estimate, as the land lies in very irregular patches, often isolated, and having an irregular frontage on a stream or ditch. On account of scarcity of water not more than one-third of the land under ditch is annually tilled, the statistics for the census year 1889 showing 5,500 acres of crops raised by irrigation.

The Taos Range to the east is well timbered with pine and spruce, and contains deposits of gold, silver, and other minerals, which are worked in a small way, development of mining industries, however, being retarded by the lack of shipping facilities.

The rainfall in the valley is estimated to be about 16 inches, the greater portion falling during August. There is no economy of water, large amounts being wasted on account of the numbers of small ditches running parallel with each other and taking the water from the river in the most wasteful manner. In place of two good high-line ditches, one on each side of the creek, so built as to carry the entire summer flow of the stream, there are several small acequias built by the early Mexican settlers in such a way as apparently to meander through the land without any system or definite order.

Three principal streams belong to the Taos Creek system, and in fact form the Taos Creek, as this name is given only to the resulting stream. Their names are Pueblo Creek, Ferdinand, and Rio Grande de Taos. From gaugings made by the hydrographers of this Survey below the junction of these creeks it appears that their winter flow does not exceed 50 second-feet. This amount is increased in the spring by melting snow, but it is doubtful if there is more water during summer irrigation, and it is even probable that at that time the supply is usually less. During the last ten years two droughts are reported to have occurred, and it is asserted that the Taos Valley for the last fifteen or twenty years has been subject to periodic droughts at intervals of about three years.

Pueblo Creek on the north enters the valley a short distance above the ancient Indian pueblo of Taos. The Indians residing here have taken out two acequias above their pueblo, one on each side of the creek. The largest ditch taken from this creek has a bottom width of 4 feet, and runs towards the town of Taos, its surplus water finally emptying into Taos Creek. Pueblo Creek carried on February 27, 1889, about 13 second-feet. Its regular summer flow is not entirely utilized.

Lucero Creek is a tributary to Pueblo Creek, coming in from the north or right-hand side, and watering the land lying between it and the Pueblo Creek, as well as a tract of land extending 2 miles to the north of the

creek. The Seco is another tributary of Pueblo Creek, its waters, however, being taken out entirely during the irrigating season, so these waters do not at that time reach Pueblo Creek. Between the Lucero and the Seco is a large tract of land that could be brought under cultivation by high-line ditches taking water from tributaries of the Arroyo Hondo, Lucero, and the Pueblo Creeks.

Ferdinand Creek issues from a narrow canyon about 3½ miles above Taos, where three or four small ditches or acequias are taken from it. The discharge of this stream on February 27, 1889, was only 3 second-feet; its summer flow was reported, however, to be considerably larger. Several years ago, during a dry season, the irrigators having land dependent upon this creek constructed a small reservoir at a favorable point several miles up the canyon, but the embankment was washed out before the end of that year.

The Rio Grande de Taos, which lies furthest to the south, has one tributary, known as the Rio Chiquito, which joins it 2 miles below the point where it enters the valley. Two small ditches are taken from this latter, while from the Rio Grande de Taos ten or more are taken out at short intervals from each other. During the summer season, when the farmers are using the water, there is little, if any, left flowing in the stream. The Rio Grande de Taos on February 23, 1889, carried 17 second-feet below its junction with the Rio Chiquito. By storage in the headwaters of this creek a large tract of land could be irrigated, an amount depending mainly upon the capacity of the reservoir.

Below Cordova the Taos River flows through a canyon to join the Rio Grande. Along its course below the town one or two acequias are taken out, but a large portion of the water is not utilized. The population of the valley is about 7,000, principally Mexicans and Pueblo Indians, these latter owning a tract of land a Spanish league square. They are peaceable and industrious, making better agriculturists apparently than their Mexican neighbors.

Wheat, corn, oats, barley, beans, potatoes, pumpkins, and other vegetables are raised in the valley, and recently apple trees have been planted with success. Alfalfa can be cut three times a year, averaging 1½ tons per acre at each cutting. The shipping facilities to and from this valley are very poor, the nearest railroad station, Embudo, being about 30 miles away.

Wheat is the most important crop grown in this valley, and flouring mills have been built at the Ranchos de Taos. Before the present railways were constructed Taos was an important flour-producing center for the surrounding towns, and even at present flour is sent by wagon or pack train to local mining camps or to be reshipped by railroad.

The Mexican system of threshing, that of treading out the wheat by goats or other animals, has led the Americans and better class of Mexicans to use other flour even when it is more expensive. An objection

to this mode of threshing is that the wheat when gathered from the ground contains pebbles about the size of the grains. It is impossible to separate these pebbles from the wheat by winnowing on account of their weight, and they are consequently ground with the wheat, making the flour somewhat gritty. Oats rank next to wheat in importance, and yield large crops. Beans and peas come next, while corn is but little grown, and then almost entirely by the Indians. Of late years the bean crop has been much damaged by the attacks of insects, amounting at times even to the loss of the crop.

Irrigation by flooding is the system practiced throughout the Taos valley. In each field, after plowing and smoothing, small banks of earth are thrown up with the plow or spade, dividing the field into a number of rectangular divisions called squares. To irrigate this land a small opening is made in the main ditch, or lateral, as the case may be, and water is allowed to flow into the first division or square, from which are openings into the next square, and so on, the water flowing from square to square over a large portion of the field.

"Banking" is but a variation of the flooding system, the water being retained as long as thought necessary in one square before it is allowed to flow into the next. The advocates of this system claim that by checking the flow in this manner the silt is deposited evenly over the whole surface, while by the former method it can be deposited only in more favorable places. The land is also more thoroughly soaked with water, and better results are therefore claimed. There is a constantly increasing use of fertilizers, such as corral scrapings and barnyard manure, and better results are obtained after their use.

Each community in New Mexico has its own customs, many of these dating as far back as the second conquest by the Spaniards. Thus, in communities often but a few miles apart, there is considerable difference in the details of water administration. Taos has the major-domo system, which prevails, with various modifications, throughout New Mexico.

Every spring one of the irrigators is elected by popular vote to the position of major-domo. His powers are wide and varied; he not only acts judicially, but he has power to see that his decisions are obeyed. The ditch is regarded as common property of all who hold land along it. In the early spring every man who takes water from the ditch meets the major-domo at the tail of the ditch and is assigned to his task by the major-domo, who measures off the sections and assigns them at random. A man is required to clean, repair, and put his section in perfect order, the major-domo alone being exempt from ditch work, but receiving no salary.

The distribution and assignment of water is entirely in the hands of the major-domo. The water is given to each irrigator for a certain period, and the decision rests entirely with the major-domo as to the length of time during which he shall have the use of the water. There

is no apparent rule as to the necessity of employing the water to best advantage, the only requirement being that no irrigator shall overrun the time allotted to him. There are complaints from both Americans and Mexicans of partiality shown by the major-domo, and it is easy to conceive into how demoralized a condition a corrupt major-domo might bring a community, especially in times of scarcity of water.

The Mexicans in the Taos Valley and the Indians are reported to have an agreement, dating as far back as the second conquest, by the terms of which the Indians were to have full and exclusive use of the water of Pueblo Creek for four days in the week. The Indians also allowed certain Mexican settlers on the Arroyo Seco to take from the Lucero, a tributary of Pueblo Creek, as much water as would flow through an old-fashioned cart or "carreta" wheel. Both of these rules are said to be observed even at the present time.

Summary of land.

Locality.	Irrigable.	Under ditch.	Cropped in 1889.
	Acres.	*Acres.*	*Acres.*
1. Cerros	100,000	960	540
2. Rio Colorado	1,800	1,500	800
3. San Cristobal	800	400	160
4. Arroyo Hondo	1,500	1,200	600
5. Taos Valley	65,000	15,000	4,000
Total	169,100	19,060	6,100

In the case of irrigable land the figures are probably much too small in the cases of Taos and Cerros. The water supply is comparatively small, and the amount of land is so vastly in excess of the available water that it is not a matter of great importance.

TRES PIEDRAS MESA.

The Tres Piedras Mesa may be taken as including all the country west of the Rio Grande and opposite the Taos Valley, extending from San Antonio Creek on the north to the Black Mesa, just above Espanola, on the south. This vast extent of practically level land is nearly all underlaid with lava. There are several townships of good land on top of the lava, but water could be brought to it only at great expense, as a ditch from the Alamosa or San Antonio River must pass through lava rock for a great part of its length. The Taos Valley Ditch Company was organized to reclaim this land, but their work is now apparently at a standstill, they having built a ditch about 40 feet wide from the Alamosa to the San Antonio, dammed the latter stream just south of Antonito, and taken out a ditch 40 feet wide from it. In May, 1889, this ditch was carrying some 500 second-feet to the end of the excavation, when the water was allowed to escape and to find its way into the Rio Grande Canyon the best it could.

EMBUDO GAUGING STATION.

In the lower end of the canyon, between the Tres Piedras Mesa and the Taos Valley, is the Embudo gauging station of the Geological Survey, located at that point for the purpose of obtaining the total discharge of the river below the Colorado divisions and above the Espanola Valley. The results of the measurements at this point are shown on the tabulations appended, and also on the diagram, Pl. LXXII. This shows a progressive increase in the amount of water from 1889 to 1891, the spring of the latter year being marked by a large flood of short duration. This flood can also be seen on the diagram, Pl. LXXI, for the Del Norte station, shown there a few days earlier and far less in amount. At Del Norte the spring flood of 1891 did not reach the maximum of the preceding year, but at Embudo it far overtops that of 1890.

Observations of the amount of sediment, as described in the previous annual reports, were carried on for a time at Embudo, and the results are shown graphically on Fig. 224, giving the observations from January 14 to April 15, 1889. In the upper part of this diagram the irregular line shows the fluctuations in the height of water, due probably to changes of temperature. The observations during January and February were made a number of times a day with great care in order to show this constant fluctuation of the height of the stream. In March and April, however, they were made only twice a day, so that the diurnal variations do not appear.

The lower part of the diagram shows the proportion of sediment in the water on those days. The dotted line connects the mean observations of samples of water taken from near the bottom of the stream, the observations themselves being shown by the small circles. The results of the sediment determinations made from samples of water taken near the surface are shown by the small crosses, the solid line connecting the mean of these whenever more than one was taken at a time. The diagram exhibits the wide range of results obtained from samples taken at the same point, at the same time, and under circumstances precisely identical. This is especially noticeable when the stream is laden with silt, check samples at that time differing greatly in the percentage of solid matter.

This lack of agreement among samples taken at times when the river is loaded with sediment is rather to be expected, from the fact that the water is moving with that peculiar boiling motion characteristic of floods, and, as can be seen by the difference in color of the water, all parts are not equally loaded. The diagram also shows that on the approach of the spring floods the proportion of sediment increases, but drops off rapidly, either by dilution or by exhaustion of the supply of fine material accumulated during periods of low water and sluggish flow.

The diagram shows the proportion of sediment by means of two scales, that of grammes per cubic foot, as given by the horizontal lines, and of

parts by weight in one hundred thousand shown by figures on each edge of the diagram. During April the proportion of sediment in the surface samples, as shown by the small crosses, increases to such an extent that this part of the diagram overlaps that showing the height of water. This diagram can be compared with that for sediment at El Paso, given on Pl. LXXIV of the last annual report. The greater amount of sediment at that latter point is shown by the fact that in the Embudo diagram the height only allows representation of 65 parts of sediment by weight in 100,000, while the smallest division of the El Paso diagram gives 100 parts in 100,000.

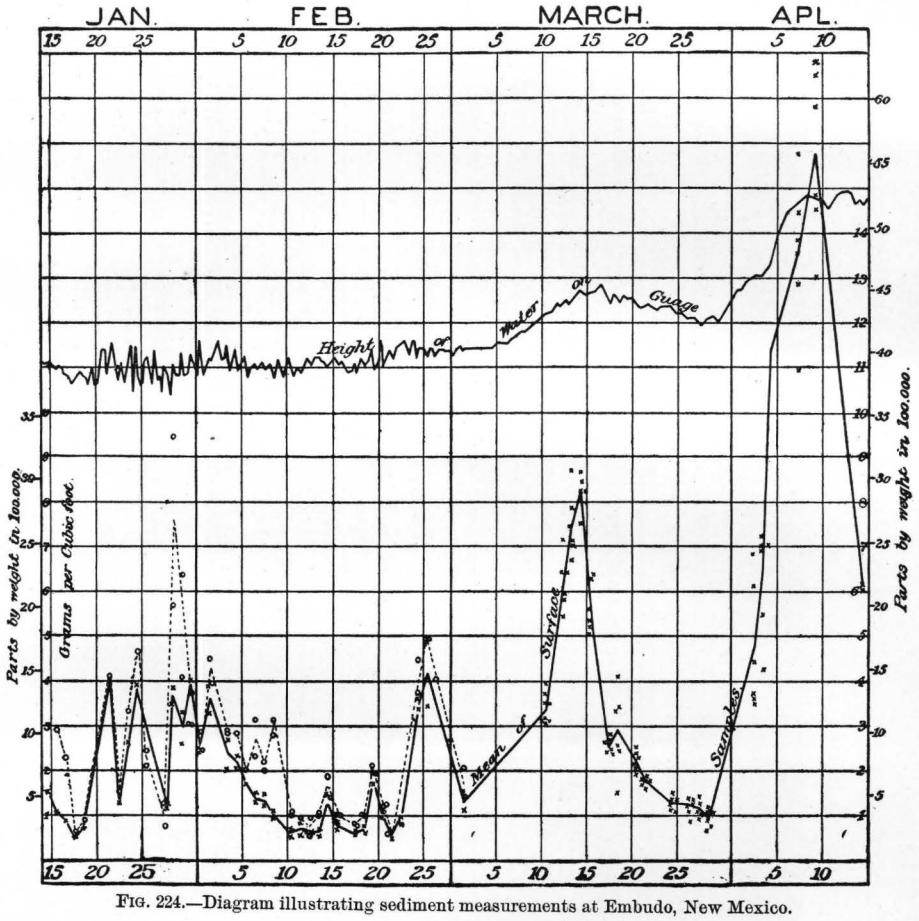


FIG. 224.—Diagram illustrating sediment measurements at Embudo, New Mexico.

ESPANOLA VALLEY.

South of the Taos district and the Tres Piedras mesa is a large valley lying along the Rio Grande and containing an area of agricultural land so great that it may be said to constitute a separate trunk-stream division of the Rio Grande system, known as the Espanola Valley. Before entering the valley the Rio Grande flows through a canyon

whose walls rise somewhat abruptly to the height of 800 to 1,000 feet. Throughout this distance the river is of a torrential character and the process of down cutting is still active. Owing to the general rocky character of the river's bed, this portion of the river is suited for the construction of headworks for a canal, which would become a high-line ditch farther down.

About three miles below Embudo Station the canyon walls retreat abruptly, especially on the west side, giving room for a border of irregular hills between the higher mesa walls and the flood plain adjacent to the river. This is the beginning of the Espanola Valley, which extends to White Rock Canyon, about 25 miles or more below. About two and one-half miles below Embudo railroad station the first acequia, of capacity of about 10 second-feet, is taken out on the east side of the river. To divert the water into it a rude dam of stones and brush has been constructed by the Mexican farmers living at La Joya.

The river assumes a different character on emerging from the canyon, the velocity being diminished and sediment deposited, forming a sandy channel and shifting banks. In this portion of the river headworks of canals can be maintained with difficulty owing to the instability of the foundations. About three-quarters of a mile below the mouth of the canyon is the Mexican village of La Joya, which stretches irregularly along the road for nearly a mile. Almost all of the low-lying land is under ditch and cultivation, as is the general rule throughout the Espanola Valley wherever the land is of good quality.

The manner of applying water to the soil is very simple. The land is laid off in squares, and the water drawn on them in most cases directly from the main ditch, though in some cases short laterals at right angles to the main ditch are used. Several thrifty orchards of apple and peach trees are to be seen at La Joya, but they were small in extent, generally not more than one-third of an acre.

From the mouth of the canyon to La Joya church there is scarcely any land that could be brought under cultivation by a high-line ditch, but below the church is a small plateau or bench, about 75 feet above the river, which might be brought under ditch, although much grading would be required in preparing the land for the water.

About 3 miles below La Joya is San Juan, an Indian pueblo, the thrift and prosperity of which, as exhibited by the fields and adobe houses, is notable. From San Juan to Espanola the lowlands are under ditch, and in the main are cultivated, but the soil appears poorer or the cultivation worse than at San Juan, and there are a few deserted houses. In the valley, as a whole, the land is irrigated only upon the lowest level, and a large tract on the east side of the river near La Joya and Alcalde, although smooth and admirably adapted for irrigation, is unused. A high-line ditch was projected, to be taken out of the river below Embudo railroad station, which was to take in this land and run as far south as the mesa beyond Santa Fe Creek. The men inter-

ested in the scheme are reputed to have obtained a small sum of money and then left without accomplishing anything in the way of construction. Not more than one-third of the irrigable land in this portion of the valley is actually under ditch.

About 5 miles above the town of Espanola the Chama River enters the Rio Grande, the muddy water brought by this stream changing the character of the river deposits. Above the junction these are sandy, but below the Chama they are of a more clayey nature and in several places the river has divided into two or more channels. Just below Espanola the Santa Cruz Creek enters the river from the east, discharging in March, 1889, about 15-second feet, but carrying a larger quantity 2 miles above Santa Cruz pueblo and the Mesilla acequia. This acequia runs about 5 miles down the Espanola Valley to and past the village of Mesilla.

Just below Mesilla are the remains of a very large ditch, which was dug about forty years ago. It extended from below Espanola to below the Huerfano Butte, a distance of from 8 to 10 miles. The owner apparently abandoned it, and the headworks were soon washed away, so that for many years there has been no water in the ditch. From the Huerfano Butte to San Ildefonso Pueblo, a distance of about three-quarters of a mile, is little or no irrigation, and no very readily irrigable land, though there are traces of old ditches, probably the end of the old ditch mentioned above.

At San Ildefonso, in the southern end of the Espanola Valley, the waters of Pojuaque Creek are used for irrigating several hundred acres, as well as for lands along this creek as far up as the village of Pojuaque. The stream was flowing about 20 second-feet when measured in March, 1889. The San Ildefonso Indians have a large body of land under cultivation between their pueblo, the river, and White Rock Canyon, all of which is served by Pojuaque water.

Only a small portion, perhaps 10 per cent, of the water of the Rio Grande is taken out in the Espanola Valley, and much of the irrigation of the valley is done with water from the creeks which flow into the river from both sides. The use of this water in preference to that of the Rio Grande is due to the greater ease with which it can be brought on the land and to the difficulty of constructing and maintaining headworks on the river.

The population of the valley is almost entirely Mexican and Indian, and, while nearly all of the easily irrigable low-lying lands are under irrigation, it is apparent that the productiveness could be much increased by better cultivation, with improved farming implements and better management. The Indians cultivate only enough land to supply their needs, and thus have large areas of fertile lands untilled. The ditches are all small and are owned and maintained by the various communities. The lands of this valley as a rule have a little alkali, but not enough to seriously interfere with agriculture. There appeared

to be a greater proportion around San Ildefonso than elsewhere, but even there it seemed to be no serious obstacle.

The eastern limit of practicable irrigation in the valley is marked by "bad lands," which consist of beds of gravel, sands, and clays, sculptured into fantastic forms by erosion similar to those shown in Pl. LXIX. The country is barren and sandy until the divide that separates the Espanola Valley proper from the Pojuaque Valley is crossed. The Pojuaque Valley is narrow, and the amount of water in the stream small, the present settlers requiring for their use all the water available. The stream flows for a great part of its course in a canyon that extends to the mountains, a few miles above Pojuaque Pueblo.

A short distance below Pojuaque the Tesuque joins the Pojuaque, the resultant stream flowing through a valley about eight miles long before reaching the Rio Grande. The Tesuque is about the same size as or a trifle smaller than the Pojuaque. The irrigable land consists of a narrow strip on each side of the stream, averaging about half a mile in width. It is doubtful if more land than at present tilled can be irrigated during dry seasons by the present unregulated supply. A high barren divide, with cedar and piñon bushes, separates the headwaters of the Tesuque from those of Santa Fe Creek to the south.

THE CHAMA DISTRICT.

The Chama,[1] which joins the Rio Grande in the Espanola Valley, is perhaps the largest tributary of that river, draining an area of 2,300 square miles, or nearly one-quarter of the total catchment area of the Rio Grande above the junction of these streams. This drainage basin consists principally of high plateaus and mountain ranges, and there are no alluvial valleys, strictly speaking, except a long, narrow valley below Abiquiu. There are, however, several low, fertile mesas, which are as valuable as valleys. The richest one is between the Nutrias and Brazos rivers, in the Tierra Amarilla grant, this tract containing also several other fine low mesas. Little, however, has been done to develop this great area, although its possibilities are large.

From Chamita, at its mouth, to Abiquiu, some 25 miles above, the Chama flows in a valley similiar to that of the Rio Grande, but with somewhat greater fall. The lower part of the river's course is through a broad valley; above this are canyons, and again a broad valley, this latter being below the canyon in the Tierra Amarilla Mountains. There are thus four general divisions, an upper and a lower valley, with a long canyon above each.

The lower Chama Valley is bordered by broken hills and bluffs of soft sandstone, similar to those shown on Pl. LXIX, clay and gravel, and the higher mesa, capped with lava, seldom approaches the river. Above Abiquiu the canyon portion, called the Canyones de Chama, commences, and extends as an almost continuous canyon to El Bado, a few miles be-

[1] Mainly from report by G. T. Quinby.

low Tierra Amarilla. There are, as is usually the case along rivers of this type, some places, locally termed "rincons," in which the valley becomes sufficiently broad for agricultural purposes. About Tierra Amarilla the third division of the river course is reached, having many of the characteristics of the lower part, the deposits in both of these divisions being probably of lacustrine origin.

The perennial tributaries of the Chama, of which there are sixteen of notable importance, vary in size from mere rills in summer to creeks whose headwaters, lying well up in the mountains, have a strong persistent flow throughout the year.

All of the tributaries entering the Chama below the Cebolla, with the exception of the Puerco or Salinas Creek, have broad sandy channels near their mouths, and thus in this portion of their course lose much water by seepage and evaporation. Their valleys are usually broad, and rise from the stream in gentle slopes on both sides, being bordered by irregular hills.

In the case of the Puerco or Salinas Creek the canyons near its mouth keep near the surface the water that would otherwise be disseminated through the sand, and on this account more water reaches the Chama. The loss of water in the Ojo Caliente, Oso, El Rito, Lower Canyones, and Cangilon is particularly large, and also, though to a somewhat less extent, in the Gallinas.

There are two general topographic features of these streams, viz: the canyon portion, in which they descend rapidly from the mountains, and the valley portion of varying width, in which they flow gently to their outlets.

On the Cebolla, Nutrias, and Nutritas the same characters exist, except that the valley portion consists of a mesa having a sheet of volcanic rock a short distance beneath the surface. The result is that a box canyon extends for a short distance from the mouth of the stream and checks in great measure the erosion above it, leaving a stream with a shallow bed flowing in a gentle depression. The Brazos, Canyones, Willow, and Little Chama belong rather to the first class of streams, those having broad valleys, but less water is lost, owing to the fact that for most of their length the sides and bottoms are formed of compact clay and the bed is narrower.

The Chama is essentially a muddy stream, and from its mouth as far up as the Gallinas Creek, not only is the Chama itself muddy, but every tributary is pouring into it a muddy torrent. Above the Gallinas the water is clearer, and its tributaries, especially the Brazos, less muddy. Taken as a whole, the Chama, however, is not so muddy as the Rio Grande south of Albuquerque, nor the Puerco below Nacimiento. The Chama and tributaries below the Cebolla carry also a considerable amount of soluble matter, and patches of alkali land are frequent. Above the Cebolla the larger streams carry but little alkali, but the smaller, particularly at low stages, apparently carry a large proportion. The alkali seems to be principally found in the lake deposits.

The amount of water in any of the streams of the Chama drainage system depends upon a wide range of modifying conditions. Most of the streams head in the mountains at an altitude of at least 8,000 feet, where the winter snowfall is usually very heavy. During the spring, while this snow is melting, the volume of the stream is swollen, and warm rains during this period are apt to produce sudden floods. After the snow has disappeared and throughout the summer occasional heavy rains cause a rapid increase in the volume of the discharge, followed by a decline almost as sudden. During the late summer and autumn the streams become low, receiving their water from the slow drainage of the ground, and remain so until the snow again melts in the spring. The increase of volume over the outflow of ground water may therefore be divided into the regular yearly increase from melting, of which an approximate estimate may be made from the amount of snow at the headwaters of the streams and the spasmodic increase from torrential rains, an adequate measurement of which can be obtained only from systematic records.

The volume of water at any point in the Chama or in any one of its tributaries depends upon two conditions: First, as has been noted, upon the weather, especially the precipitation during the season; and secondly, upon the portion of the stream at which the measurements are made—that is to say, upon the physical characteristics and structure of the valley. A great loss of water in the lower portion is characteristic not only of the Chama, but also of all of its tributaries entering below the Cebolla. This loss is occasioned by the spreading of the stream into several shallow channels in a broad sandy bed of gentle slope. The streams entering the Chama are briefly described in order upstream, the discharge of each being given as ascertained by measurements made in March and April, 1889. Oso Creek is a small stream entering the Chama from the south about 8 or 10 miles above Chamita. Its flood bed is broad and sandy, but in ordinary stages a mere thread of water flows in it. There is a brush dam near the mouth, the water being taken into the Chama Valley, as that of the Oso is very small and irregular and bordered by broken and greatly eroded hills. The discharge of the Oso March 26, 1889, was 5 second-feet.

Ojo Caliente Creek, which flows into the Chama nearly opposite Oso Creek, was measured several times and found to carry during the winter of 1888–'89 from 33 to 50 feet. The creek was higher on March 26, 1889, and was discharging about 75 second-feet.

El Rito Creek enters the Chama Valley from the north, as a small stream flowing in a flood channel nearly 200 yards in width, with banks about 8 feet in height. The valley near the mouth is narrow and the stream bed broad, but 10 or 12 miles above this point the valley widens considerably. Some 3 miles above the town of El Rito the river leaves a canyon, within which the measured discharge was found to be 33

second-feet in March, 1889. The stream at that time had evidently not acquired the full volume from the melting snow. At the same time the El Rito was flowing 9 second-feet at the point above where it empties into the Chama, the loss being probably due to evaporation and seepage.

The Frijoles is a small stream joining the Chama from the south, above Abiquiu. The bed is probably dry in summer; on March 28, 1889, however, the discharge was about 5 second-feet. The valley along this stream is of inconsiderable size.

The Canyones also enters the Chama from the south, at the lower end of a large rincon called the Vega del Riego, from a Mexican ranch in it, this point being at the upper end of the sandstone canyon above Abiquiu. The valley is sandy at its mouth, and is narrow and bordered by sandstone mesas. On March 28, 1889, the discharge was 14 second-feet, but the water was muddy, showing that the stream was somewhat swollen. In summer the bed must be dry for some distance above the outlet.

Cangilon Creek flows into the Chama from the north through a great arroyo called the Rio Seco, in passing through which a large amount of water is lost. There are openings along the course of the Cangilon containing in all several hundred acres of good bottom land. The discharge of the stream after it had emerged from Navajo canyon was found to be 28 second-feet on March 30 and 45 second-feet on April 5, 1889. The water was muddy, due to rapid melting of the snow. It is reported that the Cangilon at this point flows throughout the summer.

Gallinas Creek is a muddy stream entering the Chama from the south in a comparatively narrow, sandy valley, bordered on both sides by high sandstone mesas. The bed is sandy, and the water is spread over it in a thin sheet. Irrigation in the valley is confined to the vicinity of the town of Gallinas, some 15 or 20 miles above the mouth of the creek. The Gallinas was flowing 12 second-feet at its mouth March 29, 1889, and April 7, at Gallinas, about 20 second-feet.

Cebolla Creek enters the Chama from the east bank through a lava canyon. Above the canyon it flows through a valley, broad in comparison to the size of the stream, and with a gradual rise on each side. There is little sandy soil in the valley, but the water supply is too small to irrigate even the bottom land of the stream. With more water an enormous tract could be brought under ditch. The stream is of the type of those having clay banks, soft shale outcropping at various points in the valley, and it reaches hard rock only when it cuts through the lava sheet at its mouth. It was very muddy, flowing 12 second-feet when gauged on March 31, 1889. The discharge during summer must be very small, but it is reported that there is always some water in the channel.

Nutrias Creek also empties into the Chama from the eastern side, a few miles above the Cebolla. This valley is topographically almost identical with that of the Cebolla, and is characterized also by the great disparity between the amount of land in the valley suited for irrigation and the

small amount of water in the stream. The water of this stream was less muddy than that of the other streams above mentioned. The discharge was 10 second-feet on April 1, 1889, at the Lopez ranch, at the entrance to the canyon, below all irrigation.

The Nutritas also flows into the Chama from the east bank, a short distance above the mouth of the Nutrias and is similar to the Cebolla and Nutrias, except that this valley is somewhat narrower. Water from the Nutritas is taken out a short distance above Tierra Amarilla, and brought upon a mesa extending from that place to Park View on the Chama. There is only enough water, however, to show what might be done were it practicable in any way to increase the supply. Above Tierra Amarilla the valley rises very gradually on each side of the stream in great undulations covered by forests of long-leaf pine, none of this land being cultivated. There seems to be no surplus water in the Cebolla, Nutrias or Nutritas. The Nutritas was flowing April 1, at a point about 5 miles below Tierra Amarilla, 26 second-feet.

The Brazos is the most important tributary to the Chama, flowing into it from the east about 2 miles above Tierra Amarilla. It is formed from two streams heading high in the Tierra Amarilla Mountains, near Brazos Peak. The lower valley is broad and cultivated, but the stream flows through this in a wide, pebbly bed. From about 2 miles above its mouth to the point where it leaves the canyon it is bordered on both sides by gently rolling land covered by pine forests, which when cleared will yield valuable timber and leave several thousand acres of irrigable land. None of this pine land above Ensenada is cleared, although a couple of irrigating ditches are brought through it.

The bed of the Brazos has the bowlder-strewn character of a mountain brook, and its fall is rapid; even in stages of high water the stream is clear. On April 2, 1889, the discharge was 150 second-feet, and much of the snow in the mountains had not then melted. It is stated that the Brazos continues to discharge all summer an amount of water nearly as great as this.

The Canyones and Willow Creeks are two small streams entering the Chama from the east bank. They have very small catchment areas, and were flowing on April 4, 1889, 8 and 12 second-feet respectively. It is probable that in summer they are nearly if not quite dry. There is no cultivation in these valleys, but in places some hay is cut.

The Little Chama is the name given to the western fork of the Chama, which joins the main stream about 2½ miles below the town of Chama, flowing in a broad valley, and having steep clay banks. At the time when measured the snow was melting rapidly, and the stream was flowing bank full, and besides this, every wash and arroyo was pouring a flood of muddy water into it. It is evident, therefore, that its volume of 95 second-feet is much above the average.

Summary of water flowing in the tributaries of the Chama, as measured March 26 to April 4, 1889.

	Second-feet.
1. Oso	5
2. Ojo Caliente	75
3. El Rito	33
4. Frijoles	5
5. Canyones (Lower)	14
6. Cangilon	28
7. Puerco or Salina	40
8. Gallinas	12
9. Cebolla	12
10. Nutrias	10
11. Nutritas	26
12. Brazos	150
13. Canyones (Upper)	8
14. Willow	12
15. Little Chama	95
Total	525

This estimate does not include the water in the main branch of the Chama above the town of Chama, which must have been flowing at the rate of at least 300 second-feet. The total discharge of the Chama at Abiquiu at this time was estimated to be 750 second-feet.

Beginning at Chamita, a small Mexican town at the mouth of the river, having an altitude of 5,619 feet, the Chama Valley rises to the northward, the increase in elevation being accompanied by colder climate. At Abiquiu the altitude is 5,930 feet, but the climate is reported to be similar to that at Espanola, the Jemez Mountains to the south and rising land to the west and north affording ample shelter. From Abiquiu the land rises steadily to the west and north, and at Tierra Amarilla an altitude of 7,466 feet is reached. Here frosts occur in May, and are not uncommon even as late as the latter part of June. Much snow falls during the winter, and remains upon the ground until late in the spring. At Chama the elevation is 7,840, feet and snow usually remains upon the ground until about the first of May or even later.

Although the summer season throughout this country is short, it does not appear to have a deterrent effect upon agriculture in general, except that some of the more sensitive fruits and crops are not raised, and although the winters are colder than those of the Rio Grande Valley and the snowfall heavier, still winters as cold and snows as deep are successfully encountered by farmers in other sections of the country. There is a great compensation, however, in the increased and prolonged spring water supply.

As much as 40 per cent of the irrigable land may be considered as under ditch in the Chama Valley, not including the great area of lava mesa or the upper portion of the valley. In proportion to the amount of land in the valley suitable for irrigation the El Rito appears to have

most land under ditch, and the Vega del Riego and upper Chama, above Los Brazos, the least. In at least two cases, one above Ensenada on the Brazos, and one above Los Brazos on the Chama, a ditch ran for several miles through timbered land from which the trees had not been cleared, nor the water used on the route. Much land is also under ditch and not used on account of the peculiar location of the little isolated ranches, to water which the owner has been compelled to take water from the stream some distance above the place on which it is to be used, the intervening land thus being brought under ditch, although not owned by the irrigator.

The amount of land under crop is small, and in no instance has anything like farming on a large scale been adopted. For a large portion of the country the railways are so distant that it would appear impracticable for a farmer to attempt to raise crops larger than required for his own use, or for the limited demand of some merchant. Only in three localities is there anything approaching a general cultivation of the land. These are at Tierra Amarilla and surrounding towns, at that part of the valley between Chamita and Abiquiu, and also about the town of El Rito. In all the rest of the valley, not taking into account scattered ranches along the tributaries, the amount of irrigated land would not exceed 1,000 acres.

Summary of the estimates of irrigation.

Localities.	Irrigable.	Under ditch.	Actually under crop.
	Acres.	*Acres.*	*Acres.*
Chamita to Canyones	20,000	10,000	2,100
El Rito and Caliente	6,000	3,000	400
Vega del Riego	20,000		
Smaller tributaries	10,000	4,000	600
Two Lower Terraces (La Puente to Chama)	9,000	5,000	1,300
Upper mesa (about Tierra Amarilla)	35,000	8,000	1,100
Total	100,000	30,000	5,500

These estimates are probably too small as regards the amount of irrigable land, which may prove to be nearly 50 per cent greater than is given.

In the Chama Valley as at Taos, with but few exceptions, the water is applied to the soil by flooding "squares" or small rectangles surrounded by ridges of earth, this system of taking the water directly from the main ditch and allowing it to flow from square to square being general throughout New Mexico. Apparently when the water is allowed to flow unchecked over the land, the finer sediment can be deposited only in the most favorable places, and thus quite as much soil is washed from the land as is deposited upon it.

In the case of grass, however, after the squares are full the flow is checked, and the water kept upon the ground for some time. Thus not only does the finer material have time to settle, but the soil itself

is more thoroughly soaked with water. The general opinion of the irrigators is that as now cultivated land decreases in productiveness with constant cropping. At those localities however, where this holding the water between ridges or "checks" is practiced, the decrease in productiveness is said to be less.

Wheat, oats, peas, beans, barley, corn, and potatoes are the principal crops raised in the Chama Valley. "Rust" or "smut," a parasitic growth, is one of the plagues of the wheat growers, particularly in the neighborhood of Tierra Amarilla. The "lady bug" is a source of considerable damage to the bean crop, often resulting in its partial destruction. The yield per acre of wheat is variously estimated throughout the valley, but on successful farms a little over 20 bushels per acre is probably a fair average.

Potatoes are little grown by the Mexicans, but other inhabitants find no difficulty in raising good crops. At higher altitudes, particularly near the mountains, potatoes could, without doubt, be raised without irrigation. Corn is grown only to a small extent in the upper Chama Valley, principally from the fact that it matures somewhat later in the summer than the other crops, and when water is too scanty for the final irrigation. Alfalfa is not a common crop, but more is being sown each year, and it is reported that three good crops can be cut.

Fruit and grapes are grown in the lower part of the valley and about El Rito. Some fruit is also raised about Tierra Amarilla, and there can be but little doubt that suitable varieties of apples, pears, and the more hardy fruits can be raised all through the valley.

The soil throughout the Chama Valley is in general composed of a mixture of sand and clay, the clay usually in excess. An exception may be made to this statement in the case of the lower portion of the Chama Valley, which is very sandy. The valleys of the upper tributaries, and indeed of the upper Chama itself, have a decidedly clay character, while the ridges and higher ground are usually more sandy.

The testimony appears almost entirely on the side of the opinion that when properly irrigated the land suffers no decrease in productiveness from continuous cropping. Instances are cited in which land cropped continuously for 10 or 12 years was supposed actually to have gained in productiveness. In the lower Chama Valley there is probably a large amount of silt deposited upon the land, but in the vicinity of Tierra Amarilla the streams are clearer, and a smaller amount is deposited.

So far as ascertained there is no canal company in the Chama Valley selling water. All the ditches are owned either by communities or by individuals, and no record is kept of the cost of putting water upon land. The realization that time has a money value is almost unknown among Mexicans. When they can do anything themselves, they take no account either of their time or labor. This is shown in many localities in New Mexico where brush dams, requiring yearly a great amount of labor, are common. The farming in the Chama Valley is done almost

entirely by Mexicans, the few inhabitants of other nationality being cattle men, miners and storekeepers, and on this account it has been found a matter of great difficulty to obtain reliable estimates.

Local regulations regarding the distribution of water differ in almost every town, apparently having grown up from a mixture of Spanish and Indian customs. The customs of the Pueblo Indians are essentially communal, and have left a strong impression upon the local rules now enforced, as embodied in the major-domo system, whose code is largely unwritten, but is enforced at least among the Mexicans.

In some portions of the territory water is given to the user strictly by time; in others, by the actual need of his crop for it; in others, according to the amount of land that he has under crop; and yet again, according to the amount of work he has done in repairing and clearing out the ditch. The ditch itself is built and maintained by the joint labor of the community, and is common property in the strict sense. No one is allowed to take water from the ditch unless he has either personally or by proxy done the task assigned him by the major-domo, either in the construction or in the maintenance of the ditch. As in the case of the Taos Valley, the major-domo is elected every spring, and has charge of everything connected with irrigation. In some places he is paid a small salary during the spring months; in others his services are voluntary, except that he is exempt from work on the ditch.

SANTA FE DISTRICT.

The streams of which Santa Fe Creek is the chief and which enter the Rio Grande south of the Espanola Valley can be considered as forming a division by themselves. These rise in the range east of Santa Fe and flow westerly over high plains to join the river. In the mountains at the head of Santa Fe Creek are two small lakes, which may be considered as typical of those at the head waters of other streams flowing towards the Rio Grande. Many of these can be utilized as small storage reservoirs by constructing dams at the outlets. A description of one will serve to show the conditions surrounding them.

At the head of Santa Fe Canyon is a lake about 4 acres in area, with a depth of 20 feet. Formerly this lake was larger, but some years ago an outlet was cut reducing the level by about 6 feet. This outlet can be closed by a dam and suitable gates, so that the level of the water can be raised at least 15 feet, forming a reservoir of small size, the surface area being between 5 and 6 acres in extent. In September, 1889, at the driest time of the year, a stream of about 2 second-feet was flowing from the lake.

By the utilization of this and other small reservoirs the summer flow of Santa Fe Creek can be increased, sufficiently at least to be of great benefit to the agricultural land at the time when, by reason of low water, many of the crops, and even fruit trees, are injured by drought. The elevation of these ponds is about 11,000 feet, and the evaporation is very small, since they are surrounded and protected by the mountain peaks.

Along the valley of the Santa Fe Creek, below Santa Fe, but a small amount of land is cultivated. Agriculture is limited by the small amount of water that can be depended upon during the growing season. The stream runs through a valley with gradually sloping sides as far as Cieneguilla, a Mexican town about 12 miles from Santa Fe. At Cieneguilla the stream enters the La Bajada Canyon, which is deep and narrow as far as the town of La Bajada, below which is a broader valley with a gentle slope to the left and the edge of the mesa to the right. This valley continues almost to the mouth of the creek, a distance of some 6 or 7 miles.

The mesa between La Bajada and Pena Blanca, on the Rio Grande, has a smooth surface and gentle slope, so that water could be brought from La Bajada Canyon and many thousand acres be put under ditch, if sufficient water could be obtained by storage or other means. During the spring months a large amount of water passes through the canyon, and it is probable that much water might be saved in the canyon even by dams of a temporary character, such, for example, as are used on the Puerco.

In the neighborhood of Pena Blanca the land is as thoroughly cultivated as in any part of the Rio Grande Valley. Grain fields, orchards and vineyards abound, and the ditches are carried back close around the base of conglomerate-capped sand hills that mark the edge of the valley, so that there is but little land not under ditch.

Four miles down the Rio Grande, near the mouth of the Gallisteo, the first creek south of the Santa Fe, is the pueblo of Santo Domingo, and several miles up the creek above this is the town of Wallace. A very deep ditch runs across the little divide between the Rio Grande and Gallisteo Creek, and, although the land is well adapted for irrigation, the water is not used along the ditch, but only at distant points. The Gallisteo Creek was dry when examined in January, 1889, but showed signs of frequently carrying large amounts of water, and the railway company has done considerable work to prevent it from encroaching upon their track. It drains a large watershed, and toward the headwaters a constant stream flows in the channel.

ALBUQUERQUE DISTRICT.

Under this name can be included all the Rio Grande Valley from Pena Blanca to San Marcial. The valley is narrow, being at no place over 3 miles wide, and at many points the bounding hills or mesas approach each other so closely that no room is left for bottom lands. Around Bernalillo, Albuquerque, and Belen are areas of cultivated land of excellent quality and some large vineyards; the extent, however, is not as great as in the Mesilla Valley further down the river. Below Bernalillo and also below Belen on the east side of the river are large alkali flats, once productive fields, but now worthless from lack of drainage.

The river from Pena Blanca to San Marcial occupies a broad sandy

bed, dividing in low stages into a number of narrow and crooked channels, but in flood covering in many places nearly half of the valley. Above the pueblo of San Felipe, for a distance of from 6 to 8 miles, a large percentage of the valley is under ditch. At San Felipe the valley narrows, and between the San Felipe and Algodones Creeks a large part of the agricultural land seems to have been deserted, and several of the higher ditches have been abandoned. This is possibly the effect of the Santo Domingo and San Felipe grants, which cover nine-tenths of the valley between Santo Domingo and Algodones, and are much larger than the Indians can cultivate under present conditions.

Near Bernalillo the many vineyards and orchards give to the country an appearance of prosperity. The same may be said of the valley between Bernalillo and Alameda, about half way to Albuquerque, although a large portion of the area is occupied by the broad river bed. The country about Bernalillo is one of the wine-producing centers of the valley, and is reputed to have the largest distillery in the territory.

Near Albuquerque is more waste land, and the valley is bordered by barren hills of blown sand. This sand settles in and around the low bushes of the valley, forming hillocks, which give this portion of the valley a curious appearance. Much of the land is fenced and is devoted to raising a scanty supply of a coarse grass for grazing purposes. The vineyards and orchards are smaller, and there does not seem to be the same thrift and prosperity as about Bernalillo.

From Albuquerque to Los Lunas, a distance of some 25 miles, the the western side of the valley is broader, and has great hills of wind-blown sand for its border. Only the lower and more accessible parts of the valley are irrigated, although there is a large amount of rather sandy land which is still capable of cultivation, and which could easily be brought under ditch. The valley as far below Albuquerque as Pajarito, about 8 miles, is thickly inhabited, but the average amount of land per family cultivated among the Mexicans is very small, not exceeding a couple of acres. The number of English-speaking agriculturists in the valley is insignificant.

From Albuquerque to San Marcial the drainage of the lower lands of the Rio Grande Valley is exceedingly poor. Many ponds, some of them 8 or 10 acres in extent, are full of water during the early part of the year, and others show by the alkali coating on their sides and bottoms that the water has but recently left them. This alkali coating is so universal between Los Lunas and Belen as to give to the casual observer the impression of a light snow. Apparently the Mexicans have no system either of surface or under drainage, without which it is doubtful if much further cultivation can be successfully accomplished. The ditches in this low land are liable to frequent overflow, and much damage is yearly done by their being washed out or being filled with silt.

The pueblo of Isleta, 15 miles below Albuquerque, is said to be one of the richest in the Territory, and appears to be in a more prosperous condition than the neighboring Mexican towns. Between Isleta and Los Lunas is but little farming, but at Los Lunas the vineyards are important and some wine is produced. Very little alfalfa is grown in this vicinity.

From Los Lunas south the valley is thickly inhabited, and there is a succession of small clusters of Mexican houses. The same apparent lack of industry and thrift prevails as in many places along the river bottoms, and the disadvantages of living on the low flats are shown in the number of houses which have fallen in by the sinking of the foundations. A large part of the valley south of Los Lunas is overgrown with cottonwood thickets or bosques, as they are called. Where these are cut away the land is found to be excellent. The vineyards seem to be thrifty and in good condition wherever care has been given, but the absence of orchards is notable. All along the sides of the valley, at elevations a little higher than the portions now cultivated, are lands which probably could be irrigated by higher and larger canals.

The Rio Grande Valley below La Joya station, 53 miles south of Albuquerque, narrows again, and at San Acacia the river enters a canyon about 250 yards wide, the river occupying the greater part of this width, at ordinary stages running through the sand in several channels. Below San Acacia high bluffs on the west side of the river leave only a small strip of irrigable land some 6 or 8 miles to the southward. These bluffs are farther back from the river on the east side, so that more land can be utilized, and about 5 miles north of Socorro the valley becomes considerably broader. Throughout this section, and indeed all along the valley, farming is carried on upon a petty scale, and not more than one-third of the land is under ditch. From Socorro to San Marcial the character of the valley and its conditions are essentially the same as portions already described, there being perhaps more bosques and fewer settlements. Colonies have been started just above San Marcial, and also near Fort Craig.

The methods of irrigation in this long valley are those of a past century; innumerable small ditches take water to the bottom lands only. Every town has its acequia, an unsurveyed, irregular ditch, built without method and controlled in a haphazard way. At the head are brush dams, and along the course, whenever it crosses an arroyo, the ditch is liable at every rain to be washed out, and, at nearly every road crossing, its banks are worn down by animals and wagons. The acequias are the common property of the people using them, the water tax consisting in a share of work in the ditch repairs, an amount depending upon the quantity of land irrigated. The water is supplied by the hour, a man being allowed certain days and nights in his turn, during which time he may fill his "contra acequia." The major-domo who distributes the water is supposed to see that each man gets his proper share, reckoned in hours, and that his head gate is closed at the proper time.

The results of this rather loose system are both beneficial and injurious; beneficial in that any man, even the poorest, can pay his water tax; injurious in that no one is responsible for a continuous supply of water, and because the system, once started, is seldom or never improved, and such systems are almost always begun on a very small scale.

Irrigation along the Rio Grande is in practically the same condition as when the Spaniards first passed up the valley. Some few new customs have been introduced, but the system is essentially the old Pueblo Indian system. If anything, the Indians are now in advance of the native Mexicans. Their farms are better kept, their ditches are more regular and cleaner, and their harvests are apparently more bountiful. They are more thrifty, and having a common interest they work together with less conflict than their neighbors.

There are comparatively few fruit trees or vines in this part of the valley. Occasionally an "American" ranch is passed or the farm of a wealthy Mexican, and here are almost always trees and vines in small patches. The general appearance of lack of industry in attempting permanent improvements is due, in part, to that inherent peculiarity of the natives, freedom from all thought of the future, and in part to the uncertain state of the water supply. A few acres of corn, a small patch of wheat, and a garden of chile and onions usually suffice. It would be difficult to find another valley, settled for hundreds of years, as favorable to agriculture as this, which shows so few signs of activity. The soil is capable of producing anything that will grow in a warm, temperate climate; yet in most places corn, wheat, and oats remain the staple crops.

The land in the Albuquerque Valley is for the most part excellent, portions of it, however, being subject to overflow, and other portions, as before mentioned, containing quantities of alkali. In general, it is a rich deposit of silt on the old river flood plain. Near the mesa the plain gradually passes into hummocks, layers of sand and gravel, the height of the mesa above the river varying from 15 to 50 feet, or even more. There is no doubt that the water of the Rio Grande can be led upon a part of this mesa, the soil of which is often very fertile, in places consisting of weathered basalt, although in general it is made up of water-washed gravels.

TRIBUTARIES BELOW THE CHAMA.

SANTA FE AND ADJACENT STREAMS.

In the following paragraphs a brief summary is given of the principal streams entering the Albuquerque Valley. The first of these is Santa Fe Creek, which, as previously described, discharges a very small amount of water during the greater part of the year. Gallisteo Creek flows a large amount of flood water into the Rio Grande, but often is dry for miles above its mouth, as was the case in January and February, 1889. For some 8 miles at least above its mouth it runs through

unconsolidated deposits, and in no place can anything approaching a fixed cross section be found.

A small stream comes down through Bear Canyon, in the Sandias, about east of Bernalillo, but the water all sinks within a mile or a mile and a half of the mouth of the canyon, except in times of flood. The same may be said of the stream in Tijeras Canyon, about 17 miles east of Albuquerque, except that there is an unusually good natural dam site at the mouth of this canyon. It has been proposed to make a dam at this spot, and conduct the waters held by it out upon the mesa on the east side, opposite Albuquerque.

At the mouth of the canyon are excellent facilities for erecting the dam. The stream has cut through a mass of crystalline feldspathic rock, leaving an opening not more than 150 feet wide. The rock rises abruptly in a cliff on one side to a height of 80 or 90 feet above the level of the stream. As the valley opens out to a considerable width just above the point selected for a dam, ample room is given for a large volume of water. The stream in the latter part of January, 1889, was not flowing more than $2\frac{1}{2}$ to 3 second-feet, but was reported to be larger in November, when the discharge was about $4\frac{1}{4}$ second-feet, as shown by float gauging. This stream has cut back through the steep face of the Sandia Mountains, and drains a portion of the dip surface on the eastern side, thereby securing a larger drainage area than most of the small streams, and thus in flood a large amount of water is carried. The water can be brought to the surface of the mesa about 1 mile below the dam, and thence conducted over a practically indefinite amount of mesa land.

Hell Canyon, some 20 miles southeast of Albuquerque, contains a small stream, but it too sinks within a short distance of the mouth of the canyon. At Abo Paso and several points to the south are streams of the same character, but it is doubtful if there is a single stream on the east side between Pena Blanca and San Marcial that flows at the rate of 5 second-feet, except in time of flood, and in many seasons not one of them delivers any water within 10 miles of the Rio Grande.

West of the Albuquerque Valley are the large drainage areas of the Jemez and Puerco tributary to the Rio Grande. Little water flows from them during the summer. In fact, it may be said that on the west bank not a single stream below Pena Blanca, with the possible exception of the Jemez, reaches the Rio Grande, except during the annual freshets. The Salado comes in as an arroyo, about 8 miles north of Socorro. Water flows in it along the foot of Ladrones Peak, and some irrigation is done, but for the greater part of the distance it flows in a canyon.

JEMEZ RIVER.

The Jemez River enters the Rio Grande from the west at a point about 5 miles above the town of Bernalillo. It drains the country south of the Chama and west of the Santa Fe drainage. In the head-

waters are many open valleys, at an elevation of 8,000 feet and upwards, in which are hay ranches and cultivated lands. There are several localities at which water can be held by the construction of suitable dams. Leaving the mountains the small tributaries enter narrow canyons, finally uniting at the head of the Jemez Valley, about 5 miles above Jemez Pueblo.

This valley is from 1 to 3 miles in width. Its soil is in most places sandy, but with the application of water is very fertile. Agriculture is carried on to a small extent by the Jemez Indians and by the Mexicans at San Ysidro. Three miles below this latter town the Rio Salado comes in from the west through a broad, fertile valley. The valley continues to widen and contains large areas of excellent land. Small areas are cultivated by the Indians of Silla and Santa Ana, but the supply of water is deficient for their needs, or can not be diverted successfully from the river. The soil is very fertile and produces fine grapes, peaches, apples, corn, and vegetables.

In this portion of its course the river occupies a wide, sandy channel, in which the greater part of the water disappears excepting in times of flood. Below the Santa Ana Pueblo the river enters a narrow canyon, through which it continues to its junction with the Rio Grande. Throughout the lower part of its course the river is bordered by mesas covered by arable lands, to a part of which at least water could be brought from points in or near the canyons of the various tributaries.

The discharge of this river was measured at various times in 1889 and found to vary from 85 second-feet in the spring to 20 second-feet in October. This was a year of unusual drought, and the floods were very low and of short duration.

PUERCO RIVER.

South and west of the Jemez is the Puerco, a river which though draining a large area is dry at its mouth during the winter and early spring. The valley is uninhabited from the mouth as far north as the point at which the Atlantic and Pacific Railroad crosses it. The water from its principal tributary, San Jose Creek, sinks within a few miles of its mouth, although it is the largest stream in that part of the Territory, and when others were dry was flowing from Cubero to its mouth. For 40 miles up the Puerco no water could be found in February, 1889.

The divide between the Rio Grande and Puerco in its lower course, and in particular in the vicinity of Albuquerque, consists of a gently undulating mesa about 6 miles or less in width, bounded on both edges by sandy foothills. The valley at this point is about 2 miles wide, has a gentle slope, and the soil seems excellent, but very little attempt at farming has been made on account of the scarcity of water.

On the west side of the valley are deserted ranches where some irrigation has been done with the flood waters of small arroyos. It was evident from the wheat stubble and threshing floor that crops have

been raised. Considerable quantities of native hay are usually cut by the Mexicans from a broad, gentle valley known as the Canyon del Ojo. At the junction of the Canyon del Ojo with the Puerco a Mexican farmer has put in a bank about 200 feet long by 10 feet high behind which rain and flood water is caught. This he lets to a cattle owner for $200 per year.

The principal tributary of the Puerco is the San Jose, or, as known at the head waters, Bluewater Creek, which enters from the west. Below the Big Spring, near the town of San Jose, this creek was discharging from 10 to 12 second-feet in February, 1889. West of San Jose, up the creek, is a broad valley expanding toward the south. The creek bed had water in it, but usually when not swelled by melting snows it is dry at this point. Some irrigation is done by the Mexicans at the town of El Rito, about 15 miles below San Jose, but it is insignificant in amount.

About 12 miles below San Jose and between it and El Rito is the pueblo of Laguna, whose name, Lake Pueblo, is said to be derived from a former sheet of water made by an artificial dam erected by the Indians a few miles above the pueblo. This lake was probably from 130 to 160 acres in extent, and must have been from 10 to 12 feet deep in places. Nearly a quarter of the land formerly covered by the water from this lake is now occupied by crescent-shaped hills of blown sand. The dam was washed away in 1859 or 1860, and has not been rebuilt. Crops are grown in its basin, however, and a small carp pond is still preserved.

From the upper end of the San Jose Canyon clear to the head of the principal tributary, the Bluewater, along the line of the Atlantic and Pacific Railroad, is a valley at an altitude of 6,500 feet and of varying width, but of great fertility. A small portion is covered by a lava flow reaching from McCarty's west and north to Bluewater. Water for this extensive region can be had only by storage, but with this the region will become wonderfully productive. At present there are few inhabitants besides the Laguna and Acoma Indians and a settlement of Mexicans around Cubero. The San Jose, although in ordinary seasons small, must discharge an enormous quantity of flood water, for its drainage area is very great. The stream flows constantly at all seasons for some 3 miles below Laguna, where it evaporates in summer.

On the head of the Puerco, in the San Joaquin del Nacimiento grant, northwest of Jemez, is a beautiful valley covering an area some 15 miles long by 6 wide. It is so high that nothing but small grain can be raised, but the soil is extremely rich, and could a water supply be obtained, it would become a valuable tract of land. There is, however, no adequate water supply visible, and apparently this valley will long remain among the undeveloped resources of New Mexico. Farther south also are other valleys and bottom lands with little or no water for irrigation.

The Puerco holds a constant stream as far south as Casa Salazar, a point almost west of Jemez, and from there on the water is caught by

the Mexicans during the floods in brush dams. Each year brush and rocks are put in the bed of the stream and are filled with silt, forming a rough dam. The water detained in this manner is used for irrigating, but the whole arrangement is washed away in the winter and the process is repeated the next spring. This system is also used at points along the San Jose Creek. It is found to be the only one practicable, as it would be very difficult to put in a permanent dam on the clay foundations, which are over 100 feet deep, and rock does not appear anywhere near the river. As a whole, the land in the Puerco Valley seems of excellent quality, and less alkaline than the land in the Rio Grande Valley.

There is a large amount of land farther down in the Puerco Valley with a gradual slope toward the river, in all, perhaps, upward of 100 square miles. The strip is probably 70 miles long, and averages about a mile and a half in width. Little or nothing can be done with this unless a large amount of water can be stored, and in many parts of the valley there are few places favorable for the erection of dams. Even if a sufficient surplus of water could be stored near the headwaters to bring this land under ditch, still the water would have to be conveyed some 80 or 90 miles to reach the lower part of the valley, and it could be more easily brought upon one of the mesas above, where it could command a greater amount of land in a more compact form. The land throughout the Puerco Valley is of excellent quality, but the irrigation in the lower part of the valley seems to be confined to the small patches to which water held by the brush dams can be conducted.

RÉSUMÉ OF WATER SUPPLY.

To recapitulate, the principal sources of water supply above and adjoining the Albuquerque Valley are as follows: The Chama and Jemez are the only tributaries coming into the Rio Grande between Embudo and San Marcial that flow any considerable amount of water except in times of flood; the Santa Cruz, San Ildefonso, and Santa Clara, enter the Rio Grande in the Espanola Valley, but are insignificant in size; the Gallisteo and Salado discharge a considerable quantity of water in flood, but ordinarily are mere arroyos for miles from their mouth.

Between Embudo and San Marcial it has been estimated that there are about 400 square miles of irrigable land in the Rio Grande Valley. This land extends in a strip of over 200 miles in length, and will average about 2 miles in width. The White Rock Canyon, extending from San Ildefonso to Pena Blanca, and separating the Espanola and Albuquerque Valleys, is the only considerable canyon.

The methods of irrigation throughout the whole valley are very similar in character; the ditches are short, and the water is used first on the lowest levels, and gradually as more land is needed the higher levels are reached. The water is taken from the main ditch and applied directly to the highest of the small squares into which the tilled land is

divided, lateral ditches being uncommon. When this one is full, the surplus water is allowed to run into the next square below it, and so on until the lowest square is reached. Much damage is done annually to the lower ditches by the overflowing of the river and the consequent filling up or washing out of the ditches.

In short, irrigation along the Rio Grande is limited to narrow strips on either side of the stream. The valleys are narrow, and the amount of land with gentle slope suited to irrigation is comparatively small. The amount of surface water that stands in ponds through the lower part of the valley shows that in places, at least, considerable drainage is necessary, but it is doubtful if many of the native cultivators are able to make any outlay in draining and improving their land, in addition to the yearly expense for repairs to the acequias.

MESAS ALONG THE RIO GRANDE.

East of the Albuquerque Valley is a long mesa running from the Sandia Mountains on the north to Socorro on the south, and lying at an elevation of from 300 to 600 feet or more above the river. There is much fertile land on this mesa, but it lies so high that water can not be brought upon it except at enormous expense.

South of this is the Jornada del Muerto, the largest unbroken mesa in New Mexico, extending from Carthage on the north to the vicinity of Fort Selden on the south, a distance of about 100 miles. It is in places 35 miles in width, and is bounded on the east by the Sierra Oscura, San Andres, and Organ Mountains, and on the west by the smaller range of mountains bordering the Rio Grande or by the river itself. The surface is to the eye apparently level, and is covered for the greater part of the year by a grass, furnishing feed for large herds of cattle. Wells have been drilled at various points, and water struck at a depth of about 300 feet, but this is often so impregnated with salts as to be worthless.

The preliminary examinations made by this Survey show that in all probability it will be impracticable to bring water from the river upon this land, both on account of the expense and the deficiency of supply, and these level tracts with deep soil are apparently absolutely worthless for agricultural purposes. The mountains bordering the plain are low and unfitted for storing water on account of the uncertain rainfall, and the snowfall does not accumulate. Many arroyos enter the plains but none cross them, and rarely the water from a "cloud burst" in these mountains reaches the Rio Grande.

The Mesa Cuchillo Negro embraces a large extent of country west of the Rio Grande and opposite the Jornada del Muerto, lying along Rio Alamosa, Rio Cuchillo Negro, Rio Palomas, Arroyo Seco, Rio Animas, and Rio Perches. The valleys on these streams are all narrow and the bluffs high, above these being mesas containing much good land. As the fall of these streams is rapid, it may be practicable to take water out of them on to the mesas, but before this can be done a patient study

and examination of the ground must be made. The streams all head on the continental divide, and furnish a spring flow which, if stored, could be used on these mesas.

The valley bottoms lie from 300 to 500 feet below the mesas and have precipitous sides, thus making it difficult to take a ditch out of the river and carry it over the mesas. All mesa land must be irrigated, if at all, by waters stored in the upper valleys of the small streams. The development of irrigation work here, therefore, must consist in the designing of small systems of storage reservoirs and canals, work requiring much time in the examination of the country.

MESILLA VALLEY.

After leaving the Albuquerque Valley, for some miles below San Marcial, the river flows through a comparatively narrow bottom, which is not more than a quarter of a mile wide and is bordered in places by steep rocky bluffs, these disappearing farther down the river. Ten miles below San Marcial the bottom lands nearly or quite disappear, and on the left side the Fra Cristobal Mountains rise abruptly from the water's edge; while on the right or west side the ground rises gradually from the river's bank to the foothills. The river channel continues of this character to a point below the little Mexican town of San Jose where, after contracting, the valley opens again to a width of about half a mile, and abruptly contracting again the river enters a canyon.

This canyon extends for about 6 miles and varies in width from 500 to 1,500 feet at the high-water mark. The walls of the canyon are of gravel and conglomerate, overlaid by lava, which in some places, particularly on the left bank, reaches a thickness of 40 feet. The walls at the highest part are about 100 feet high, decreasing to 50 or 60 feet in places, and are cut by arroyos.

Below this gorge the river again widens, and there are patches of irrigable land at the mouths of small creeks, but the river bottom itself is narrow, and the river bed, being nearly half a mile in width, occupies nearly all of the narrow valley.

At Santa Barbara, about 10 or 12 miles above Rincon, there was formerly a large Mexican settlement in the valley, which here widens to a breadth of nearly 4 miles. The inhabitants are now gone and the village is in ruins. The probable reason is that their land became so water-soaked and saturated with alkali that they could raise nothing. By exercising a little care in drainage a few new settlers are now farming just below.

These alternations of narrow gorges and bottom lands continue nearly to Fort Selden. In this course are points at which the river bottom lands are between 5 and 6 miles in width. A very small part of this, however, is cultivated; probably there are not 100 acres of crops irrigated. There are several points at which reservoirs could be made by placing dams across constrictions in the channel. Usually, however,

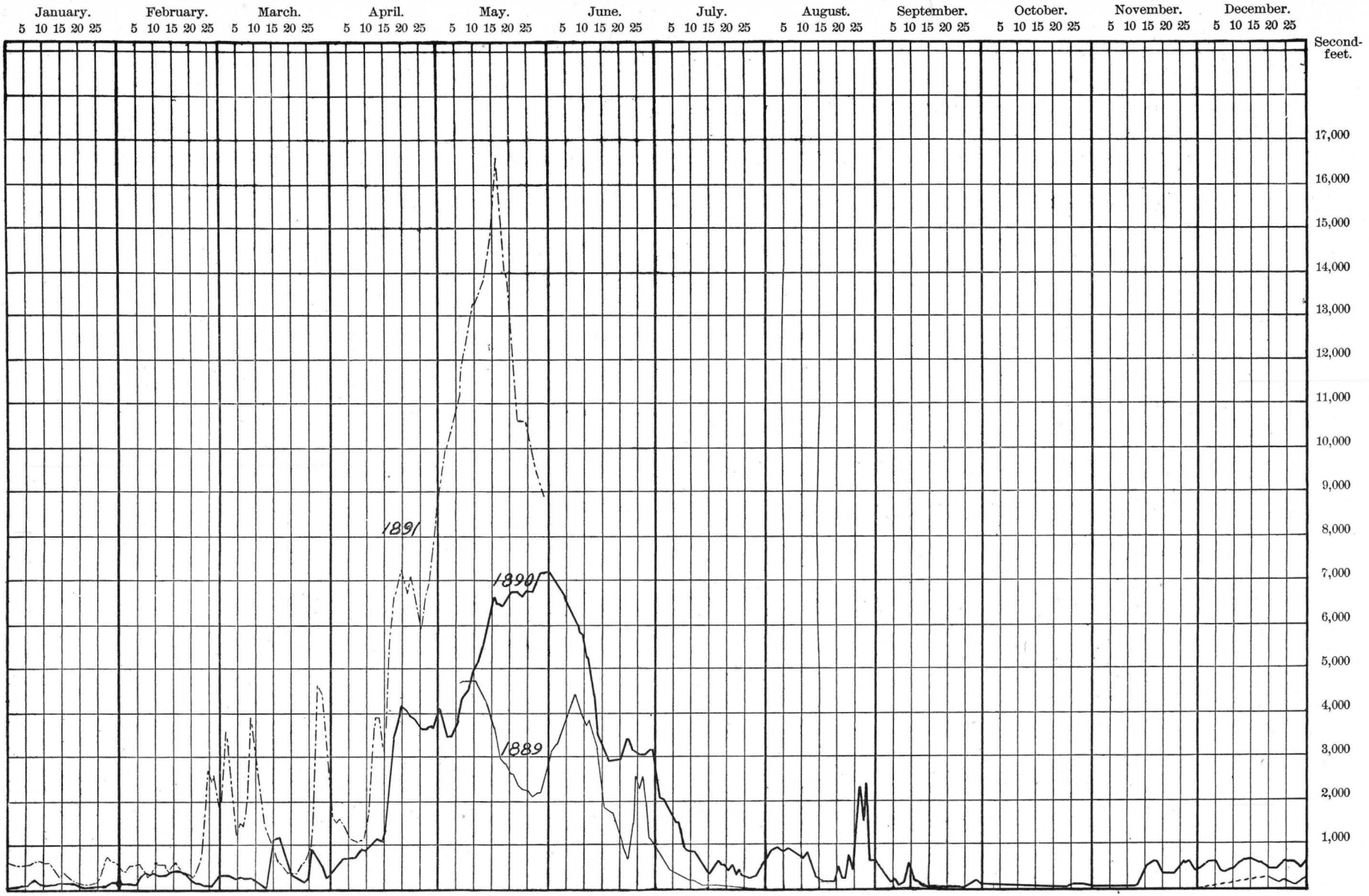
the bed of the stream is deeply filled with gravel, and it would be difficult to obtain good foundations. These reservoir sites on the main river can be utilized for storing water for the Mesilla Valley, thus allowing the summer flow of the river to be freely used on lands farther north.

Below Fort Selden the valley opens, and continues, in general, broad and fertile down to the constriction at El Paso. In this course is the Mesilla Valley, one of the best localities for fruit-growing along the Rio Grande. This valley, stretching from Fort Selden reservation on the north to the Texas line on the south, a distance of 35 miles, and with a width varying from 8 to 10 miles, includes land equal to any in the United States for the cultivation of the vine and many varieties of fruit. Below the Texas line to El Paso, 15 miles farther down the river, the soil is nearly equally as fertile, but remains almost uncultivated.

The Mesilla Valley contains probably, all things considered, the most valuable land along the Rio Grande, and the necessity of providing an ample and permanent water supply is unquestioned. The soil is of wonderful fertility and great depth, but agriculture has made slow advances, on account of the uncertainty of the future supply of water. The continued diversions along the river for hundreds of miles above this valley render the inhabitants apprehensive as to their future. At the same time that water is supplied plans must be made for drainage, for the rich bottom lands tend to become water-logged, developing the alkaline crust, as is the case in valleys below Albuquerque.

The amount of water flowing out from the Mesilla Valley for the last two years is shown graphically on Pl. LXIII, the means and extremes for each month being given in the tables appended. The gauging station is located at Fort Bliss, a short distance above the town of El Paso, the measurements being made above the Mexican dam at that place and above the head works of all ditches or canals. This diagram should be compared with that showing the discharge at Embudo, and also that for Del Norte, the similarity of these being evident at a glance. The early spring floods at El Paso are especially notable, these evidently coming from tributaries below Embudo, since they do not appear on the sheet for that station.

In briefly reviewing the use of water along the whole Rio Grande in Colorado and New Mexico, it is stated by Mr. W. W. Follett that in the San Luis Valley, besides numerous ditches, there are five large canals with a combined carrying capacity of 8,000 second-feet, although few now carry over half their maximum flow. Even then 4,000 second-feet is being used in this valley, but of course much of this water finds its way back into the river at or above the canyon. Between Embudo and San Marcial about 1,000 second-feet are used, and in the Mesilla Valley, from Rincon to El Paso, 900 second-feet are needed. At El Paso the new ditch, which owns the water rights of the old ditches on the United States side, has a capacity of about 400 second-feet, and the Mexican ditches have a capacity of about 800 second-feet.



DAILY DISCHARGE OF THE RIO GRANDE AT EL PASO, TEXAS.

Thus there is needed to supply the demand below Embudo 3,100 second-feet, as roughly estimated. Seepage will cause some water to be used many times over, but even then, except in years of maximum flow, there will be a shortage of water. Then those valleys to suffer first will be the Mesilla and the Ysleta, in which the products are worth many times as much per acre as those of the land on which the water has been used. This shows the urgent need for reservoirs. With them the Territory of New Mexico can support a much larger population in the Rio Grande Valley, but without them her progress will be slow.

GYPSUM PLAINS DISTRICT.[1]

In southern New Mexico, between the Rio Grande and Pecos, are extensive deserts, which for want of a better name may be distinguished as the Gypsum Plains. These plains are the bottom lands of a vast basin completely surrounded by hills and mountains, and extending from about White Oaks nearly to El Paso, in Texas, a distance of more than 125 miles, with a width varying from 10 to 30 miles. On the north are the Oscuro and Jicarilla Mountains and foothills; on the east the Sierra Blanca and Sacramento Mountains; on the south the Guadalupe and El Paso Mountains and foothills of the Hueco Mountains; and on the west the Organ, San Andres, and Oscuro Mountains. From each of these ranges numerous streams flow into the basin, but the water all disappears before reaching the center. Near the western margin of the plain, at the base of the San Andres range, is an extensive salt marsh, and to the south of this are the so-called White Sands, a gypsum formation.

Portions of this plain can in time become agricultural land by storing water among the higher mountains. The Sacramento, White, and Organ Mountains have a considerable depth of snow each winter and a heavy rainfall in the summer. These ranges are the only ones in this vicinity which offer opportunities for storing water.

In the center of the Gypsum Plains near the northern end is a flow of basalt, which, from all outward signs, appears to be recent, so modern in fact that there is a popular belief to the effect that it has been ejected since the Spanish invasion. At a point 15 or 20 miles north of the flow are the ruins of an ancient town; and it is reported that traces of an extensive irrigating system may still be seen near the town. At present there is no water near the place, and the canals are said to be tilted at different angles. The basalt stream is fully 30 or 35 miles in length, and has a width varying from one-quarter of a mile to 4 miles.

On the northeast of the plains is the Sierra Blanca Peak, the highest in the White Mountains, having an elevation of 11,892 feet, and wearing a cap of snow during the greater part of the year. There are numerous peaks over 8,000 feet high upon which the snowfall is very deep.

[1]From report by R. S. Tarr, 1889.

The streams flowing from these mountains towards the west sink shortly after leaving the foothills. Among these the most important are Tularosa, Bonito, and Tres Rios. On each of these along the lower valleys farming is done by irrigation, and higher up in the mountain valleys good crops of oats, corn, and potatoes are raised without irrigation. Among the lofty peaks, deeply cut by erosion, covered with snow and drained by numerous constantly flowing streams, are probably a number of valuable reservoir sites. These will be of great utility, for to the south and southwest are the plains of almost unlimited extent at present, on account of the scarcity of water, not even grazed by cattle.

PECOS RIVER.

GENERAL TOPOGRAPHY.

The Pecos,[1] rising on the eastern side of the Santa Fe Range, flows for a while as a typical mountain stream through narrow valleys and deeply cut gorges, then leaving the tilted rocks, cuts the horizontal strata of the mesa country, this horizontal character of the rocks prevailing throughout the Pecos Valley. Among the sandstones the country is eroded and broken by arroyos, and the amount of agricultural land is necessarily small.

Below Fort Sumner, however, the topography of the valley changes. The canyon-like walls disappear, and are replaced by low rolling hills. The ascent from the river on each side becomes more and more gentle toward the south, until near Roswell there is an imperceptible gradation from the flood plain to the prairie, this change in the topography being due to change in the character of the rocks, limestone and gypsum prevailing throughout this fine agricultural land. Arroyos and gulches become rare and canyons are practically unknown, the passage from canyons to prairie land being very gradual.

The drainage of the lower Pecos in New Mexico is very imperfect, and there are broad tracts of country having no surface drainage whatsoever. The water sinks into limestone rocks, and establishes an underground drainage. The consequence of this is the formation of numerous shallow "dry lakes," which are in reality sink holes, many of these draining large areas. These contain water each year, and it is a constant surprise to the people of the country that they do not leave an alkaline crust upon disappearing, as would result if the water escaped by evaporation. East of the Pecos is the rolling prairie country of the Staked Plain, and to the west the White and other mountain chains rise out of the broken plain.

The Pecos Valley is without doubt one of the finest in New Mexico, yet it has been unknown and little developed. The reason for this is that it has been for years, and indeed until very recently, the border land of civilization. Apaches, Comanches, and Navajos had their battle

[1] From report by R. S. Tarr, 1889.

grounds here and made war upon their common enemy, the white man. Life and property were not safe, and none but the boldest of frontiersmen had the hardihood to brave the danger, the peaceful agriculturist finding no secure place.

The fine grazing land, the abundance of water, and the wildness of the life attracted only the adventurous cattlemen, who came in from Texas, Arkansas, and the surrounding territories, and developed an extensive cattle industry. Farming being considered as an interference with cattle raising, farmers were prevented even by violence from settling, and the country was held for cattle only; but by the overstocking of the ranges and the low price of cattle the owners have become so impoverished that they are in many cases forced to look to other means of self-support, and efforts are now being made to develop agricultural resources.

On the middle Pecos near the river are two classes of land—bottom land and mesa. On the lower Pecos the bottom land is also present, but the mesa is replaced by prairie. In both divisions on approaching the mountains the country becomes broken into foothills. The bottom land is irrigable, yet not one acre in a hundred has been reclaimed. It has a rich deposit of silt, uniformly level, and capable of a high state of cultivation. It is estimated that there are between 250,000 and 300,000 acres of this land lying in a narrow strip on the middle Pecos, but broadening out southward to an average width of probably 2 miles or more. A portion of it is subject to overflow, especially along the lower Pecos. In such places there is considerable alkali, though by no means as much as in similar portions on the Rio Grande.

The mesa land has a fairly good soil, in general rather thin, and composed entirely of weathered sandstone. Being high above the river and deeply cut by arroyos, it is not well placed nor suited for irrigation, and it is doubtful if any considerable portion of this upland country will be tilled. The prairie country, on account of its excellent soil, level character, and slight elevation above the river, is well suited for irrigation and offers excellent opportunities for reclamation.

CLIMATE AND WATER SUPPLY.

The climate of the Pecos Valley is typical of the arid country in which the rainfall is from 12 to 15 inches per year. In descending the valley both the elevation and the latitude become less, and there is a gradual change toward a warmer climate. The entire valley is well suited to grape culture, and at Roswell the climate is similar to that of Las Cruces on the Rio Grande. Some snow falls every winter, but in the southern portion of the valley it rapidly disappears. The rainfall comes mainly in June, July, and August, in the form of showers, and is therefore extremely variable and uncertain.

The main Pecos is formed by the confluence of the Gallinas with the Pecos at La Junta. Water flows perennially in these streams, at least

as far down as the Atchison, Topeka and Santa Fe Railroad, but between this line and La Junta the water entirely disappears by evaporation and seepage during many months of the year. On January 30, 1889, the bed of the Pecos at Las Colonias was so dry that a well 15 feet deep barely furnished a water supply for the stock and citizens of that town. A mile or two above Eden some small springs flow into the Pecos, and from this point the river channel constantly contains water. The river valley shows signs of powerful erosion, due to the floods of the spring and summer months. North of Puerto de Luna the river has a rapid slope, and is kept within its banks in time of flood, but below this point the water becomes more and more sluggish and muddy. In time of flood it overflows the flood plains extensively, but in low water meanders about among sand bars in the river bed. Above the Agua Negra Chiquita, near Santa Rosa, the water is practically free from alkali, but this stream and every one south of it add to its alkaline character.

UPPER TRIBUTARIES.

The most important tributaries of the middle Pecos, because of the constant source of supply, are the Agua Negra and Agua Negra Chiquita, entering just above Puerto de Luna. The latter on the east side of the river receives an unfailing supply of water from two large alkaline springs. The smaller rises out of the ground in a canyon about three miles from the Pecos, and carries, it is estimated, 6 second-feet. The larger spring has its source about a mile and a half from the Pecos, at the base of a low sandstone cliff on the edge of an alkaline marsh. It is remarkable for its size and depth, the basin of the spring having a diameter of about 70 feet, and a stream of water flows from it carrying about 15 second-feet, receiving additions from numerous small springs on the way through the marsh to the Pecos.

The Agua Negra flows from the Canyon Pintado, a very long arroyo on the west side of the Pecos, draining a large area of mesa country on the east side of the Manzano Mountains. During the summer rains, when great floods of water rush down the canyon, it is reported that little or none reaches the Pecos through the canyon, the greater part sinking into the arroyo bed, at one point, it is said, actually flowing into the ground through a hole. Several springs appear at various places, but they soon sink into the sand. About 3 miles from the mouth of the canyon a large and constantly flowing spring supplies a stream of water of about 7 second-feet. This may be in part the water which disappears farther up the canyon, but its constancy would seem to indicate some additional and more distant source. It is a clear alkaline water, which from its black color has been called Agua Negra by the Mexicans.

These two streams and numerous smaller springs furnish the Pecos with a considerable body of water. At Puerto de Luna the river in early Feburary is usually 150 to 200 feet wide and 2 feet deep in places,

with an average depth of one-half foot or less, and a velocity of not more than 3 feet per second. Its bed is of changing sand, and is fully 200 yards wide between the flood-plain banks, showing that powerful floods must fill the river at times when it overflows its banks. It is a treacherous stream, more difficult to control than even the Rio Grande. Near Puerto de Luna it is continually encroaching on its banks, and portions of several farms have been washed away within a few years.

Excepting occasional small springs from the Agua Negra and Arroyo Yeso, there are no living tributaries to the Pecos below Fort Sumner on the west side for a distance of 50 miles. The Yeso carries a small body of water of not more than 2 or 3 second-feet. Various arroyos, creeks, and springs of alkaline water flow into the Pecos between the Yeso and the Spring River at Roswell, but none of them are of importance, few reaching the river, and these few carrying mere threads of water.

At Roswell is the finest and most easily controlled supply of water in the territory, and an equally good body of land to be irrigated. There are five sources of water supply, the Pecos, the Hondo, the North Spring River, the Berenda, and the South Spring River. The Pecos is treacherous and difficult to control, and it is said never to fail even above the Spring River, although in summer it is often very low.

The Berenda River is one of the Spring Rivers, all of which have their source in small ponds supplied by perennial springs. The sources of all are in the midst of the prairie, within a few miles of each other and the Pecos. The Berenda, the northernmost of the three, had in February, 1889, a width of 12 feet, an average depth of $2\frac{3}{4}$ feet, and a surface velocity of 1·9 feet per second, giving approximately a discharge of 50 cubic feet per second.

The North Spring River rises in springs having a temperature somewhat higher than the average air. At 2 p. m., February 9, 1889, when the air temperature was 59° the water temperature was 67°. The union of the streams from the several springs forms the North Spring River, which had at that time a discharge of approximately 50 second-feet. Both the Berenda and the North Spring rivers empty into the Hondo before reaching the Pecos, but the South Spring River flows directly into the Pecos, the discharge being 73 second-feet.

The Hondo, formed by the confluence of numerous brooks rising in the White Mountains, flows for some distance through the foothills, and then enters the prairie country west of Roswell. Just before emptying into the Pecos it receives the water of the Berenda and North Spring rivers. In the summer above the mouth of these rivers it becomes very low and the bed even dries. In 1886 it was dry for two months; in 1887 for three weeks; in 1888 for only one. On the prairie it flows in a tortuous course through a narrow channel, cut in loose gravel, from 8 to 15 feet deep.

Float observations at Long's Ranch, 10 miles west of Roswell on the

Hondo, showed that the river on February 10, 1889, discharged 48 second-feet. Below the junction with the Spring rivers it carries about 200 second-feet at the point where a large ditch is to be taken out.

The discrepancy of 52 cubic feet per second between the measurement of the combined flow of the Hondo and its two tributaries and of the separate measurements is mainly due to the increase in size of the stream between the points where the observations were taken, due to the supply from numerous small springs. There are many of these in sight, and undoubtedly many which do not appear, and these swell the size of all the streams considerably. They are all alkaline and warmer than the air temperature, one of them being 61° and another 62°.

The entire absence of tributaries on the eastern side of the Pecos is very striking, and is due no doubt to the pervious character of the soil of the Staked Plains, upon which no drainage system is established. The only supply of water which the Pecos receives from this side comes from a few small alkaline springs or from a small arroyo which carries water once or twice in a season.

LOWER TRIBUTARIES IN NEW MEXICO.

Below Roswell the first stream of importance is the Rio Felix, which rises among the southeastern foot-hills of the White Mountains, and after a few miles sinks and does not again appear until within 4 miles of its mouth, a distance of 25 miles, where it appears again as a series of springs.

The Penasco takes its rise in the Sacramento Mountains, and formerly flowed 40 miles as a fair-sized brook, then entering a strip of marshy land 10 to 12 miles long it disappeared. There was practically no connection between the Upper and Lower Penasco, the latter commencing in a series of springs about 12 miles from the Pecos. A few years ago a cattle company cut a ditch connecting the Upper and Lower Penasco, and since then there is a continuous stream with water running 30 miles farther than formerly.

The Seven Rivers are seven small springs in the prairie, from each of which a small stream flows for a short distance, then sinks. About 35 miles below Seven Rivers is the Black River, which drains a portion of the eastern slope of the Guadalupe Mountains. It is larger than the Berenda, and carries an unfailing supply of water. This river is about 35 miles long, but is a small stream to within 16 miles of the Pecos, where its volume is considerably increased by numerous springs. It flows through a series of lakes, and is subject to extensive floods on account of the large area which it drains. A small stream, the Blue River, flows into the Black River a few miles from its mouth. The Delaware is the last stream to enter the Pecos in New Mexico, only about 7 miles being in this Territory. It is larger than the Berenda at Roswell.

From this brief description it will be seen that the constant, never-

failing supply of water in the Pecos comes from springs which must receive their supply from a great distance. This is owing to the peculiar structure of the country and the prevalence of the easily dissolved limestones, which allow the waters to make underground channels for themselves and thus flow for considerable distances out of sight. The melting snows and summer rains furnish a variable supply which fills the channels and frequently overflows the flood-plains of the Pecos and its tributaries. The river is alkaline on account of the character of the springs. No silt is received during a portion of the year from any tributaries except the Hondo and possibly the large streams south of it, yet the Pecos is muddy to an extreme, being busily employed in removing a portion of the mud brought down the arroyos in vast quantities after every rain.

AGRICULTURE ALONG THE PECOS.

The agriculturist who needs the water of the Upper Pecos River for irrigation finds himself confronted by almost insurmountable difficulties. Even the patience of the Mexican is exhausted by the freaks of this stream, and his brush dams are certainly not a success. Above Anton Chico the Mexicans succeed in irrigating small patches of land, but all their methods are crude and their results are unimportant.

Below Anton Chico all the irrigation is in the hands of Mexicans as far south as Fort Sumner. A short distance north of Anton Chico a few Mexicans succeed in raising occasional crops of oats and corn without irrigation, but farming on this plan is not a success there.

At Whitmore's ranch are the Gallinas Springs, which boil up through the clay and discharge altogether 2 or 3 second-feet, the water being used to irrigate a small farm by storing that which flows during the night to aid the supply by day. There is a large extent of valley land in this neighborhood at present uncultivated on account of the uncertain supply of water in the Gallinas River, which is frequently dry in the growing season.

From Gallinas Springs nearly to Las Colonias the river flows through a canyon with some irrigable land on either side. Above Las Colonias the canyon broadens until the walls, which are 200 to 300 feet high, are fully 2 miles apart. From the base of these cliffs on either side to the river the land is capable of irrigation, although the Mexicans have reclaimed only the narrow strip bordering the river. By the end of August the water fails in the river at this point, and there is little if any in it again until about April. On the east side some of the rich bottom lands are capable of raising a poor crop of corn without irrigation, owing, no doubt, to seepage from the river.

Below Las Colonias the canyon walls come closer together, and there is no irrigable land for 15 miles, or until Agua Negra Springs are reached. Here the valley broadens out again to a width varying from one-half mile to 2 miles or more. From this point southward the valley contracts and broadens out again at varying distances until the canyon country is left behind a few miles above Fort Sumner.

On the Pecos and Gallinas rivers north of Puerto de Luna about one-half of the easily irrigable valley land is under cultivation, but in all this region nothing has been done in the way of permanent improvement; no trees are planted, few vines, and very little alfalfa. Either the Mexicans are not thrifty, or else they are afraid to run the risk of losing trees and vines by drought and bursting of dams.

IRRIGATION WORKS ON THE PECOS.

The town of Puerto de Luna, a Mexican town, is divided into two parts by the Pecos. The western town has a very good acequia taking most of the water of the Agua Negra, and thus possesses a constant supply. All the water is utilized on small Mexican farms, each a few acres in extent. On the east side of the river many unsuccessful attempts have been made to take water out of the Pecos after the usual Mexican method, and even the Mexicans are convinced that the Pecos is entirely too changeable and violent a river for brush dams. A ditch 4 miles in length has been constructed, and four times the dam has been swept away, leaving the irrigators without water in the midst of the season. The last dam was built in the autumn of 1887, at which time a road was built to the mesa top for brush, and several thousand dollars in labor were expended in constructing the dam, which was swept away in the spring. The inhabitants are reduced to extreme poverty and are in despair. In 1888 and 1889 they were entirely without water, and, as it did not rain during the summer, those who tried to raise crops without irrigation made complete failure. The only man who had fruit trees was forced to irrigate them by carrying water in pails.

Between Puerto de Luna and Roswell little land is irrigated. Puerto de Luna is practically the limit of Mexican advance, though below there an occasional Mexican farm is found, irrigated either by a small private acequia or by spring water. At Roswell more land is cultivated, but the proportion of irrigated to irrigable land not irrigated is very small. Between Roswell and the Texas line, including the country about Roswell, there were in 1889 not more than 3,000 or 3,500 acres of land under cultivation on both sides of the river. In this tract of country there are 300,000 acres of land that can easily be reclaimed. Within a radius of from 2 to 3 miles from Roswell there were in 1889 less than 2,000 acres of cultivated land, including about 300 acres of alfalfa, 40 acres of fruit trees and vines, and 50 acres of timber planted under the timber-culture act.

The amount of cultivated land is increasing rapidly each year, and especially in the last few years there has been great activity in ditch construction. The following statements of the carrying capacity of the various acequias about Roswell in 1889 were furnished by the constructing engineer, the estimates being based upon the number of acres that each ditch could flood to a depth of 18 inches during the irrigat-

ing season, taking into account the water supply, character of the land, and size and slope of the ditch:

	Acres.
From Berenda River:	
Boon Ditch	40
Milne Ditch	100
Crow Ditch	150
From North Spring River:	
Ballard Ditch	300
Pioneer Ditch	700
Stone Ditch	1,500
Roswell Ditch	(1)
From Hondo River, Fountain Ditch	20
From South Spring River:	
East Sea Ditch	150
Corn Ditch	200
Mills Ditch	300
Poe Ditch	300
Roberts Ditch	1,500
South Sea Ditch	2,000

When all these ditches were running to their full capacity about one-half the water was taken out of the Berenda, while the amount taken

FIG. 225.—An acequia at Roswell, New Mexico.

from the North Spring River did not appear to be materially decreased, and in the South Spring River very little water was left. The Berenda at its head waters is a small stream, and possibly the carrying capacity of the first three ditches has been underestimated.

A view of one of these small ditches is given on Fig. 225, showing the general character of these acequias and the regulating gate at the head. These regulating gates, as previously stated, are of wood, roughly made, all such works being constructed by the irrigators. On

[1] Supplies the town.

the left-hand side of the picture are stacks of alfalfa, which has been raised by means of the water of the ditch. There is nothing unusual in the general appearance of this ditch, and the picture is introduced merely to show the general character of the country, since it might have been taken almost anywhere in the Rio Grande Basin.

Since 1889 several large irrigating systems have been laid out and in part completed along the Lower Pecos in New Mexico, and even extending into Texas. The most notable is that in the vicinity and south of the town of Eddy, where a masonry dam located a few miles above the town serves both to divert the water into the canals and to a certain extent to impound the floods. These canal systems have been described in great detail in various publications,[1] rendering it unnecessary at this time to enter into a description of them. The storage of surplus water is a matter of great concern to all these canal companies and irrigators, and a number of favorable reservoir sites have been surveyed and plans have been drawn up for extensive works of this character.

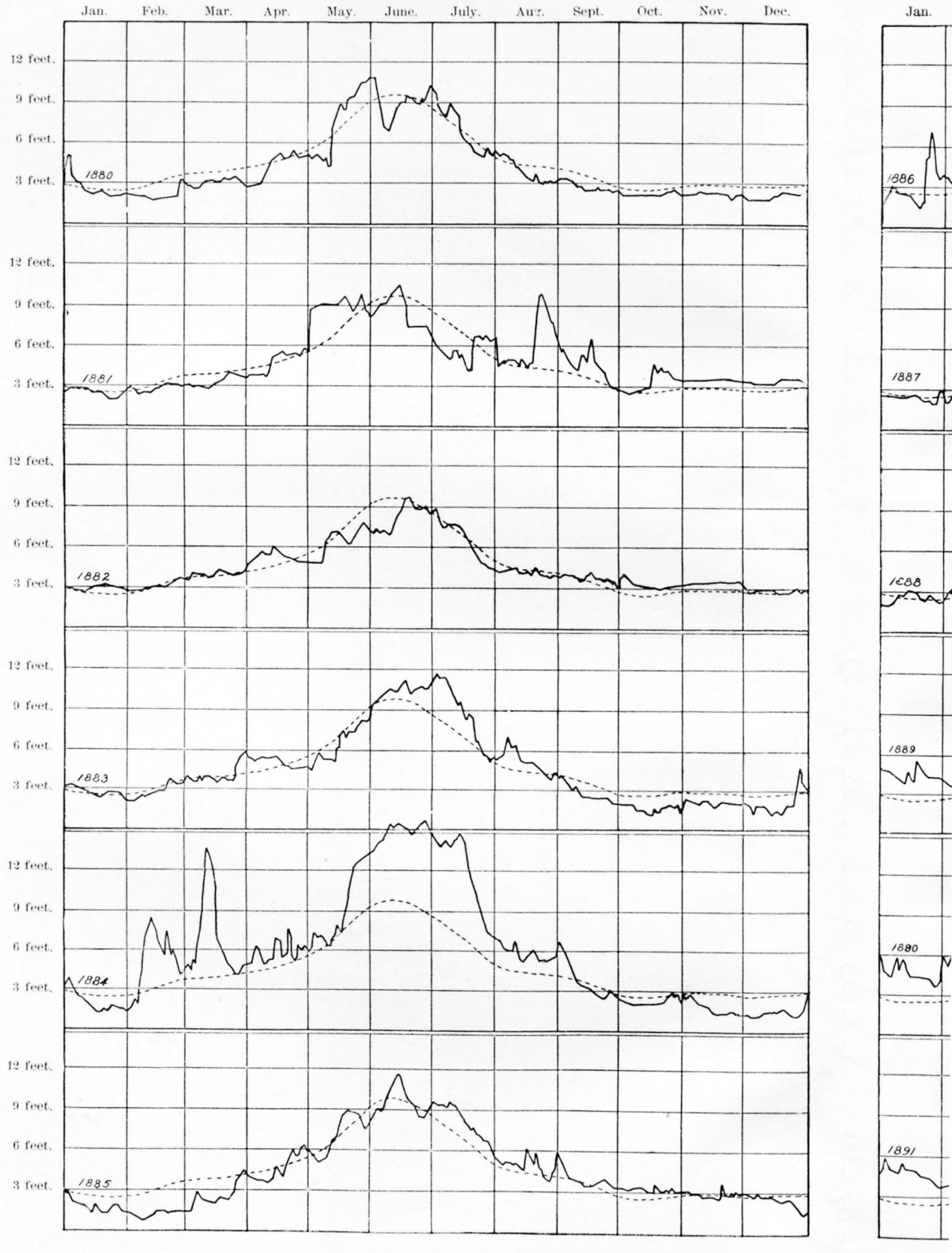
DRAINAGE BASIN OF THE COLORADO RIVER.

This great river, draining an area of 225,049 square miles and delivering a great volume of water into the Gulf of California, has within its catchment basin the most diversified and wonderful topography on the continent. The Grand and Green Rivers, rising in Colorado, Wyoming, and Utah, receive their waters from the western side of the Rocky Mountains and from the Wasatch and Uinta ranges. Uniting their floods to form the Colorado, they flow through the most stupendous canyons of the world, from 3,000 to 6,000 feet in depth below the tops of the plateaus, into which the tributary streams also have cut gigantic gorges.

After leaving the canyons the stream meanders through the broken lands and deserts south of the Great Basin, and shortly before reaching the Gulf of California receives at Yuma the waters of the Gila River, which drains southern Arizona and a part of New Mexico, and whose basin is described in detail farther on.

On Pl. LXXIV are given the fluctuations of the river at Yuma for each year since 1880. The dotted line indicates the average height of the river during the entire period through which measurements have been made, and the irregular line indicates the stage of water during the particular year whose date is affixed to the left side of the diagrams. An examination of these diagrams shows that in the year 1880 the height of the river was in general below the average, rising above this only for short periods and quickly falling. In 1881 and 1882 the

[1] Notably by H. M. Wilson, in the Engineering News, New York, October 17, 1891, and also in pamphlets issued by the Pecos Irrigation and Improvement Company, Eddy, New Mexico.



GAUGE HEIGHT OF THE COLORADO RIVER AT YUMA, A

height followed the normal very closely, and in 1883 was for a great part of the year a trifle above.

In 1884 floods of unusual extent occurred; in March the water was higher than it had been for many years, and in the latter part of May, during June, and the first half of July the floods were unprecedented both in amount and duration. Throughout the western part of the continent this year was notable for the excessive rainfall and height of the rivers, and even in the subhumid regions the rainfall was so great that settlement was encouraged in localities where no crops have been matured since that year. By referring to the diagram of annual rainfall in the Rio Grande Basin, Fig. 223, and of that of the annual rainfall in the Gila Basin, Fig. 226, it will be seen that in nearly all the localities whose rainfall is plotted the depth of precipitation in 1884 exceeds that of the years immediately preceding or succeeding.

In 1885 the river was in general below the normal height, and in 1886 was at nearly the same stage, the June flood being larger than in the preceding year. In 1887, 1888, and 1889 the river remained at or below the normal, the June flood of the latter year being so small in comparison with that of March as barely to show an increase. In 1890 the water remained above the normal for the whole year, but the June flood, which promised to be so large, dropped off abruptly in the middle of the month.

The spring of 1891 was characterized by the greatest flood of which a record has been kept. This came, as have most of those of February and March, from the Gila Basin, where a large amount of damage was done by the extraordinary rains. This sudden flood is interesting from the fact that it was probably the cause of the submergence of a portion of the Colorado Desert in the central part of San Diego County, California. The lowest part of this desert, at a point about 60 miles west of the Colorado River, is 225 feet or more below sea level. The Southern Pacific Railroad runs through this depression, and the unexpected appearance of the water at this remote point occasioned some alarm and also damage to the salt works on the lowest ground.

Discharge measurements of the Colorado River were made by the Wheeler Survey in 1875 and 1876 at three points—Stone's Ferry in Nevada, below the mouth of the Virgin, at Camp Mohave, Arizona, and at Fort Yuma, California, the results of which are given in a memorandum by Lieut. Bergland.[1]

At Stone's Ferry the measurements on August 12, 1875, gave the area of section as 5,723 square feet, width 480 feet, mean velocity 3·217 feet per second, and discharge 18,410 second-feet. The high-water mark of 1871 was 17·01 feet above surface of water at the time of observations. Increase of area at high water was 9,773 square feet. The

[1] Annual report upon the geographical surveys west of the 100th meridian in California, Nevada, Utah, Colorado, Wyoming, New Mexico, Arizona, and Montana, by George M. Wheeler, first lieutenant of engineers, U S. A., being Appendix JJ of the annual report of the Chief of Engineers for 1876, pp. 71–72, 119–125, Washington, 1876.

whole discharge at that time takes place through the section. Assuming the mean velocity to remain the same as on August 12, 1875, the increase in discharge would be 31,440 second-feet; but as in reality there would also be an increase in the velocity, the increase in discharge would be somewhat greater than this.

At Camp Mohave on September 2, 1875, the area of section was 4,628 square feet, width 1,116 feet, mean velocity 2·508 feet per second, and discharge 11,611 second-feet. The high-water mark of 1874 was 8 feet above surface of river on that date. The increase of area of section at high water, excluding overflow on flats, would be 13,656 square feet, and the increase in discharge through the section would be 34,274 second-feet, but as a considerable quantity of the bottom beyond the section is then covered with water, this will not represent the total increase.

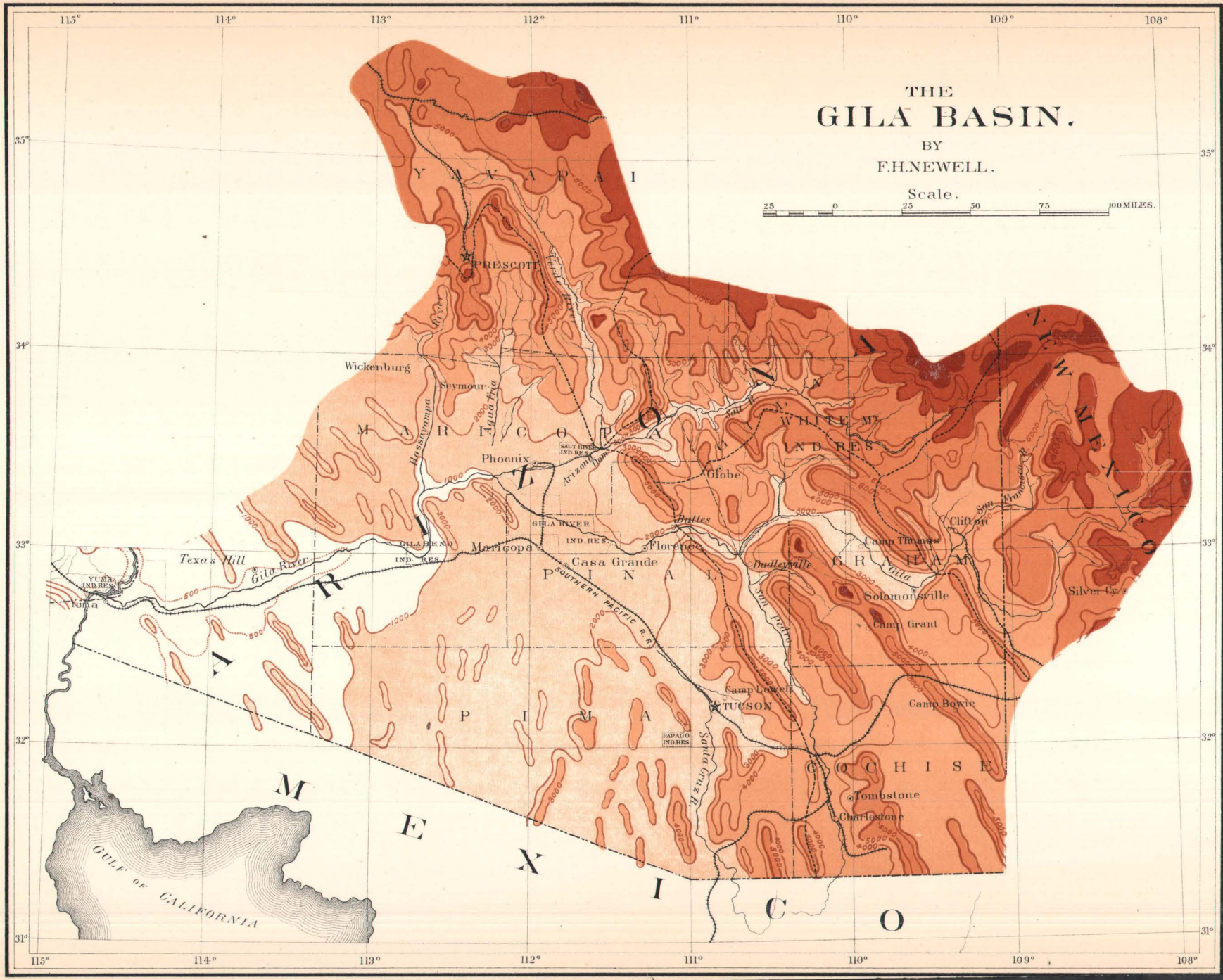
At Fort Yuma on March 20, 1876, the area was 2,726 square feet, width 461 feet, mean velocity 2·809 feet per second, and discharge 7,659 second-feet. The high-water mark of 1862 was 10·19 feet above the surface of the river. The increase of area of section at high water would be 5,059 square feet. The increase in discharges through section would be 14,244 second-feet. Here the velocity throughout the section would be increased at time of high water, and a large quantity would flow outside of the section, since the bottom lands would be flooded.

Adding the increase of discharge, due to the increase of area, to that measured, the flood discharges at the three places would be at least 49,850, 45,885, and 21,903 second-feet, respectively, to which is to be added the amount passing outside the sections, which in the case of Fort Yuma is large. It is stated that the computed increase for Camp Mohave is probably nearer the truth than that for the other localities.

THE GILA BASIN.

TOPOGRAPHY AND ALTITUDES.

The Gila Basin (Pl. LXXV), the most southerly portion of the great Colorado drainage basin, includes the greater part of Arizona, as well as a portion of New Mexico and of Sonora, in the Republic of Mexico. In all this area of 66,020 square miles the success of agriculture depends upon the artificial application of water to the crops. This water is derived from the Gila River and its tributaries by means of canals and ditches, which distribute it to the fields of each farmer. These streams fluctuate greatly, being at times subject to sudden floods, especially during summer rains, when they often sweep out bridges, dams, and canal head works, while at other times they may diminish until the water almost disappears. In floods there is, of course, far more water than can be used, although at this season as much as possible is put upon the crops, especially the forage plants, and great quantities are turned upon the fields in order to saturate the ground; but, on the other hand, during the ordinary low stages of the streams, the acreage of crops is limited to that which can be watered by the diminished flow.


THE
GILA BASIN.
BY
F.H.NEWELL.
Scale.
25 0 25 50 75 100 MILES.
115° 114° 113° 112° 111° 110° 109° 108°
35° 34° 33° 32° 31°
Y A V A P A I
M A R I C O P A
P I N A L
G R A H A M
G O C H I S E
PRESCOTT
Wickenburg
Seymour
Phenix
Globe
Florence
Casa Grande
Maricopa
Tucson
Tombstone
Charlestone
Solomonsville
Clifton
Camp Thomas
Camp Grant
Camp Lowell
Camp Bowie
Dudleyville
Silver Cy.
Texas Hill
Gila River
Gila
Salt River
Verde River
Hassayampa River
Agua Fria
Arizona Canal
Santa Cruz R.
San Pedro
Francisco R.
Brittes
GILA RIVER IND. RES.
SALT RIVER IND. RES.
GILA BEND IND. RES.
PAPAGO IND. RES.
YUMA IND. RES.
Yuma
SOUTHERN PACIFIC R.R.
WHITE MT. IND. RES.
NEW MEXICO
MEXICO
GULF OF CALIFORNIA

On Pl. LXXV is given a map of the basin on a scale of 40 miles to the inch, with contour interval of 1,000 feet. This is taken from the U. S. Geological Survey map of 1891 and shows in a general way, as is necessary on this scale, the elevations in this basin. It has been derived from all material accessible and gives at a glance the present condition of our knowledge of this important region.

By glancing at this map it will be seen that the high land of the basin, as indicated by the darker color, is along the northeastern edge. By consulting the full map from which this is taken it would be seen that this rim of the basin is not composed of high mountain ranges, as might appear from the small map alone, but is really the edge of a great plateau. Against the edge of this great plateau the prevailing winds from the south or southwest strike, and, being forced upward, as they rise deposit their moisture in the form of rain or snow, which, rolling backward, forms the small streams that, uniting, feed the Gila.

The map shows these little streams flowing in a general southwesterly direction and in the northern part of the basin uniting to form the Verde, which flows southerly parallel to the face of the cliffs. A little farther to the south and east these streams unite in the Salt, which also flows very nearly parallel to the edge of the drainage basin, but to the west to meet the Verde. On the extreme eastern edge of the basin the plateau-like character gives place to mountain ranges, and a less regular arrangement of the small tributaries is found there. They flow in almost every direction, to unite finally in the Gila, which takes a course nearly parallel to that of the Salt.

The remainder of the rim of the basin is poorly defined. The elevations are lower, and consequently the precipitation is less, and, with little rainfall, the streams are small, and seldom extend sufficiently far from the mountains to unite into a perennial river. Most of them sink into the broad, sandy plains soon after leaving their canyons; and while from the considerations of the topography they may be considered as belonging in the drainage basin of the Gila, yet they seldom or never contribute to its waters.

Thus the drainage basin of the Gila may be considered as consisting of two great divisions—that on the northeast, shown on the map by the heavy tints, rugged and precipitous, catching the moisture from the clouds; and that to the southwest consisting principally of vast areas of nearly level land, shown in lighter tint, much of it exceedingly fertile, and in every way adapted to agriculture, excepting in the one particular, the lack of water. Were it not for the position of these high plateaus, all of this fertile land would remain forever valueless to the farmer, and thus it is that the mountain region, even if it were of no other use, would still be valuable as a collector of rainfall. This great area, however, is not wholly useless, for much of it is valuable mineral land, the mines from which have brought prosperity to parts of the basin.

Assuming that this map of the drainage basin is approximately correct, sufficiently so for general purposes, computations have been made of the area of land lying at different elevations, the results being as follows: The total area of the basin is 66,020 square miles. Of this area—

9 per cent is under 1,000 feet.
19 per cent is between 1,000 and 2,000 feet.
16 per cent is between 2,000 and 3,000 feet.
14 per cent is between 3,000 and 4,000 feet.
15 per cent is between 4,000 and 5,000 feet.
12 per cent is between 5,000 and 6,000 feet.
8 per cent is between 6,000 and 7,000 feet.
7 per cent is over 7,000 feet.

The greater portion of the land lying at an elevation of less than 3,000 feet, may be classed as sandy plains, in large part agricultural if water could be supplied; in other words, about 44 per cent of the entire area of the basin would fall into this class. The lands over 5,000 feet in elevation may be considered as mountainous catchment areas. These aggregate 27 per cent of the entire basin, and it is from this 27 per cent, or a portion thereof at least, that all of the water comes.

The greater part, if not all, of the grazing and mining regions are included within this 27 per cent, as well as all the timber. The land from 3,000 to 5,000 feet above the sea is partly plain and partly foothill. A small part is agricultural, especially at the headwaters of the Verde and those of the Upper Gila, but in the main it is broken country, of little value even for grazing.

In this connection it is important to note the political divisions which have been made in the drainage basin, for much of their prosperity depends upon the wisdom and foresight with which the boundaries of States and counties have been laid out. This is particularly the case in the arid regions, where the one thing of value is the water, and where the land takes its value only from its position as regards the water supply. If the boundaries of States and counties had been made to coincide with natural divisions, so that the streams with their headwaters would lie in one grand division, the future control and management of the water would be comparatively simple; but in the cases (which are unfortunately too common) where, for example, the headwaters of a stream are in one State and the irrigable land in another, there is constant strife, or even an abandonment of great natural resources.

The Gila basin includes, besides the greater part of southern Arizona, a small portion of the Territory of New Mexico, and the State of Sonora, in the Republic of Mexico. In the case of this latter country the rim of the basin has been arbitrarily assumed, as there are no available maps which define it, and on the southwestern edge the boundary between the United States and Mexico is taken as the limit of the basin. This area, by counties, is shown in the following table:

	Square miles.	
Socorro County, New Mexico	3,893	
Sierra County, New Mexico	156	
Grant County, New Mexico	2,818	6,867
Republic of Mexico		1,168
Apache County, Arizona	2,550	
Graham County, Arizona	6,152	
Cochise County, Arizona	6,004	
Gila County, Arizona	3,212	
Pinal County, Arizona	5,300	
Pima County, Arizona	10,596	
Yavapai County, Arizona	9,685	
Maricopa County, Arizona	9,815	
Yuma County, Arizona	4,671	57,985
Total		66,020

Nearly 88 per cent of the entire area is in Arizona, a little over 10 per cent in New Mexico, and nearly 2 per cent in Mexico.

By a glance at the map, Pl. LXXV, it will be seen that the Gila River proper rises in southwestern New Mexico, near the Arizona line, and flows southwesterly through Arizona to its confluence with the Colorado River. Its total length from the source in New Mexico to the junction with the Colorado River, not including its many windings, is fully 500 miles. Besides the main Gila, the principal tributaries and streams of the basin are the San Pedro and Santa Cruz rivers on the south, and the Salt, Verde, Agua Fria, and Hassayampa rivers on the north.

The floods of the Gila are usually short and violent, the highest water occurring during the months of January and February. During a freshet the river rises in some places from 8 to 12 feet, and increases in width from 300 feet to a mile and a half. It is sometimes impassable for weeks, and has the appearance in places of a sea of muddy water. The season of low water occurs during the months of June and July, the river bed being then dry in places.

AGRICULTURAL LANDS.

The aggregate area in this basin on which crops were raised by irrigation in the year ending June 30, 1890, was found by the Census Office to be 61,857 acres, or 96·65 square miles, this land being along the main river and its tributaries, principally near the foothills, or among them wherever the valleys opened out, leaving room for flood plains. This is between one and two tenths of 1 per cent of the entire area of the basin, or, as the land is principally under 3,000 feet in elevation, is about three-tenths of 1 per cent of this latter class. But in addition to the lands on which crops were raised there is estimated to be an acreage fully twice as large under irrigation, that is, to which water has been brought and perhaps applied in certain years or seasons, but upon which crops were not matured in the census year, owing either to scarcity of water or the undeveloped state of the country.

It is evident from previous statements that this acreage under irrigation is but a small percentage of the total amount which, with ample water, might be cultivated; in fact, this latter total is so large, so much beyond the possibilities of water supply, that estimates as to its extent have little or no practical value. It is sufficient to know that there are in the Gila basin at least 10,000,000 acres of fertile soil, the greater part of which is without water. In other words, the soil and climate are favorable to an expansion of agriculture, which is limited only by the water supply.

Not only does the basin possess all the elements of sucessful agriculture, but it has the advantage of local markets and a constantly increasing demand for the products. The mining regions call for all kinds of food stuffs and forage, and, in fact, many grades of ore depend for successful handling upon a small reduction in cost of living, and consequently, of wages of the miners. There is thus a close interdependence between agriculture and mining, the prosperity of the one reacting upon the other; large crops increase the possibility of working the minerals, and the more laborers there are at the mines the greater is the demand for all kinds of produce.

In this connection it is interesting to note the relation which now exists between the area of the catchment and the area upon which crops have been successfully raised, that is, for which there has been an ample water supply. It is impossible to obtain, without better maps, the exact area of catchment, but assuming for purposes of comparison that it lies above 5,000 feet in elevation, it is found that for every acre irrigated there are in round numbers about 180 acres of catchment area, or for every 1,000 square miles of catchment crops have been raised on a little over 5 square miles. This obviously is a very small ratio, and progress will constantly tend to increase it rapidly at first, and then more and more slowly.

DUTY OF WATER.

This relation between the area of catchment and area cultivated depends directly upon the average duty of water, which, taking the basin as a whole, is very small, although there are instances to show that it can be greatly increased. Calculations have been made that with ordinary care and economy a second-foot should serve 120 acres. It is probable, however, that it will take some years of experience before a majority of the farmers can successfully accomplish this, and more or less hardship may arise in attempting to carry out such economy. Complaints are now made by the farmers that the larger canal companies do not furnish them sufficient water, while the canal superintendents assert that far more than a sufficient amount is allowed.

An approximation of the duty of water in the Gila Valley can be made by knowing the amount which enters through the canyons as compared with the crops irrigated. Eliminating the floods, it has been

found, for example, by the hydrographers of the Geological Survey that about 200 second-feet passed through the buttes above Florence during the year in which, as ascertained by the census, there were about 6,600 acres of crops successfully irrigated. This would give a water duty, measuring the water in the river, of only 33 acres, but it should be noted that a great quantity of this water was wasted, and was used on lands on which crops were not matured. On the lower Salt the measurement of the average flow, deducting the floods, for this time was about 600 second-feet, and about 30,000 acres of crops were raised, giving a water duty of 50 acres. This water duty is also very low, from reasons similar to those given above, but is higher from the fact that the canals were distributed along a greater distance, and much seepage water returned to the river to be used a second time.

Some conception of the average flow of the streams of the basin may be obtained by knowing the acreage of crops successfully irrigated, assuming as correct the statements of the irrigators that these crops demanded all the water available in the streams during the time in which they were maturing. Since there were in the basin 61,857 acres irrigated successfully, it follows that with a water duty of 50 acres to the second-foot the available water supply was at least 1,237 second-feet, or with a water duty of 30 acres to the second-foot, was 2,062 second-feet.

After the water duty has been increased to the greatest possible amount and the limit in this direction has been reached, there must be vast areas suffering for water. Under present methods, as much water as possible is turned out upon the ground in time of flood in order to produce complete saturation and great quantities are used upon the alfalfa and other forage crops. Then, as the rivers fall, water is employed to mature the cereals and vegetables, and finally during a drought the available supply is concentrated upon perennial plants, letting others perish in order to save vines, fruit and shade trees.

There thus arises in this method of progress without water storage a condition of affairs in which the acreage under cultivation adjusts itself to the average perennial supply. In other words, the amount of land on which crops can be raised will be that which the river in an ordinary year will supply with water. If less comes than usual, a portion of these crops must burn under the heat of the sun; if more than usual flows, a larger acreage will mature, and more cuttings of the hay crop can be made. It may be said for the Gila Basin, as well as for the greater portion of the arid region, that this condition has nearly taken place. The acreage of crops planted each year demands all the water or even more than flows during the times when they are maturing and the need is greatest.

While therefore the extent to which irrigation can increase without water storage can not be satisfactorily estimated, it is apparent that this can not be very great. Every irrigator looks forward to the per-

fection of water storage as the only method of relief from present uncertainties and losses.

WATER STORAGE.

In this basin a number of excellent sites are known to exist; two in particular have been so often discussed that it is sufficient merely to refer to them. The first is in Pinal County, 15 miles above Florence, where the Gila flows between two "buttes," forming a canyon 200 feet or more in width, with perpendicular walls on each side. In this canyon a dam of sufficient magnitude would impound, from various estimates, enough water to irrigate a large part of the plains below. The second is at Oatman Flats, in the western part of Maricopa County. The Gila at this point flows between bluffs of limestone from 111 to 126 feet high, and at a distance of 1,195 feet from each other. There is a large storage basin above, in which, by means of a suitable dam, sufficient water could be stored during the storm floods to serve the Lower Gila Valley during the dry season.

Besides these there are numerous places where dams could be constructed and smaller bodies of water stored. It is reported that Salt River, a short distance below the mouth of Tonto Creek, passes through a box canyon with vertical sides rising to the height of 100 feet. A suitable dam built here would impound sufficient water to furnish a part of the Salt River Valley with an abundant supply.

But while there is no doubt as to there being suitable localities in which water can be held, there is some question as to the quantities of water to be depended upon to fill these reservoirs annually. Each year there are short, sudden floods carrying considerable volume of water for a few hours, and at longer intervals, perhaps of three or five years, there are enormous floods, whose violence and duration is phenomenal. These latter, however, are rather to be feared than to be depended upon as beneficial.

The question arises, will the ordinary floods, such as happen every year without exception, fill these storage reservoirs? Can they be depended upon, and do they always carry the requisite amount of water? This is a question, unfortunately, which is far from being answered, and the operation of the Geological Survey being carried on for such a short time, tends rather to increase the doubt than to satisfy it. The year during which the measurements were made was one of comparative scarcity, and these measurements, as shown on later pages, do not give the great quantities of water available for storage that is popularly supposed to exist.

As before intimated, it is necessary to carry on measurements of this class for several years before engineering estimates can safely be prepared. Thus the first steps toward water storage in this basin on any large scale, one in which a majority of the inhabitants will be concerned, is to continue such measurements for a sufficient number of years to determine the necessary facts.

A study of rainfall is interesting and may yield instructive results. If the river flow varied directly with the rainfall, the matter would be greatly simplified, but, unfortunately, the relation which exists between the precipitation as measured in the rain gauges and the amount of water available is not one of direct proportion, but is influenced by so many factors that conclusions based upon the measured rainfall alone are apt to be misleading.

RAINFALL.

Since the water supply comes primarily from the rains, it is well before describing the different portions of the basin in detail to present some of the broader facts concerning the amount and distribution of the precipitation. Compared with the size of the basin, there are but few stations at which rainfall has been measured for a long series of years, and these unfortunately are mainly in the valleys, where the precipitation is least. As a general thing, it may be said that in this basin, owing to the diversity of topography in the higher lands, the rainfall increases with the altitude, and therefore the greater part of the precipitation occurs along the northeastern edge of the basin, while out on the great plains through which the Gila flows, and where the best agricultural land is situated, there is the least moisture, the average at Yuma being less than 3 inches, at Texas Hill, 4 inches; at Maricopa, 5 inches; and at Casa Grande, a little over 4 inches; while, on the other hand, near and among the mountains, or rather the slopes of the edge of the great plateau, the rainfall increases to 10, 15, or even 20 inches and over.

The precipitation of this basin is given in the various publications of the Signal Service, and for the present purpose it is sufficient to present in graphic form some of the general results. On Fig. 226 is given the annual rainfall for seventeen stations, the amount of rainfall for each year being represented by the height of the black blocks, the diagram being similar to that for the Rio Grande Basin. Wherever a blank occurs on this sheet, it signifies that no rainfall observations were made, or that they were incomplete. In looking at this diagram, the most striking fact is the exceedingly irregular character of the rainfall, its variation in amount at one place from year to year, and lack of coincidence for the same year for several places; that is to say, while at one place there is less rainfall for a given year than in the year preceding, for another locality there may be more. There is, however, a certain general variation which may be traced in a broad way; that is taking all of the stations for any one year, the average shows often a decided difference from that of the average of all stations for the year preceding or succeeding. In order to bring this out, the average for all stations in and adjoining the basin has been plotted, as shown in the central figure in the bottom row of the diagram. On examining this, the most notable features are the excessive rainfalls of 1868, 1874, 1878 and 1884, and the diminished rainfalls of 1870, 1880 and 1885,

showing a curious alternation of ten-year periods, which, however, may be regarded as coincidences.

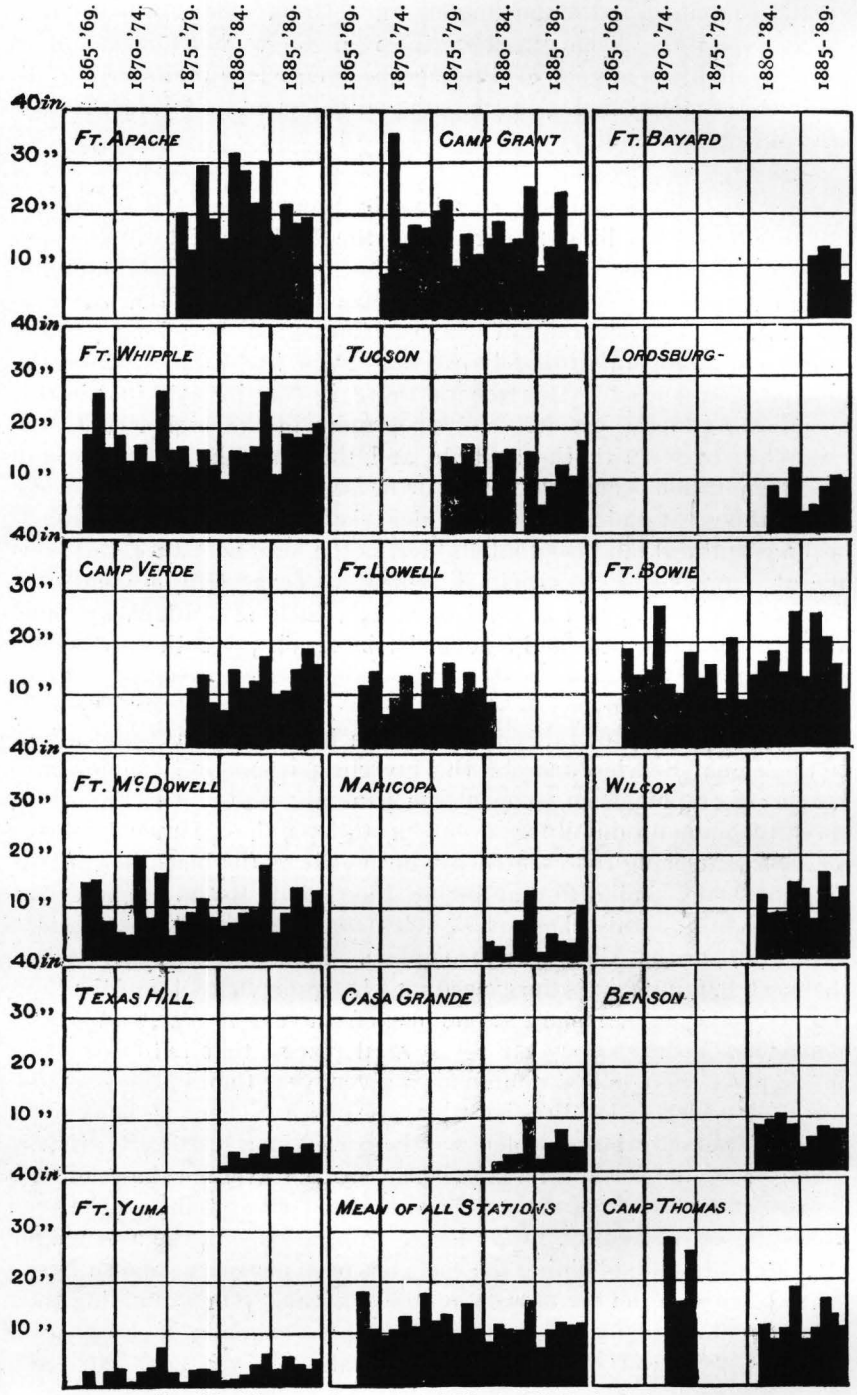
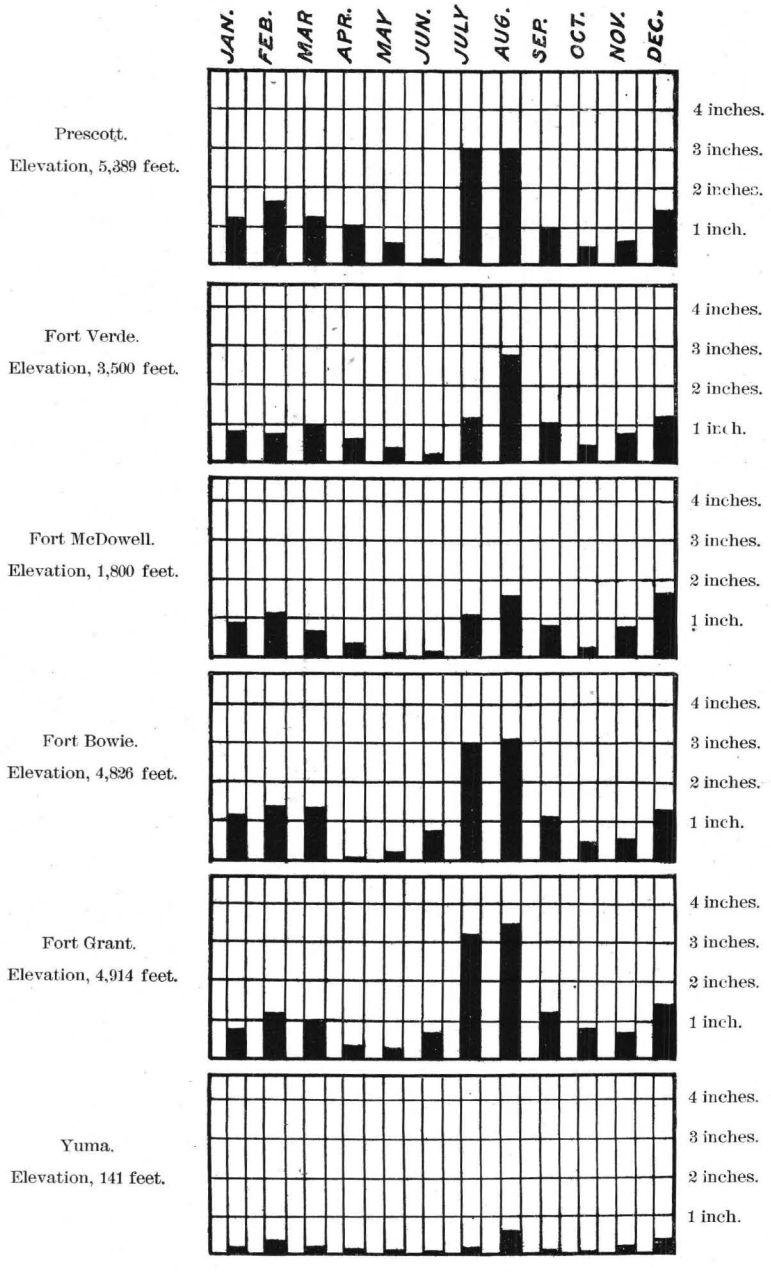


FIG. 226.—Diagram of annual rainfall in the Gila Basin, Arizona.



AVERAGE MONTHLY RAINFALL AT STATIONS IN THE GILA BASIN, ARIZONA.

The year 1884 was an unusually rainy one throughout this basin, as well as throughout a great part of the West, as previously noted, while 1885 was a year of minimum precipitation. Since those years, the average rainfall has been nearly constant, and perhaps diminishing slightly through 1888 and 1889. There is, of course, no regularity about such matters, but a study of the experience of the past is valuable, as indicating the range through which the amount of precipitation has varied, and therefore through which it may alternate again.

While the amount of annual rainfall is important, it does not have such a direct bearing upon agriculture as does the monthly and seasonal distribution of the rain; in other words, a small annual precipitation may be compensated for by a distribution of rainfall such that it all occurs during the months when most needed. On the other hand, a large annual precipitation may be of small use to the farmer from the greater part occurring at times when the water is not needed, and when it runs off into the rivers. Pl. LXXVI shows graphically the relative amount of rainfall during the months for six different stations. This is the average of from twelve to fifteen years,[1] and while it does not represent the amount which may be expected to fall on any one month, it does show the distribution through long periods of time. The most notable feature of this diagram is the gradual decrease of the rain from February to June, the sudden increase in July and August, a second diminution in the fall, nearly, though not quite, to that of early summer, and a second gradual increase in the winter to an amount about half that of the summer.

The relation between the rainfall and the amount of water which flows in the river, commonly known as the run-off, is not a matter of direct proportion, as before noted, on account of the many modifying circumstances. A rainfall of 1 inch may or may not cause a greater rise than one of half an inch, depending upon the rate at which it falls. For example, a long-continued, gentle rain may slowly saturate the ground and contribute very little to the run-off, while, on the other hand, the same amount of water falling in a sudden local storm often causes an immediate response in the streams and produces a violent flood. Although a knowledge of the rainfall can not give information as to the water flowing in a river, yet it is of the greatest value in other connections.

In this connection Pl. LXXVII, showing a portion of the drainage area of the ill-fated Hassayampa Reservoir, is introduced to exhibit the characteristic topography of the higher part of the Gila Basin. In the background are shown the steep slopes of the mountains, almost bare of vegetation, and from which in time of rain the water runs immediately into the gullies and canyons. This view shows the Hassayampa Reservoir shortly after it was filled with water for the first time, the

[1] Charts showing the normal monthly rainfall in the United States extracted from the monthly weather review, with notes and tables prepared under the direction of Gen. A. W. Greely, Chief Signal Officer; Washington, 1889.

tops of the higher trees still appearing above the water. The vegetation throughout that country is very scanty, and, as shown in the foreground, there is none of the smaller growth and carpet of grass so common in the humid regions.

UPPER GILA DISTRICT.

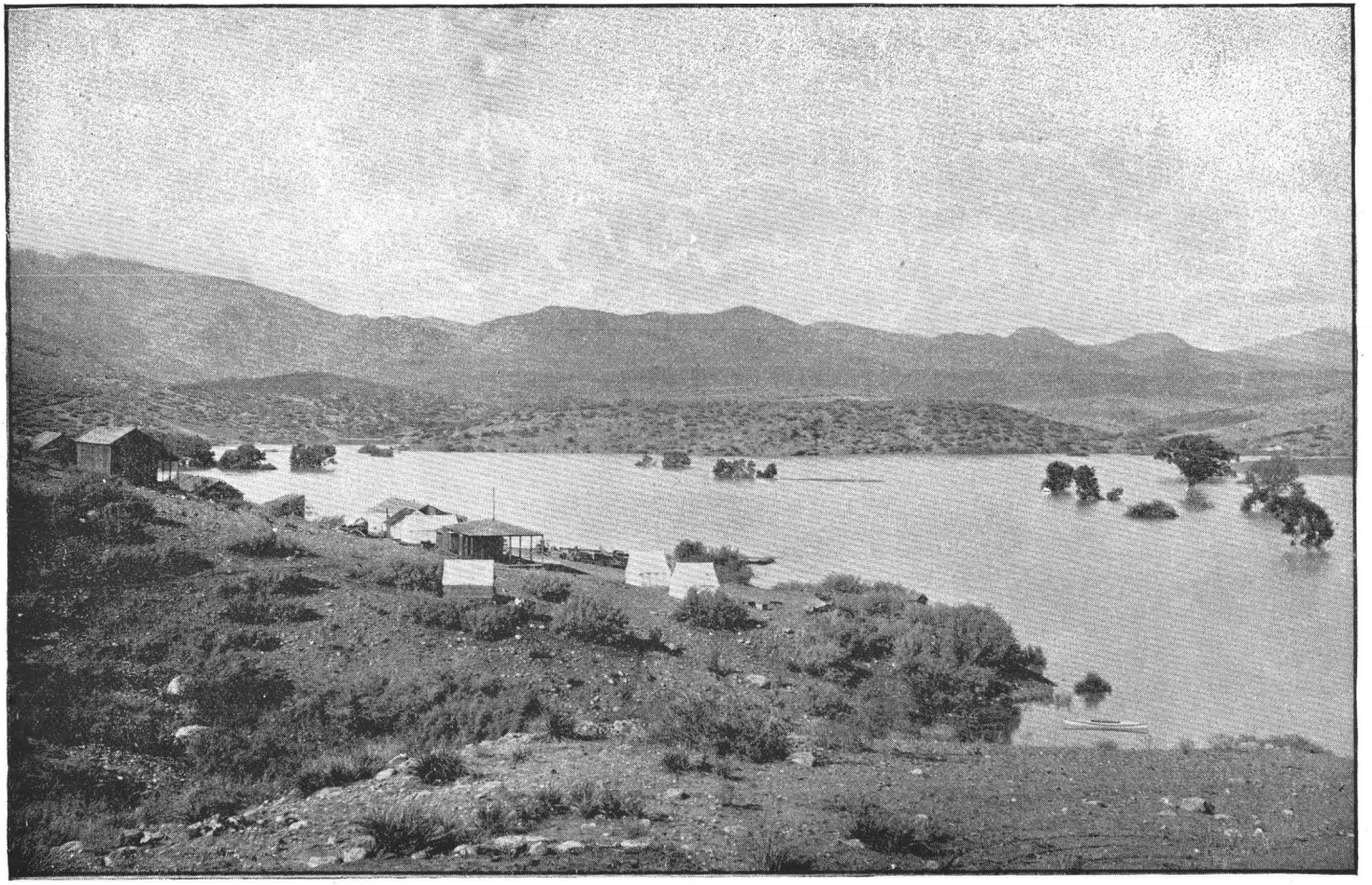
The headwater basins of the Gila, as shown on the map, are as follows: Upper Gila, San Pedro, Verde, and Upper Salt. The Trunk River divisions are the Middle Gila, Lower Salt, and Lower Gila, while the principal lost river basins are the Agua Fria, Hassayampa, and Santa Cruz, each of which will be discussed in order.

The Upper Gila district or headwaters of the main Gila may be considered as including that part of the basin from the highest catchment down to the buttes above Florence, excluding, however, the San Pedro. This area embraces that portion of the basin from which the most water may be supposed to come, as well as certain large bodies of irrigated and irrigable lands. The total area is 10,930 square miles, comprising 3,893 square miles in Socorro County; 156 square miles in Sierra, and 2,818 in Grant County—these three counties being in New Mexico; and in Arizona—4,220 square miles in Graham County; 880 square miles in Gila County, and 530 square miles in Pinal County.

The elevation ranges from 3,000 feet up to 10,000 on the highest peaks. The principal streams, besides the Gila itself, are the San Francisco River and its branches, the Gila Bonita, and the Mogollon River. The San Francisco is a perennial stream, which derives its principal supply from melting snow, and becomes very low, although it has not actually become dry before the summer rains.

The Gila in this portion of its course flows throughout the year, and is subject to sudden and violent floods, especially during the summer season. The supply for this district is comparatively ample, and therefore no attempt has been made to increase it by storage. During 1889 and 1890 crops suffered greatly on account of the scarcity of water, for, judging from general report, there was less water than during the previous decade. It is probable, however, that the supply was ample for the acreage irrigated in the census year. In general, for wheat, barley and oats, water was plentiful, but late crops often suffered and were lost.

In the valleys comprised within this district crops to the extent of 9,137 acres, or 14·3 square miles, were raised by irrigation in the census year. This amounts to a little over one-tenth of 1 per cent of the total area of the district. The largest body of irrigated land is in the Pueblo Viejo Valley, extending from the canyons above Solomonville westward. In this valley, besides the land under crop, there are large tracts to which water can be brought by the ditches at present in operation, the names of which, as reported to the survey by Mr. T. E. Farish, in 1889, are given below. Under the head of acres is the probable acreage which the ditch may be made to cover.



HASSAYAMPA RESERVOIR.

Ditches and irrigable lands.

	Length.	Covers.		Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Montezuma	9	6,000	Mejia	5	2,000
San Jose	7	3,000	Maxey	8	4,500
Union Canal	8	6,000	Oregon	5	2,500
Central Canal	12	6,000	Nevada	6	3,000
Sunflower Canal	3	1,500	Darby	4	1,000
Smithville Canal	5	2,000	Michelena	4	1,500
Gonzales	5	2,000			

Besides the above there are two or three small private ditches, covering in the aggregate about 4,000 acres, bringing up the entire acreage which could be reclaimed by ample water to 45,000 acres. In Pinal County there are three private canals between the mouth of the San Pedro and the town of Riverside, as follows:

	Length.	Covers.
	Miles.	*Acres.*
Shields	2½	480
Winkleman	1½	480
Brannaman	1¼	320

Many of the canals given above have sufficient water at all times for the area under crop, while others are reported to be dry for a few weeks in June and July. The question of water storage, however, has not as yet attained great prominence, as by far the greater part of the tilled lands in this basin along the river have ample water, and there are still tracts in various localities which may, with proper care and economy of water, be brought under irrigation.

THE SAN PEDRO DISTRICT.

The San Pedro rises in Sonora, Mexico, and flows northerly through Cochise County, a corner of Pima, and the western end of Pinal County, Arizona, entering the Gila below Dudleyville, 45 miles above Florence. This total area comprises about 2,820 square miles, of which 120 miles are in Mexico, 1,900 miles in Cochise County, 267 in Pima, and 533 in Pinal County. The limits of this district can not be accurately defined as there are no good maps of this extreme southern portion of the United States, and the outlines can be sketched only in a general manner. Eastward of this district and south of the upper Gila district is a large area of about 5,700 square miles, which has been included within the hydrographic basin of the Gila, but in which there are no large streams, whatever rainfall there is being usually evaporated before streams of any size are formed.

The water supply of this basin comes almost entirely from the San Pedro River, which is perennial, but which, like all other streams of the basin, fluctuates greatly. The season of scarcity usually occurs in May and June, the rains of summer tending to swell the river in July, Au-

gust, and September. No attempts at storage have been made, but the irrigators appreciate the necessity of so doing, and regard this matter as of first importance. The supply is considered sufficient for the small grains and hay, but for late crops of corn and beans there is sometimes a scarcity. It is reported that there was more water in 1890 than for some years previous.

The river, receiving most of its waters from a country of very light snowfall, depends for the greater part upon the showers of summer. For many miles it flows over a sandy bed between high banks. During the rainy season the waters rise suddenly, even, it is reported, to 12 feet in places, assuming then the character of a torrent. In droughts it shrinks to an insignificant stream of clear water, sinking into the sands and again reappearing, where the ground water is forced to the surface by impervious layers or bed rock.

In the upper San Pedro Valley are several thousand acres devoted to stock raising, much of which can, however, be irrigated in time by a careful conservation of the waters. For a distance of over 60 miles along the river small ditches have been taken out. The soil of the valley is fertile, producing good crops of alfalfa, wheat, oats, barley, vegetables, and various fruits.

The following is a list of the canals, as given by Mr. T. E. Farish in 1889:

Canals of San Pedro Valley.

	Length.	Covers.		Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Brown	1½	160	Watterman No. 2	1½	320
Cook	1½	200	Watterman No. 1	1½	320
Dodson	2	320	Swingle	2	480
Pusch	2	640	Harrington	1¾	480
Bates	1½	160	Latten	1	80

In the lower portion of its course the river is in places dry, owing to the diversions made by a large number of small canals. In addition to the main stream there are in the mountains, at the outlets of various canyons, a number of small springs, whose waters have been used for agricultural purposes and which are of considerable value to the owners, but these do not form a notable feature in the water supply of the district. The total area upon which crops were raised in this district during the census year was 2,672 acres, or nearly 4·2 square miles, or 0·15 per cent of the entire basin.

Water storage is urgently needed, and there are unquestionably facilities for this, the great obstacle being the lack of information as to the amount of water available. Measurements of water in this basin were begun at a station near Dudleyville, to obtain the amount discharged into the Gila. The station was placed at this point largely from the fact that it could be operated in connection with the gauging

station at the Buttes, above Florence. The measurements were begun on April 9, 1890, and continued until the hydrographic fieldwork was suspended. The results are as follows:

San Pedro—Dudleyville, Arizona.

[Drainage area, 2,870 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per square mile.
1890.	*Sec. feet.*	*Sec. feet.*	*Sec. feet.*	*Acre feet.*	*Inches.*	*Sec. feet.*
April 9 to 30	21	5	14	833	·005	·005
May	9	5	6	369	·002	·002
June	5	1	3	179	·001	·001
July	225	1	13	800	·005	·005
August	507	102	295	18,140	·121	·105
Total	.....	.....	.....	.....	·134	.....

It so happened that the gaugings were made during a year when the floods were apparently small, although at a season when they were liable to occur with violence. After the work was suspended there were several periods of high water, but the quantities discharged can not be computed, as the gauge rod was injured. Judging from the reports of residents of the valley, this was a year of minimum river flow, so that the measurements must be considered as far below the average.

THE MIDDLE GILA DISTRICT.

The middle Gila district is a trunk river division, and depends for its water supply upon the amount which comes from the two districts above mentioned, namely, the upper Gila and the San Pedro. The limits of this district are somewhat arbitrary, the district being considered as extending from the Buttes above Florence to the junction of the Gila with the Salt, and including on both sides of the river that portion of the great plain which can be irrigated from the Gila River. There were in this district 6,619 acres of crops irrigated, as shown by the census of 1890. The water supply for this land comes wholly from the Gila River, and the development of agriculture within the district depends upon the conservation and economic employment of this water. In the latter part of June the bed of the river is often dry, its water being diverted by the numerous canals of this district. Floods are liable to occur with great violence in July and August, as well as in January, February, and March. There is usually sufficient water to mature one crop, but it is reported that the second crop has been lost repeatedly. According to the statements of the irrigators, the year 1890 was one of the dryest known, while during 1889 the supply may be considered as about at an average.

In the Middle Gila Valley, beginning just below the canyon, 12 miles above Florence, the following canals were reported by the hydrographers as taking water from the river in 1889:

Canals of the Middle Gila Valley.

	Length.	Covering.		Length.	Covering.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Moore's	3	300	Montezuma	6	1,000
McClelland	3	300	Pat Holland	7	1,000
Sharp	3	160	Alamo Amarillo	7	1,000
Stiles	4	300	Brady	4	1,000
Swiss	2	200	Adamsville	4	1,000
Brash	4	400	White	3	200
Florence	43	20,000	Walker & Dempsey	3	300

The amount of water available for this basin was accurately determined by the Geological Survey during about one year; but their work was stopped at the end of this time by lack of further appropriation. The gauging station was established at the Buttes, about 15 miles above Florence, at a location well known from the favorable advantages which it offers for the storage of water. Here measurements were made from August 26, 1889, to September 1, 1890, the results of which are given in the following table, and are shown graphically on Pl. LXXVIII. According to the statements of men who have been for some years in that district, the water supply of that year was lower than usual. This assumption, however, will not hold if diversions of the water continue to be made in the Upper Gila district, where there is still a large acreage of good arable land to be brought under cultivation.

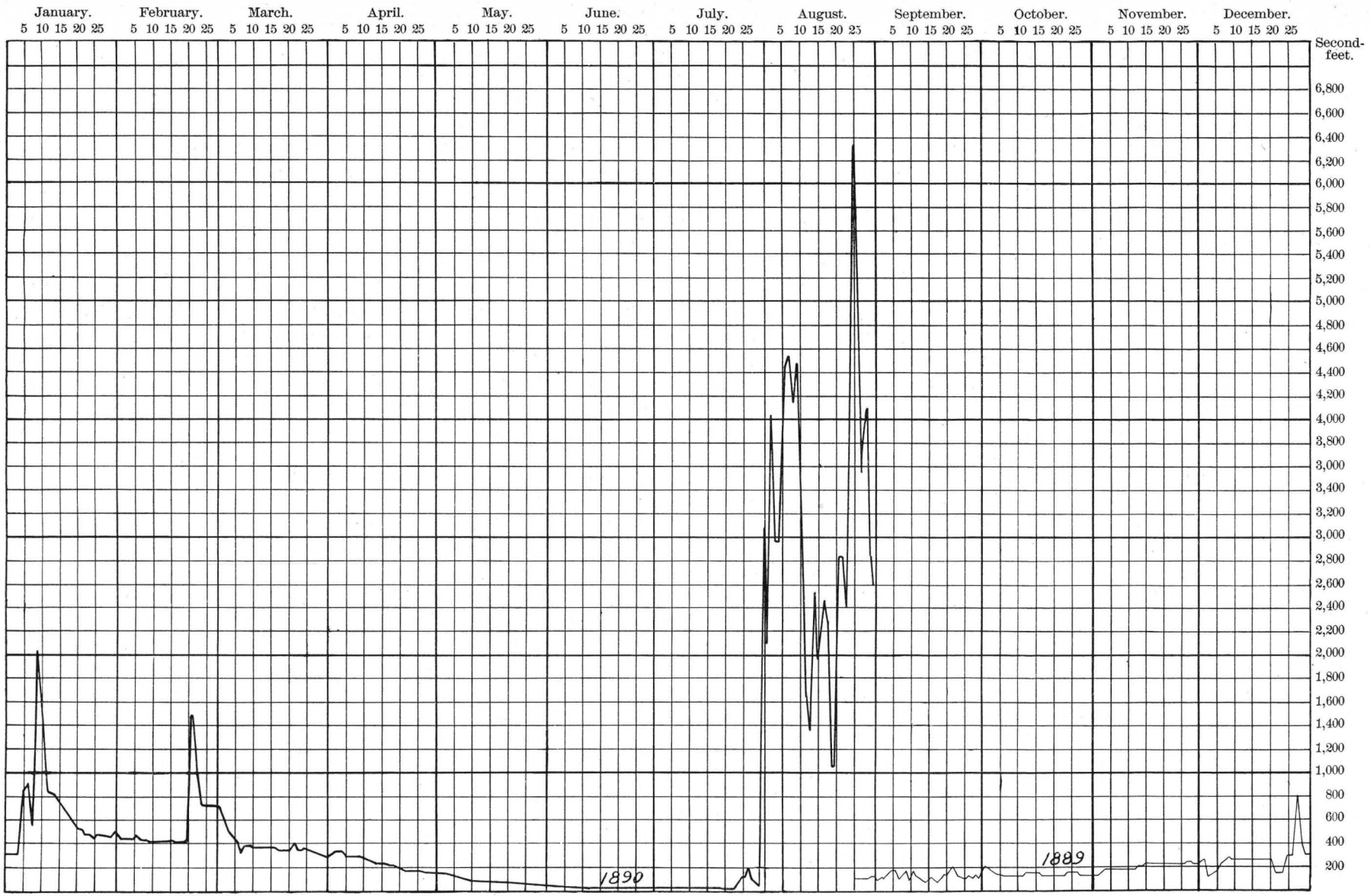
Gila River, Buttes, Arizona.

[Drainage area, 15,370 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per square mile.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-feet.*	*Inch.*	*Second-ft.*
Aug. 26–31	124	110	115	7,072	·008	·007
September	210	90	128	7,616	·009	·008
October	210	140	157	9,655	·014	·012
November	250	156	212	12,614	·015	·013
December	890	124	275	16,912	·020	·018
1890.						
January	2,100	310	680	41,820	·051	·044
February	1,514	405	578	32,079	·039	·037
March	710	300	387	23,800	·029	·025
April	333	158	238	14,161	·017	·015
May	150	35	87	5,350	·007	·006
June	35	27	28	1,666	·002	·002
July	3,112	11	130	7,995	·009	·008
August	6,330	1,115	3,137	192,925	·235	·204
Total, 1 year			6,037	366,593	·447	
Mean			503			

In the latter part of the above table is given the depth of the run-off in inches, and it is of interest to note the small amount of this and the relation between it and the depth of rainfall as measured at various points in and near the basin.

In the following table the depths of precipitation is given as published in the reports of the Signal Service for the months during which



DAILY DISCHARGE OF THE GILA RIVER AT THE BUTTES, ARIZONA.

the river gaugings were made, and at the bottom is the mean of the depths of the stations reporting. If it be considered that this in a general way represents the average for the basin, or at least varies with the average rainfall in the basin, a comparison can be made between the rainfall and run-off. The heavy rains of September do not appear to have had an immediate influence on the river. On the other hand, the decreasing rainfall in September, October, and November is accompanied by a gradual increase in discharge of the river, indicating that while the precipitation may be less in amount, yet, as winter approaches the showers may have a greater and greater influence on the river discharge.

Comparing the total of the monthly mean precipitation—15·56 inches—with the total depth of run-off for the year—0.447 inch—it appears that a little less than 3 per cent of the rainfall of the basin reaches the gauging station, under the assumption that this average of the measured rainfall represented that for the entire basin. If no diversions of water for irrigation had been made in the upper Gila and San Pedro districts, this percentage would have been larger, reaching possibly as high as 5 per cent. It is to be noted that over one-half of the run-off of the entire year came in August.

Monthly precipitation at stations in and adjoining the Gila Basin, in inches.

Station.	1889.				1890.							
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
Bisbee	3·79	0·38	0·20	0·29	2·34	0·20	0·24	0·15	0·00	0·03	6·07	5·71
Dos Cabezas	0·58	1·11	T	0·12	1·28	.....	0·08	0·95	0·00	0·03	3·90	5·07
Dragoon	0·18	.....	0·00	0·97	2·11	0·43	0·00	0·32	0·00	0·00	4·09	4·73
Dudleyville	1·55	0·78	0·82	1·88	1·63	1·46	0·52	0·75	.....	T	.....	.....
Fort Bayard	2·19	0·67	0·00	T	1·40	T	0·11	T	0·00	T	4·17	3·86
Fort Bowie	2·79	0·74	T	0·57	0·78	0·23	0·03	0·59	0·00	T	4·97	4·06
Fort Grant	0·69	0·94	0·16	1·11	1·58	0·46	0·46	0·92	0·01	0·20	3·24	4·54
Fort Huachuca	2·46	0·04	0·14	0·75	1·50	0·10	T	0·34	0·00	0·00	4·38	4·49
Fort Thomas	0·38	0·26	0·34	1·18	1·92	0·49	0·45	1·21	0·00	T	2·02	4·11
Pantano	2·52	0·04	0·00	0·96	.....	0·75	0·15	0·79	0·00	0·00	2·49	6·30
San Carlos	2·13	0·71	0·50	2·05	2·10	1·40	0·88	1·31	0·00	0·00	2·25	3·26
Silver King	0·97	1·17	0·83	5·23	3·77	2·93	0·64	2·63	0·00	.....	.....	.....
Teviston	2·30	0·60	0·20	0·20	3·80	T	0·20	3·00	0·00	0·00	5·20	4·00
Wilcox	2·79	0·80	0·02	0·50	1·61	0·35	0·11	0·63	0·00	0·15	2·64	5·20
Mean	1·80	0·63	0·23	1·13	1·98	0·67	0·27	0·97	0·00	0·03	3·24	4·61
Run-off	0·009	0·014	0·015	0·020	0·051	0·039	0·029	0·017	0·007	0·002	0·009	·235
Per cent	0·5	2·22	6·5	1·7	2·57	5·82	10·7	1·7	0·00	6·6	2·7	5·0

The most important question is as to how much water could have been saved during this year, if a suitable dam had been at this place. It is evident that not all the water could be held; a certain amount must be allowed to flow down the channel for the ditches below.

It is also necessary to assume that there would be a constant loss of water by evaporation. The measurements of this factor have not been continued for a time sufficiently long to give a large range of results, but from an examination of these and other data the following rate has been assumed in round numbers:

Loss by evaporation from a water surface.

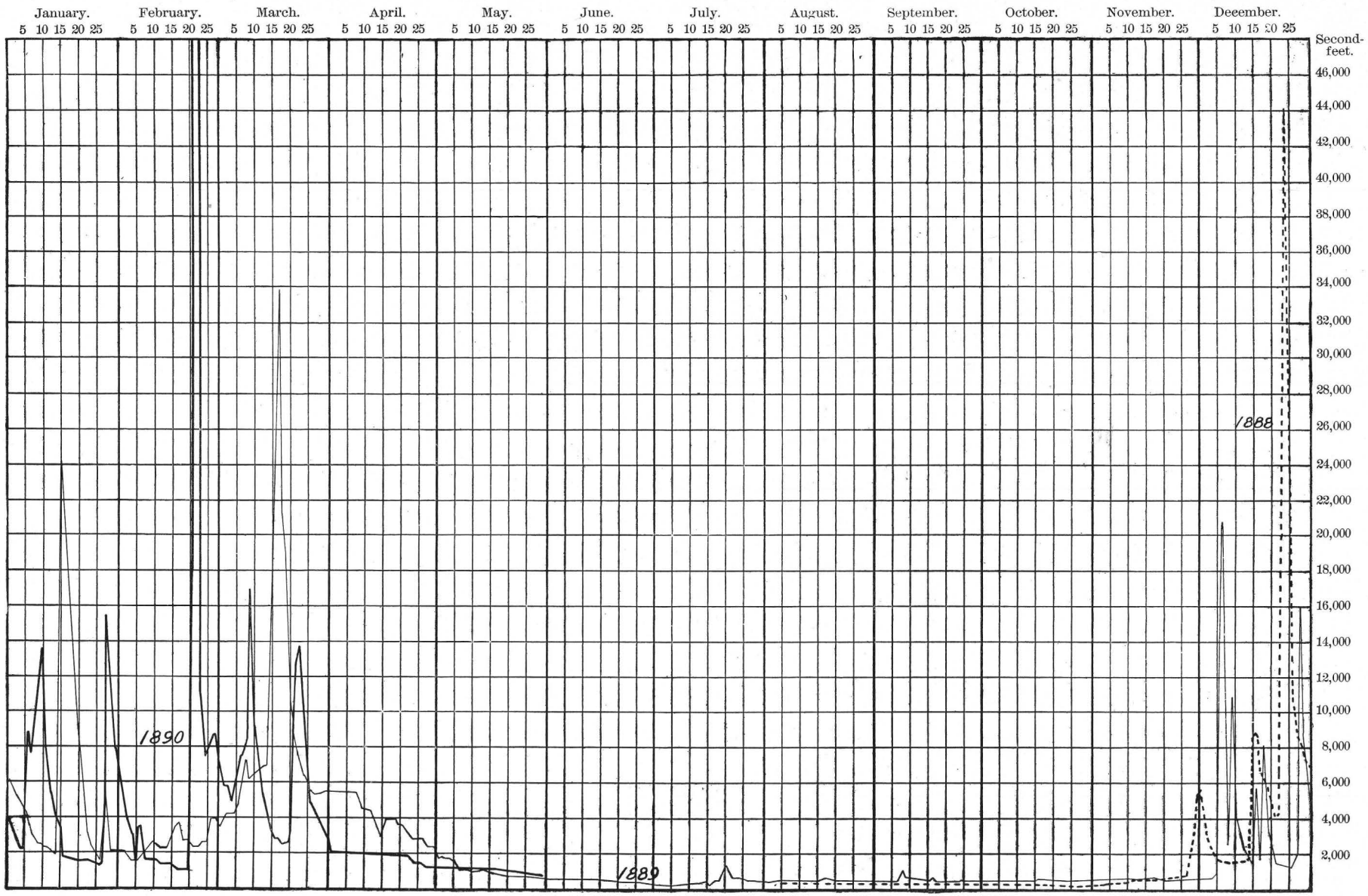
Month.	Quantity.	Month.	Quantity.
	Inches.		*Inches.*
January	3	August	13
February	4	September	10
March	6	October	6
April	7	November	5
May	10	December	4
June	11		
July	12	Total	91

In order to obtain general ideas concerning the amount of water which could have been stored during the year in which measurements were made, one or two examples may be given, taking different rates of outflow for the various months. For any given acreage under cultivation a certain amount of water must be allowed to flow in the river all the year round, less being needed in winter than in the heat of summer, but some being used even in the former season, especially on forage crops. These examples are placed in tabular form for convenience.

In the first case it is assumed that no water is held during September, October, and November of 1889, but that in December, January, and February only 150 second-feet are allowed to flow in the river; in March, April, and May, 250 second-feet; in June, July, and August, 300 second-feet. The first column gives the months. The second column the average inflow of the supposed reservoir in second-feet; that is, the measured amount of water flowing in the river. The third column gives the amount assumed to be discharged steadily from the reservoir. The fourth column gives, in round numbers, the loss by evaporation in acre-feet, making certain assumptions as to the size of the reservoir and consequent area of surface exposed to evaporation. The fifth column gives the amount of water which is left in the reservoir at the end of each month.

Month.	Inflow.	Outflow.	Evaporation.	Bal. at end of month.
1889.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Acre-feet.*
September	128	.....	.....	.....
October	157	.....	.....	.....
November	212	.....	.....	.....
December	275	150	100	7,400
1890.				
January	680	150	500	39,760
February	578	150	1,000	62,728
March	387	250	2,000	69,222
April	238	250	2,000	66,502
May	87	250	3,000	53,396
June	28	300	2,000	35,076
July	130	300	2,000	22,536
August	3,137	300	4,000	193,036

In the second case, all of the water being allowed to flow during September and October, 200 second-feet is discharged into the river during November, December, January, and February, and 250 second-feet in March and April. This amount is then increased to 300 second-feet in



DAILY DISCHARGE OF THE SALT RIVER ABOVE PHENIX, ARIZONA.

May and 350 in June, July, and August, leaving a balance at all times in the reservoir as shown in the fifth column.

Month.	Inflow.	Outflow.	Evaporation.	Bal. at end of month.
1889.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Acre-feet.*
September	128	.....	.....	.....
October	157	.....	.....	.....
November	212	200	15	700
December	275	200	80	5,230
1890.				
January	680	200	400	34,330
February	578	200	1,000	54,320
March	387	250	2,000	60,760
April	238	250	2,000	58,045
May	87	300	2,500	42,445
June	28	350	2,000	21,295
July	130	350	1,500	6,275
August	3,137	350	4,000	170,275

The amount of land which would be irrigated by the streams which have been assumed in these examples as coming from the reservoir will vary largely with the character of crop, especially the proportion of forage plants, these requiring water at all seasons. A conservative estimate, however, of 75 acres to the second-foot will probably cover all contingencies. This duty, as is recognized, is small, from the fact that the water is returned to the river from the reservoir and is not taken directly by short canals upon the land. In the first case assumed in these examples of a flow of 300 second-feet in June, July, and August, at least 22,500 acres can be covered, and in the second case, with a larger percentage use of water during the winter, 26,250 acres can be irrigated.

These examples and an infinite variety of others which might be taken, using different combinations of figures, merely serve to show that even in a dry year sufficient water can be held to protect a large acreage and render irrigation a matter of certainty. Other engineers, in figuring the amount of water available, will undoubtedly take other values, and in most cases they will estimate that a far larger acreage can safely be covered, since these examples are taken with a wide margin of safety.

THE VERDE DISTRICT.

The Verde district embraces the drainage basin of the Verde River and its tributaries, having a total area of 6,000 square miles, of which the greater part is in Yavapai County, only 700 square miles being in Maricopa County. In this district 1,948 acres of crops were irrigated successfully in the year ending June 30, 1890. The water supply in general is good, and a far larger area, now partly irrigated, can be watered.

Among the principal tributaries of the Verde are Walnut, Granite, Oak, Beaver, and Clear Creeks. Walnut Creek is dry during a portion of the year, its waters being entirely diverted upon the adjacent land.

On Granite Creek the supply is reported to be ample for the acreage under irrigation, but there is more land needing the waste waters of the floods. Oak Creek supplies an amount more than sufficient for the lands in the vicinity of Cornville. The other streams entering below carry larger quantities of water than is used at any time.

The largest body of irrigated and easily irrigable lands is in the Verde Valley proper, which is situated in the southern part of Yavapai County, extending from a canyon 20 miles or more above Camp Verde to another narrow pass about 10 miles below the fort. In this valley large crops of alfalfa, barley, oats, wheat, corn, and potatoes are reported to be raised, as well as apples, pears, plums, peaches, and apricots. The Verde River here flows continuously, with an occasional flood from local rains. The water supply is good, but crops have suffered from accidents to canals or difficulty of turning the water into them.

Measurements of the discharge of the Verde were attempted at a point about a mile above its junction with the Salt River, in order to obtain the amount discharged and its relative importance. The station at this point was operated in connection with one on the Salt River, about a mile above the Verde, and observations at both points were carried on during a large portion of the summer and fall of 1889. It was found impracticable, however, to obtain the daily heights on account of the distance of these stations from the homes of persons who were competent to act as gauge observers, and the difficulty of measuring these rivers in time of flood necessitated the abandonment of the work in order to concentrate all efforts on the Gila River.

The results of the measurements are given in the following table, and they may also be found in greater detail in the previous annual report. These do not show a very decided fluctuation of the river, but serve to give definite ideas as to the ordinary summer discharge of this stream:

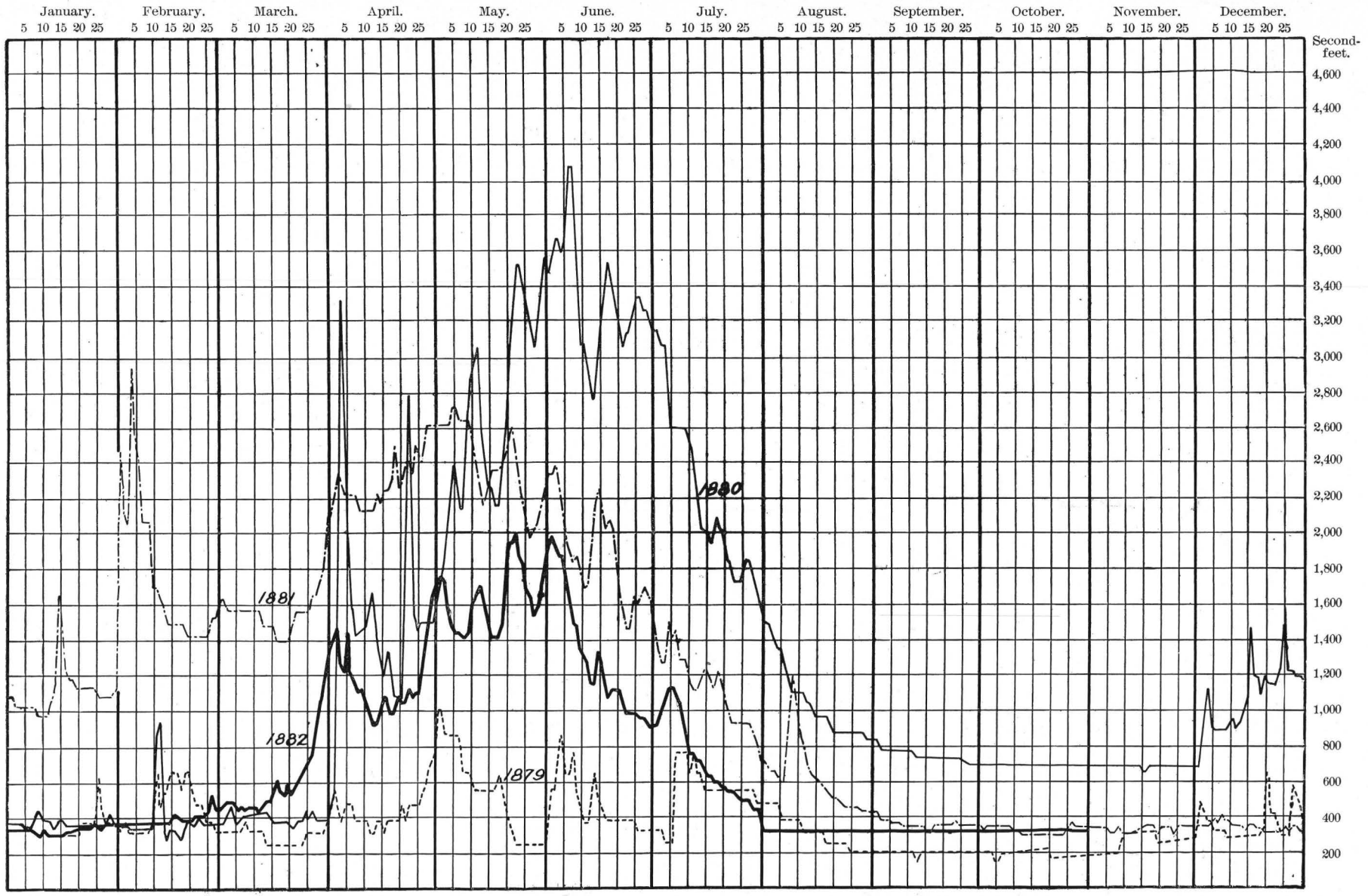
Verde River, 1 mile above Salt River.

[Drainage area, 6,000 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inch.*	*Sec.-feet.*
August 14–31	480	154	207	12,730	·04	·03
September	340	140	192	11,424	·03	·03

THE UPPER SALT DISTRICT.

The Upper Salt Basin lies between the Verde and the Upper Gila, and is similar in many respects to these headwater basins. The total area is 6,260 square miles, of which 927 miles are in Yavapai County, 1,935 miles in Apache, 2,430 miles in Gila, 420 in Graham, 424 in Maricopa, and 124 in Pinal County. Owing to the mountainous character of this district there were only 815 acres of crops cultivated by irrigation



DAILY DISCHARGE OF THE KERN RIVER AT RIO BRAVO RANCH, CALIFORNIA, 1879 TO 1882.

in the census year. The valleys are in general narrow, the only opening of any importance being along the Salt River, between Pinal Creek and Tonto Creek. The water supply is, therefore, ample for all the accessible land of this district.

This basin may be taken as including the area of the Salt River headwaters down to the junction with the Verde. The country is rugged and heavily timbered at the higher elevations, and there are not many large valleys along the river where agriculture can be carried on. The principal streams entering from the north are Black River, Bonita, White Mountain, Carrizo, Cibicu, Canyon, Cherry, and Tonto Creeks, and from the south Pinal and Pinto Creeks. The principal agricultural land of the basin extends from a point below Pinal Creek to Tonto Creek, some farming being carried on also along Sally May Creek and Tonto Creek.

Measurements of the water flowing out of this drainage basin were made, as stated above, at a point about a mile above the junction with the Verde, being carried on at the same time that measurements were made on that river, and later at a point in the canyons about 20 miles above the Verde. The results of these latter measurements are given in the following table, which exhibits the ordinary range in amount of the summer water:

Salt River in canyon—20 miles above the Verde.

[Drainage area, 5,880 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Sq. mile.
1890.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inch.*	*Sec.-feet.*
May 28–31	520	520	520	31,980	·10	·09
June	520	193	298	17,731	·06	·05
July	375	185	215	13,222	·04	·04
August 1–28	2,200	600	1,362	83,763	·27	·23

THE LOWER SALT DISTRICT.

The Lower Salt district is the principal subdivision of the Gila Basin, since it includes the largest area of irrigated land and the greatest canal systems of Arizona. It may be said to begin at the junction of the Salt and Verde, and to extend to or below the great bend of the Gila, including on each side some of the most fertile land of the Territory. The total acreage on which crops were raised by irrigation in the census year was 29,171 acres. This is but an insignificant portion of the total amount on which products might be raised with a sufficient water supply, for, as previously stated, there are enormous tracts of fertile land, whose extent is so great that no probable increase of water supply can cover them.

The Salt River is the only source of water; the situation here is similar in many respects to that of the middle Gila district, but has the advantage that the headwater districts do not contain such large

bodies of irrigable land as do the headwaters above the middle Gila. There is said to be ample water for the present acreage cultivated in the fall and spring, but in summer the supply is scarce, so much so that crops have been lost, and trees and shrubs have perished for lack of water.

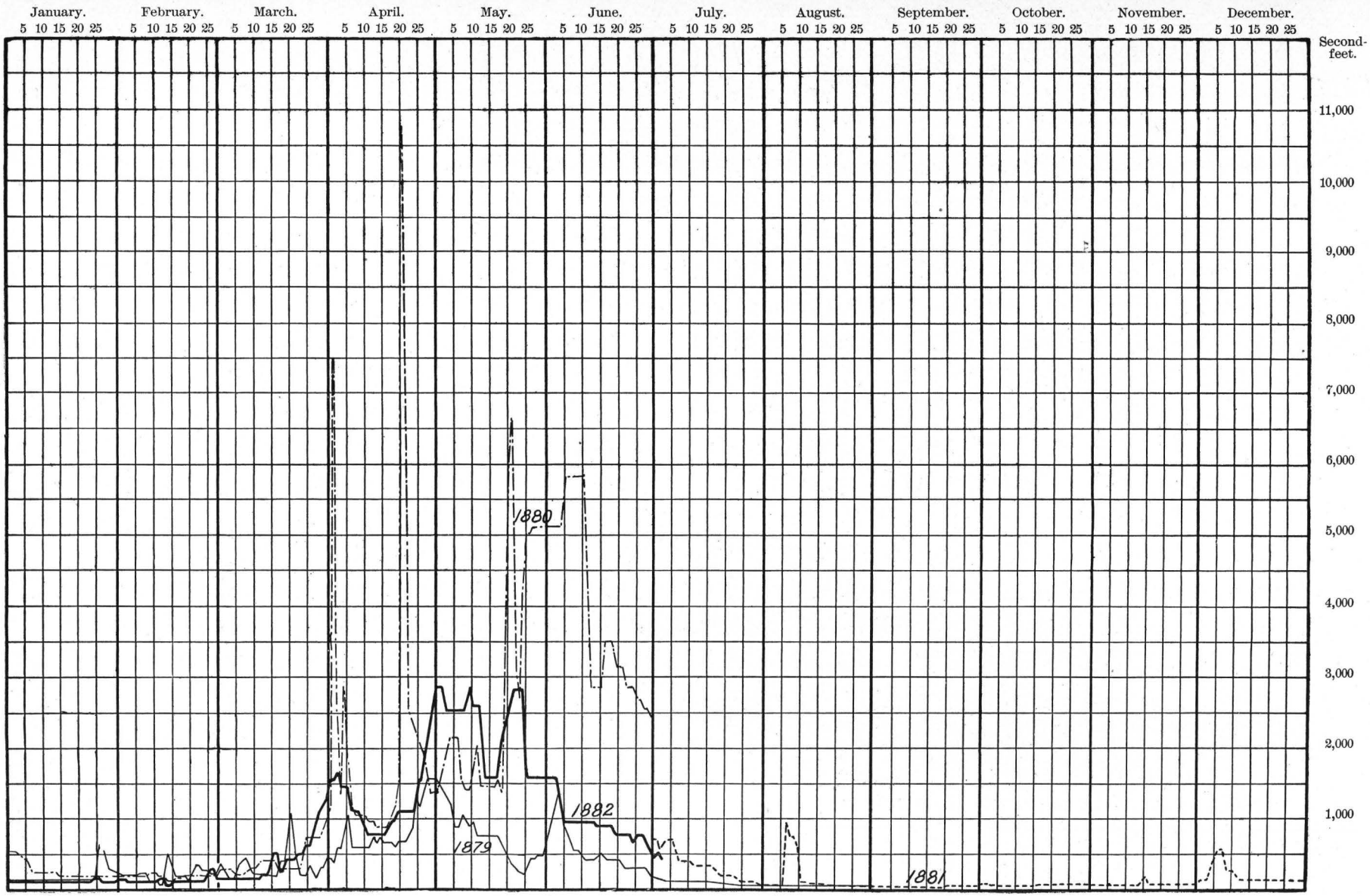
In the Salt River Valley, in Maricopa County, the following canals were reported in 1889 as being taken from Salt River:

Canals.	Length.	Canals.	Length.
	Miles.		*Miles.*
Arizona	40	Utah	6
Grand	22	Farmers	5
Maricopa	14	Highland	22
Salt River Valley	18	Dutch Ditch	4
San Francisco	9	Monterey	4
Tempe	19	Griffin	3
Mesa	9		

It may be added that, excepting in floods, all the water in Salt River has been utilized, and nothing more can be done in the way of land reclamation without the construction of storage reservoirs. If this were done it is estimated that sufficient water could be impounded during the storm floods to reclaim double the area now under cultivation. The soil is very productive. Large crops of wheat, barley, and alfalfa are grown, and fruits of all descriptions flourish and yield bountifully.

Measurements of the amount of water entering this subdivision were made, as before mentioned, by establishing stations on the Salt and Verde rivers, a short distance above their junctions, but these were continued only a few months as it was found impracticable with the small force available to keep up the work. Estimates of discharge, however, have been prepared by Mr. Samuel A. Davidson, engineer of the Arizona Canal Company. These are based upon weir calculations of the water flowing over the submerged dam built by this company at their headworks. These were begun in August, 1888, and daily observations continued up to the present time, the results of which are kindly given by Mr. Davidson, as shown in the following table. Measurements of this character being based upon certain assumptions and the use of constants determined in a small way, their degree of accuracy is open to question, but, at least, these measurements, or rather the computations based upon them, have a great value as showing the relative amounts of water in the different months and seasons.

On Pl. LXXIX is shown graphically the daily mean discharge as computed by Mr. Davidson, and the irregular character and extraordinary fluctuations of the stream are clearly brought out. The most noticeable feature is the great flood of February 21, 1890, when, according to Mr. Davidson's computations, the discharge increased suddenly from 1,000 second-feet to over 143,000 second-feet. This, however, is eclipsed



DAILY DISCHARGE OF THE KAWEAH RIVER AT HOMER'S RANCH, CALIFORNIA, 1879 TO 1882.

by the flood of February 18 to 25, 1891, which, is not shown upon Pl. LXXIX, the data being received too late for illustration. On February 17 the mean discharge was 835 second-feet, increasing the next day to 154,000 second-feet, and on the 19th to 276,000. This first flood diminished rapidly, averaging on the 20th only 69,100, and on the 22d 14,890. This was followed by a second swell greater than the first, the flood increasing until on the 24th a maximum of 300,000 second-feet was reached. This subsided almost as rapidly as it came, so that by the second day after the river was carrying less than 15,000 second-feet.

This flood was very destructive, carrying away bridges and portions of canals, submerging great areas in the Gila Valley, and causing a sudden rise in the Colorado, as shown on Pl. LXXIV, the greatest flood for that decade at least. The Arizona Canal Company's weir across the Salt River was damaged, a portion of the canal washed out, and the channel of the stream so altered that computations of daily discharge could no longer be made without new data.

Salt River, Arizona Dam, Arizona.

[Drainage area, 12,260 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Max.	Min.	Mean.		Depth.	Per sq. mile.
1888.	*Sec. feet.*	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Inch.*	*Sec. feet.*
August			350	21,525	.03	.028
September			350	20,825	.03	.028
October	350	300	331	20,356	.03	.027
November	5,760	425	842	50,099	.08	.068
December	43,489	1,665	6,698	411,927	.63	.545
1889.						
January	24,953	1,665	5,947	365,740	.56	.48
February	3,940	1,534	2,605	144,577	.22	.22
March	33,794	3,563	8,745	537,817	.82	.71
April	5,559	2,496	3,975	236,512	.36	.32
May	1,784	622	1,039	63,898	.10	.08
June	615	356	470	27,965	.04	.04
July	1,311	334	495	30,522	.05	.04
August	755	389	417	25,645	.04	.03
September	1,172	389	521	31,000	.05	.04
October	704	319	440	27,060	.04	.04
November	629	532	576	34,272	.05	.05
December	25,371	557	5,686	349,689	.53	.46
1890.						
January	15,750	1,376	4,982	306,393	.47	.40
February	143,288	1,045	10,097	560,383	.86	.82
March	17,228	2,566	6,421	394,891	.60	.52
April	2,077	1,369	1,840	109,480	.17	.15
May	1,369	630	914	56,211	.09	.08
June	672	397	511	30,404	.05	.04
July	872	397	524	32,226	.05	.04
August	7,734	1,114	3,885	238,927	.37	.32
September	3,685	725	2,339	139,170	.21	.19
October	7,465	753	2,768	160,232	.25	.23
November	30,504	766	4,717	280,661	.43	.38
December	30,366	1,110	6,259	384,928	.59	.51
1891.						
January	17,127	1,060	3,416	210,084	.32	.28
February	300,000	825	39,201	2,175,655	3.32	3.10

THE LOWER GILA DISTRICT.

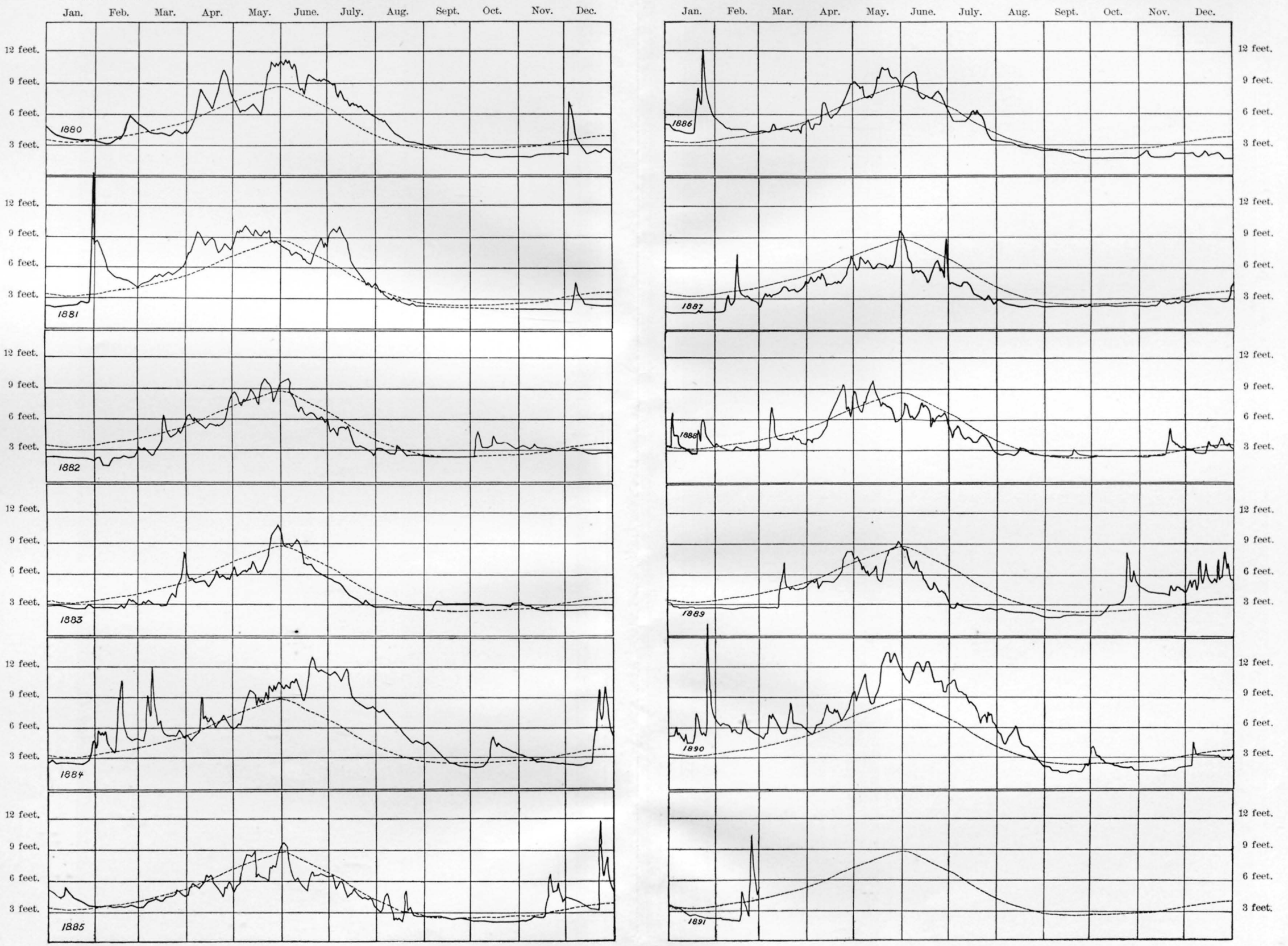
The Lower Gila District may be said to include the arable land from Gila Bend to Yuma, where the Gila River empties into the Colorado. This is a main-trunk district, receiving the waters which escape from the Middle Gila District and from the Lower Salt, and since these in turn receive their waters from four head-water districts, it will be recognized that the supply here depends very largely upon the action which is taken in these six subdivisions. There were only 555 acres on which crops were reported raised by irrigation in 1889, but a far greater acreage has been brought under ditch. There are a large number of extensive canals and ditch systems projected or under construction in this district, but whose success must apparently be a matter of some doubt.

The land of the Lower Gila District is of great fertility and is adapted to the cultivation of many fruits of the semitropic zone, as, for example, oranges, lemons, and other citrus fruits. It is thus known as the citrus belt of Arizona, and promises to become of great importance in these productions. Besides the fruit, alfalfa, barley, and wheat are reported to be cultivated, and vineyards have been successfully planted. The following canals were reported as built or under construction in 1889, to take water from the Gila in Maricopa County:

Canal.	Length.	Covers.	Canal.	Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Buckeye	30	20,000	Citrus	14	5,000
Gila River	8	5,000	Monarch	8	2,000
Enterprise	12	6,000	Gila River Irrigating Co	12	.....
Gould Bros	8	3,000	Gila Bend Canal Co	30	18,000
Palmer	22	12,000			

The Gila River Irrigating Company proposes to build a large dam at the Black Buttes below the mouth of the Hassayampa and carry water south and southwest, taking in the entire valley on both sides of the river to the Yuma County line, making a canal 75 miles long, covering 500,000 acres of land. The Gila Bend Company have completed 22 miles of their canal, under which 3,400 acres are reported to be irrigated at present. The names of the canals, together with their lengths and amount of land below each, taken from the Gila in Yuma County, as reported by the hydrographers, are given below:

Canal.	Length.	Covers.	Canal.	Length.	Covers.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Mohawk	35	40,000	Contera	7	2,000
Redondo	5	1,500	Saunders	10	4,000
Farmers	13	10,000	Araby	8½	2,000
South Gila	22	12,000	Antelope	7	2,500
Purdy	10	7,000	Toltec	3	.....



GAUGE HEIGHT OF THE KINGS RIVER AT KINGSBURG, CALIFORNIA, 1880 TO 1891.

THE AGUA FRIA AND HASSAYAMPA DISTRICTS.

The Agua Fria and Hassayampa districts lie south and west of the Verde Basin and between it and the Lower Gila District. The water supply of each is so small and the amount of arable land so large that they may each be considered as lost basins, although in time of large floods they may contribute to the Lower Gila.

The total area of the Agua Fria Basin to Gilette is 1,420 square miles. The supply of water, however, is not sufficient for all crops under cultivation, and in very dry seasons some are lost. The head waters of this district are in Yavapai County, where the principal industry is grazing, while the great portion of the arable land is south of this, in Maricopa County. The Agua Fria rises in the mountains southeast of Prescott and flows south as a clear mountain torrent, but as it enters the plains of the Gila the waters sink into the broad, sandy channel. In flood times, however, a great volume of muddy water is poured through the usually dry channel, entering the Gila a short distance below the mouth of the Salt River.

The Hassayampa District lies to the west of the Agua Fria, and, like it, has its headwaters in Yavapai County. Of the total area of 1,810 square miles in this district, about 937 square miles are in this county and 873 square miles in Maricopa County. In the headwaters of this basin was the Walnut Grove Dam, whose destruction in February, 1890, was the cause of considerable loss of life and property. On Pl. LXXVII is given a view of the reservoir formed by this dam. Hassayampa Creek, like the Agua Fria, is subject to violent freshets, whose waters reach the Gila, but at other times the stream sinks into the sands.

THE SANTA CRUZ DISTRICT.

The Santa Cruz District lies in the southern portion of the Gila Basin west of the San Pedro District. The limits of this district are extremely difficult to define, on account of the lack of good maps of the region. There are, however, approximately 3,500 square miles in this district, of which a small part of the head waters is in the Republic of Mexico and the remainder in the county of Pima, Arizona. The principal streams of this district are the Santa Cruz River and its tributaries, the Sonoita and Potrero. These creeks rise in the mountains of the south, where the elevation is from 4,000 to 5,000 feet, and join to flow northward as the Santa Cruz. The waters are finally lost in the sands not far from Tucson. In the upper part of the stream, among the rocky canyons and narrow valleys, is ample water, but in the lower portion of the stream there is, during the dry season, an amount insufficient to supply all the needs of the present acreage under cultivation, of which in all there was, in 1889, 2,672 acres.

In addition to the lost river basins before mentioned there are in the great drainage basin of the Gila areas aggregating 33,300 square miles, over which the rainfall either does not give rise to streams, or if little

streams are formed, they do not attain notable importance. Scattered through this region, much of it fertile land, are small localities where water can be brought from springs or pumped from saturated beds below the surface to irrigate small farms or gardens of stock-raisers. On the plains are many places where there is grass enough for herds of cattle if only water can be obtained sufficient for their needs. Deep wells have been sunk for this purpose, and large tanks for holding storm waters constructed, and occasionally there is obtained a surplus of water, by which a few plants are sustained. This method of irrigating will unquestionably spread gradually, but there is little to require the attention of others than those locally interested. The problems here are such that each man must solve his own for himself, and thus are in sharp distinction from the condition of affairs in the great districts above described, where the action of every man in his use of water has its influence, though slight, upon the prosperity of others.

SACRAMENTO AND SAN JOAQUIN BASINS.

In these basins, lying wholly within the State of California, a careful examination of the water supply was begun in 1878 by the engineering department of that State, under the direction of its engineer, Mr. William Hammond Hall. Hydrographic measurements of an extensive character were begun and carried on successfully through several years, and a large amount of information bearing not only upon irrigation, but also upon the improvement of rivers, the flow of mining detritus, and drainage of swamp lands. At that time gauging stations were established, these being in many instances at or near railroad bridges crossing the streams, the height of the water being kept by employés of the railroad.

Many of the gauges established at that time have been kept in good order and read at regular intervals up to the present time. Credit is due to the officials, especially the chief engineer, of the Southern Pacific Company for the continuation of these gauge-height readings, whose value in connection with discussions of river flow is of the highest order.

In 1889 Mr. Hall, then supervising engineer for this Survey, began a series of measurements on certain rivers on which gauging stations had previously been established by the California State engineering department and the fluctuations of whose waters had been recorded by the railroad employés. The results, however, of these last attempts lie chiefly in the perfection of the methods to be employed on such streams and the devising of an apparatus for gauging from the shore, as described in the preceding annual report.

Briefly stated, the results of the river-gauging work of the State engineering department of California are as follows. The field work began in June, 1878, and during part of that and the succeeding year several parties were engaged in making gaugings of rivers and canals in connection with careful surveys for the purpose of acquiring facts

bearing upon the solution of the problems of drainage, river improvement, mining detritus, and irrigation. Gauging surveys were made of the Sacramento at five places, viz, at Colusa, at Butte Slough, at Knight's Landing, at the mouth of the Feather River, and at the mouth of the American River, and also a survey of the American River itself.

At the same time a second party made gaugings of Kings, San Joaquin, Fresno, Chowchilla, Mariposa, Merced, Kaweah, and Tule Rivers. A third party examined the San Joaquin from the Stanislaus north, and a fourth party made gaugings up toward the headwaters of the Sacramento, namely on the Cosumnes, American, Bear, Yuba, Feather, and intermediate streams, as well as on the creeks northward to Chico Creek; also the Sacramento, both at Tehama and in the Iron Canyon, above Red Bluffs, and Stony Creek, besides all the other tributaries north of Stony and Chico Creeks. Observations of river height were maintained for a time on all the principal streams. There were in all, during the years 1878 and 1879, ninety-one gaugings made on rivers and two hundred and forty-three on canals, and there were established six self-registering tide gauges, one hundred and twenty-seven height rods or nilometers on rivers and fifty-two on canals.

The gaugings on large rivers were made mainly by current meters, but on the small streams and canals the discharge was computed by means of float observations or in some instances by Kutter's formulæ. In some cases careful surveys were made at each guaging station extending for several miles, with cross sections every 400 feet, or with less care for 1 or 2 miles with cross sections at less intervals, down to a distance of one-half mile and sections every 200 feet. On the creeks and canals the general length of gauging survey was from 600 to 1,200 feet. All the rods and height gauges were connected by leveling, giving their relative elevation and the slope of the river from place to place.

In 1880 field work was continued, the gauging stations in the San Joaquin were put in repair and records collected; regaugings were also made of the Kern River and of the canals. In Los Angeles County in the summer thirty streams and ditches were gauged, and later in the season the discharge of eighty-eight small streams, ditches, artesian wells, etc., were obtained by making one hundred and eighty-three gaugings. At about the same time the low-water discharge of the streams flowing into the San Bernardino Valley was estimated by means of twenty-three guagings. This practically ended the field operations of the State engineering department as far as hydrographic work was concerned.

From the data obtained in the field computations of discharge were made for most of the rivers mentioned above, and the results of the gaugings and computations were published in 1886 in a volume entitled "Physical Data and Statistics of California," in which are given for each month and season, from November, 1878, to October, 1885, the maximum, minimum, mean, and total discharge in second-feet, together

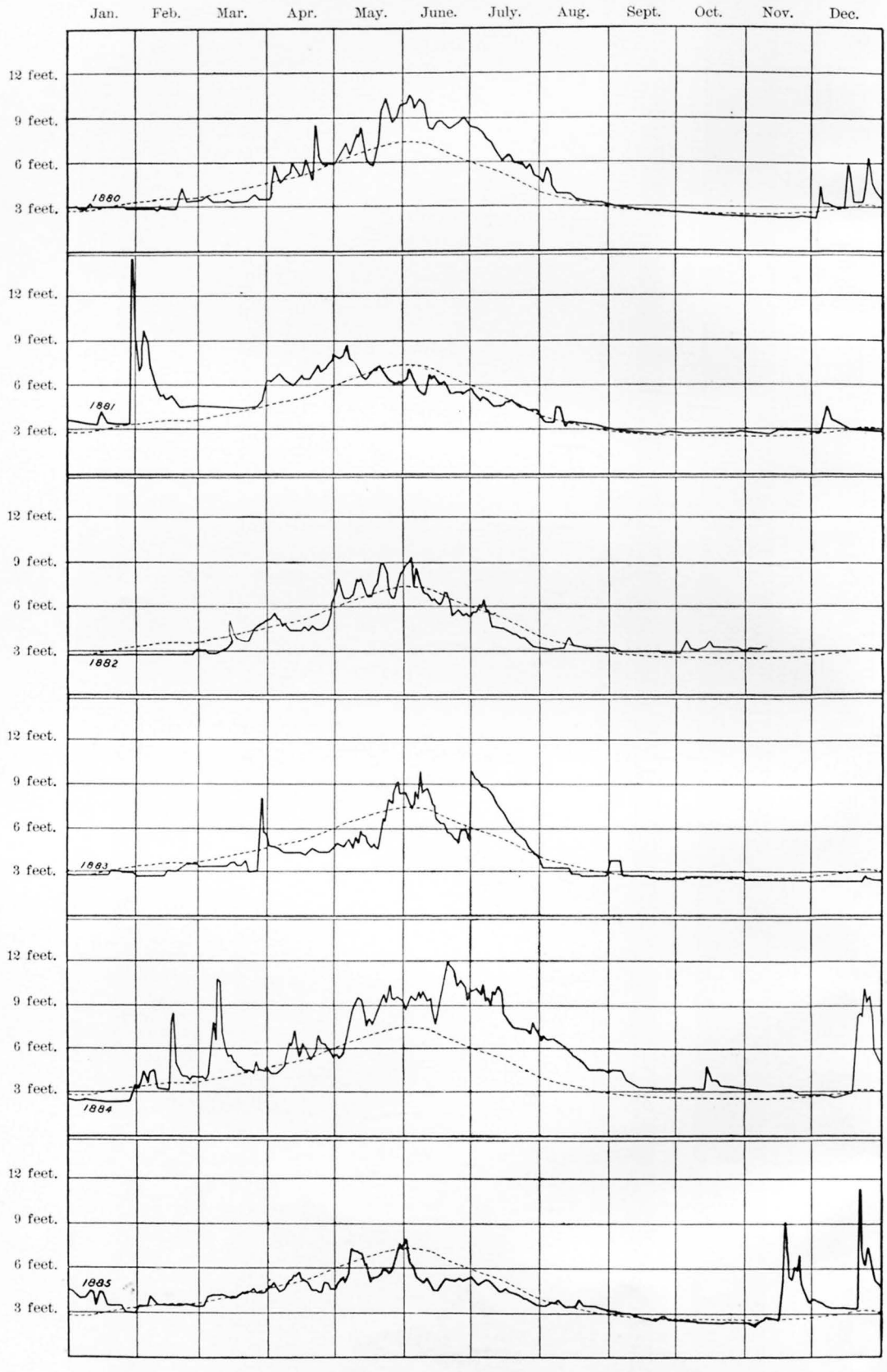
with, in most cases, the depth of water drained and the amount drained per square mile from the basins of the following rivers, viz:

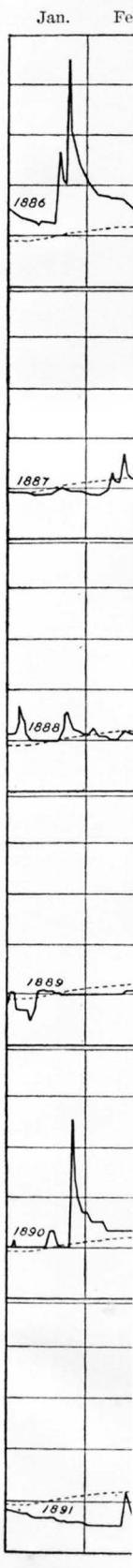
Sacramento River, at Collinsville.
Cosumnes River, at Live Oak Suspension Bridge.
Dry Creek, at base of foothills.
Mokelumne River, at Lone Star Mill (base of foothills).
Calaveras River, at Bellota.
Stanislaus River, at Oakdale.
Tuolumne River, at Modesto.
Merced River, at Merced Falls.
Bear Creek, at base of foothills.
Mariposa Creek, at base of foothills.
Chowchilla Creek, at base of foothills.
Fresno Creek, at base of foothills.
San Joaquin River, at Hamptonville.
Kings River, at Slate Point (base of foothills).
Kaweah River, at Wachumna Hill.
Tule Kiver, at Porterville.
Deer Creek, at base of foothills.
White Creek, at base of foothills.
Poso Creek, at base of foothills.
Kern River, at Rio Bravo Ranch.
Caliente Creek, at base of foothills.

The information obtained from the State engineering department of California and from the Southern Pacific Company relating to the gauge height and discharge of the rivers in this basin is presented herewith on Pls. LXXX to LXXXVIII, in order to afford an opportunity of comparing the behavior of these streams with those in other parts of the arid region. These plates are arranged in geographic order, following the rule elsewhere laid down of taking the tributary streams in succession from the headwaters to the mouth. The headwaters of the San Joaquin, being nearest the Colorado Basin, are first presented.

In the cases of many important streams, the height of whose waters has been recorded for a series of years, the relation between the discharge and height has not as yet been obtained. Although our knowledge would be far more complete if the daily discharge were known, yet the range of height of the river for a long period gives many facts of importance and is of sufficient value to justify the representation of these fluctuations. The curve of average height for all the years during which gauge readings were made is placed on these diagrams. This may be considered the normal curve for the river, and when placed in connection with the actual fluctuations of the stream each year, the abnormal variations of that year are at once apparent. In looking over these plates it will be seen, for example, that on some years the height remains persistently below the normal, while on others it is above, and still on others varies widely in both directions. As a matter of course no year follows exactly the normal or average curve.

U. S. GEOLOGICAL SURVEY





GAUGE HEIGHT OF THE SAN JOAQUIN RIVER AT HERNDON, CALI

KERN RIVER.

Kern River is the largest stream in the southern end of the San Joaquin Valley, draining a large area in the mountains west of the main range of the Sierra Nevada. This stream has been gauged at the Rio Bravo Ranch, just below the point where the river leaves the canyons and above the irrigating canals, this locality being about 12 miles from Bakersfield. The record of river heights was kept for 1879, 1880, 1881, and 1882, and daily mean discharges, shown graphically on Pl. LXXX, were computed for these years. By referring to this plate the wide range in annual discharge is seen, and also the characteristic irregular fluctuations.

In 1879 there was apparently no spring flood, but in place of this almost continuous low water, broken only by slight fluctuation, as represented on the diagram by the dotted line. In 1880, on the other hand, the discharge, shown by the fine black line, reached the maximum of 4,070 second-feet in June, and the flood as a whole was large and persistent, being preceded by a sharp rise on April 3 and extending to the end of July. The high water of 1880 continues into 1881, as shown by the line consisting of dots and dashes. This flood, however, did not reach the height of that of the previous year, but attained its maximum early in May, and then with minor fluctuations fell rapidly through June and July.

In 1882 the discharge, as indicated by the heavy black line, was intermediate between those of previous years, coinciding in winter and late summer fairly well with the discharges of 1879 and 1880. In addition to these, the mean discharges for 1883 and 1884 have been published in the Physical Data and Statistics of California, having been computed by using the rainfall measurements of these years as a basis and assuming a certain relation between these and the river flow.

TULE RIVER.

The drainage area of this river lies west of the head waters of the Kern, the main stream flowing directly westward and emptying in time of floods into Tulare Lake. At other times the water is all used for

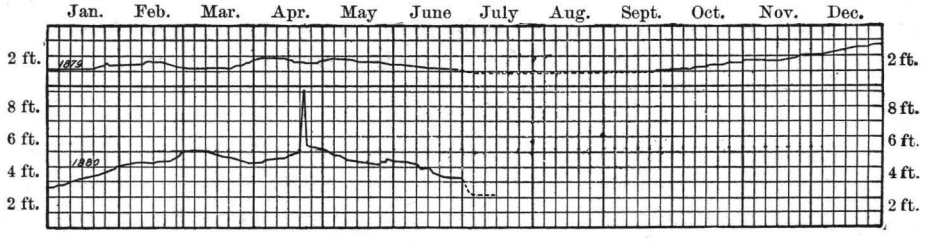


FIG. 227.—Diagram of daily gauge height of the Tule River, California.

purposes of irrigation from Porterville to Tipton. Measurements were made about 5 miles above Porterville, but below the head of the Pioneer Canal. The gauge height only for this stream is shown on Fig. 227, for

the greater part of 1879 and the spring of 1880. This fragmentary record serves to give in a general way the character of the stream during those years. In the early part of 1879 the water, as in the case of the Kern River, was extremely low, and the flood rise is scarcely apparent. At the beginning of the succeeding winter, however, the water began to rise and continued until April, when there was a slight fall, succeeded in the latter part of May by a sudden flood, the effect of this flood being felt far into the summer.

The mean monthly discharge of this river for these and the succeeding years up to and including 1884 has been published,[1] and also the mean discharges for the same period of the adjoining creeks, the Deer, White, and Poso.

KAWEAH RIVER.

The Kaweah drainage area lies between that of Tule River and of Kings River. The river enters the San Joaquin Valley northeast of Tulare Lake and furnishes water for large areas in the vicinity of Visalia. Discharge measurments were made principally in the vicinity of Three Rivers, being thus in the mountains above some of the smaller tributaries. The discharges for 1879, parts of 1880, 1881, and 1882 are shown on Pl. LXXXI.

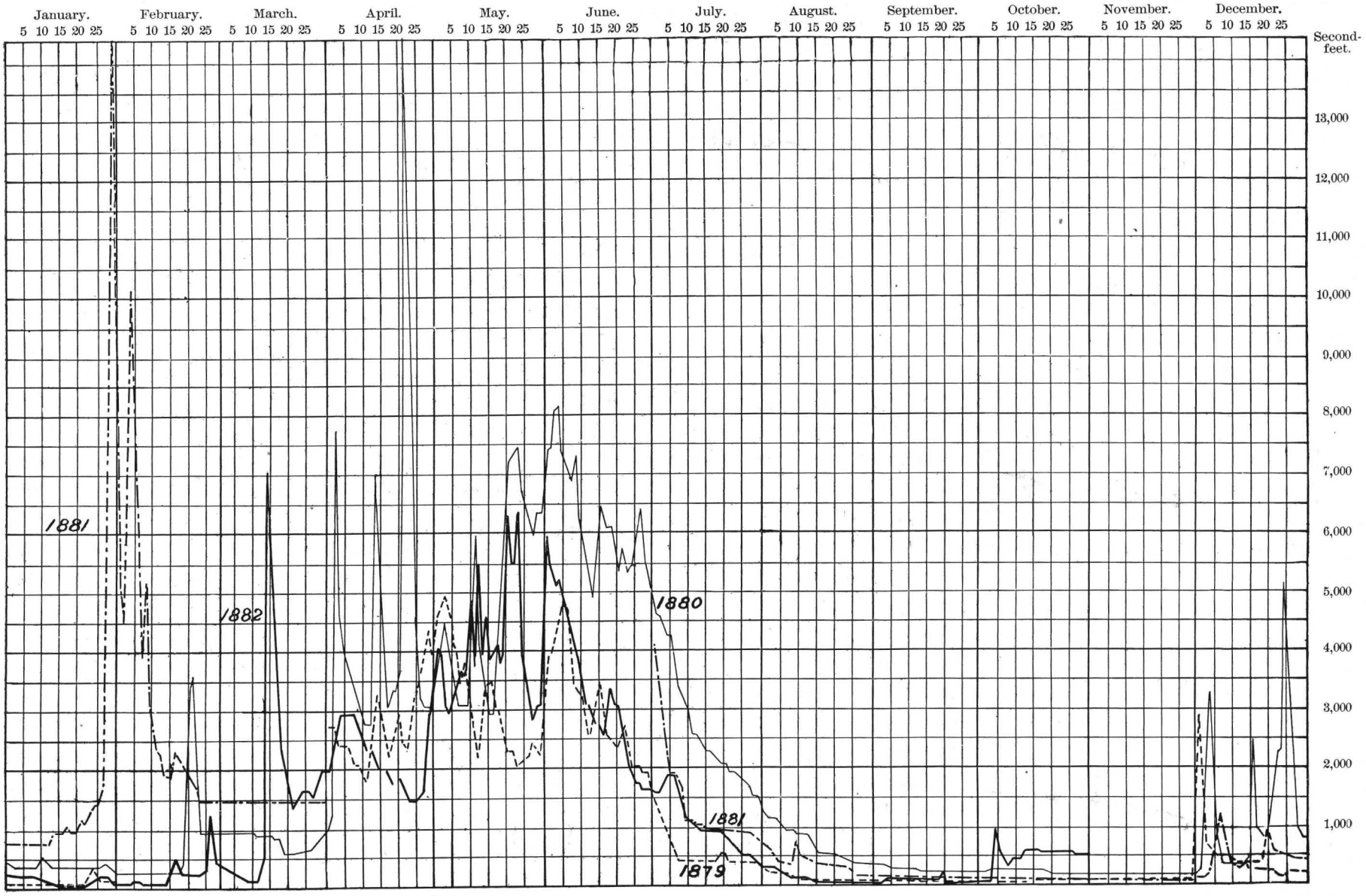
The discharge for 1879, as in the case of the rivers above mentioned, was very small, but in 1880 heavy floods occurred, some of which, as for example that of April 20, were of unusual violence. The record from July 1, 1880, to June 30, 1881, has not been preserved, but the fall and winter of 1881 are shown and the spring of 1882, the discharge for this latter period being indicated by a heavy black line.

KINGS RIVER.

The State engineers found this important river exceedingly difficult to measure, on account of the shifting character of its bed and banks or of other obstacles. Gaugings, however, were made by them at various points, by means of which they were enabled to make computations of the discharges from 1879 to 1884, inclusive. One of the most important factors in this computation was the record of gauge height kept at the Southern Pacific Company's bridge near Kingsburg. This record, which has been maintained up to the present time, is given on Pl. LXXXII, in connection with the curve of average river height for the entire period.

This diagram exhibits the relative height of the river in each year and the time of occurrence and extent of the floods, as, for instance, in the years 1880 and 1881 the water in general was above the average, while in 1882 and 1883 the spring floods did not reach their usual height. In 1884 the flood was large, and especially notable from the fact that

[1] Physical data and statistics of California, collected and compiled by the State engineering department of California, William Ham. Hall, State engineer, Sacramento, State printing office, 1886, pp. 459, 460.



DAILY DISCHARGE OF THE MERCED RIVER AT CENTRAL PACIFIC RAILROAD BRIDGE, CALIFORNIA, 1879 TO 1882.

it occurred late in the season, a great part coming in July. During the year following the water remained low, and in 1886 was a trifle above the normal. The years 1887, 1888, and 1889 were similar in character as regards the small size of the floods, while 1890 rivaled 1884 for the extent of high water.

SAN JOAQUIN RIVER.

The San Joaquin was gauged both at the edge of the valley and at the Southern Pacific Railroad crossing, near Sycamore, now Herndon, the record at this lower point, however, being the most extended, having been kept by the Southern Pacific Company continuously to the present year. The discharge for this place for the years 1879, 1880, 1881, and 1882 is shown on Pl. LXXXIII. On account of the peculiar irregular character of these discharges, they are represented in two groups, 1879 and 1880 being placed together, and also 1881 and 1882 by themselves, since the lines for these last two years would fall intermediate between those for the preceding two years.

Low water for 1879 and high floods in 1880 are shown to have characterized this river as well as those farther south. The sudden flood of February 1, 1881, almost equaling those of May and June of the preceding year, is notable as showing the irregularity in time of these freshets. It is interesting to compare these lines with those representing the discharges of rivers in Colorado, Utah, and Montana, where the floods are more gradual and do not as a rule occur with such violence. It is to be noted that these sharp irregular fluctuations are due to changes of temperature rather than to rainfall, most of the floods being caused by the melting of the snow among the mountain summits, the effect of the flood being of course intensified by warm rains, if these occur.

The mean monthly discharge for these years and for 1883 and 1884 has been computed by the California engineers, and could probably be estimated up to the present time from the gauge readings kept at Herndon. The gauge heights themselves are, however, given on Pl. LXXXIV for direct comparison among themselves. The heavy flood of 1880 is apparent by the position of the black line above the dotted, and the smaller floods of 1881 and 1882 can also be seen. In 1884 the flood was the greatest recorded both in amount and duration, as was the case in the Colorado basin, as previously noted. The year 1885 was noted by the continuance of the river height for long periods below the normal, and 1886 by an equal persistency above the normal. In 1887, 1888, and 1889 the river continued at low stages, but in 1890 rose again to heights unknown since 1884, falling off in the winter, the beginning of 1891 being marked by unusually low water.

By comparing diagrams of discharge for 1880, 1881, and 1882 with those of gauge height for the same period, the difference between these two classes of graphic illustrations is apparent. As the water rises a

greater and greater amount flows in the stream for every increase in height. The diagram of discharge is so drawn that the vertical spaces represent equal quantities of water, while in the gauge height diagrams the vertical distances represent heights of water without regard to quantity. Thus the two diagrams show the same fluctuations on the same days. The lower parts of both diagrams are very nearly alike, since at low stages the discharge increases very nearly with the additional height, but the upper part of the discharge diagram in comparison with that of gauge height appears as though stretched out in a vertical direction, from the fact that the quantity discharged at the high stages is increasing rapidly.

MERCED RIVER.

The discharges for this river at the gauging station near the railroad bridge between Delhi and Livingston are given on Pl. LXXXV for the years 1879, 1880, 1881, and 1882. As shown by the diagram, these discharges show great irregularities, but during May fall within a comparatively small range. The early floods of the year are particularly noticeable for their intensity, as, for instance, that of 1881.

TUOLUMNE RIVER.

The Tuolumne is one of the most important rivers in the northern part of the San Joaquin Valley. It flows nearly due west from the

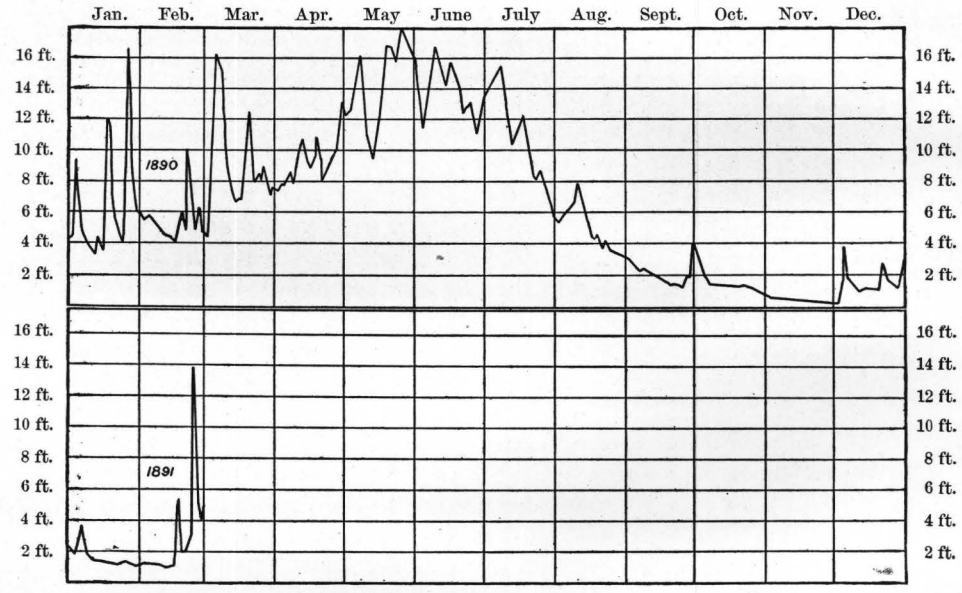
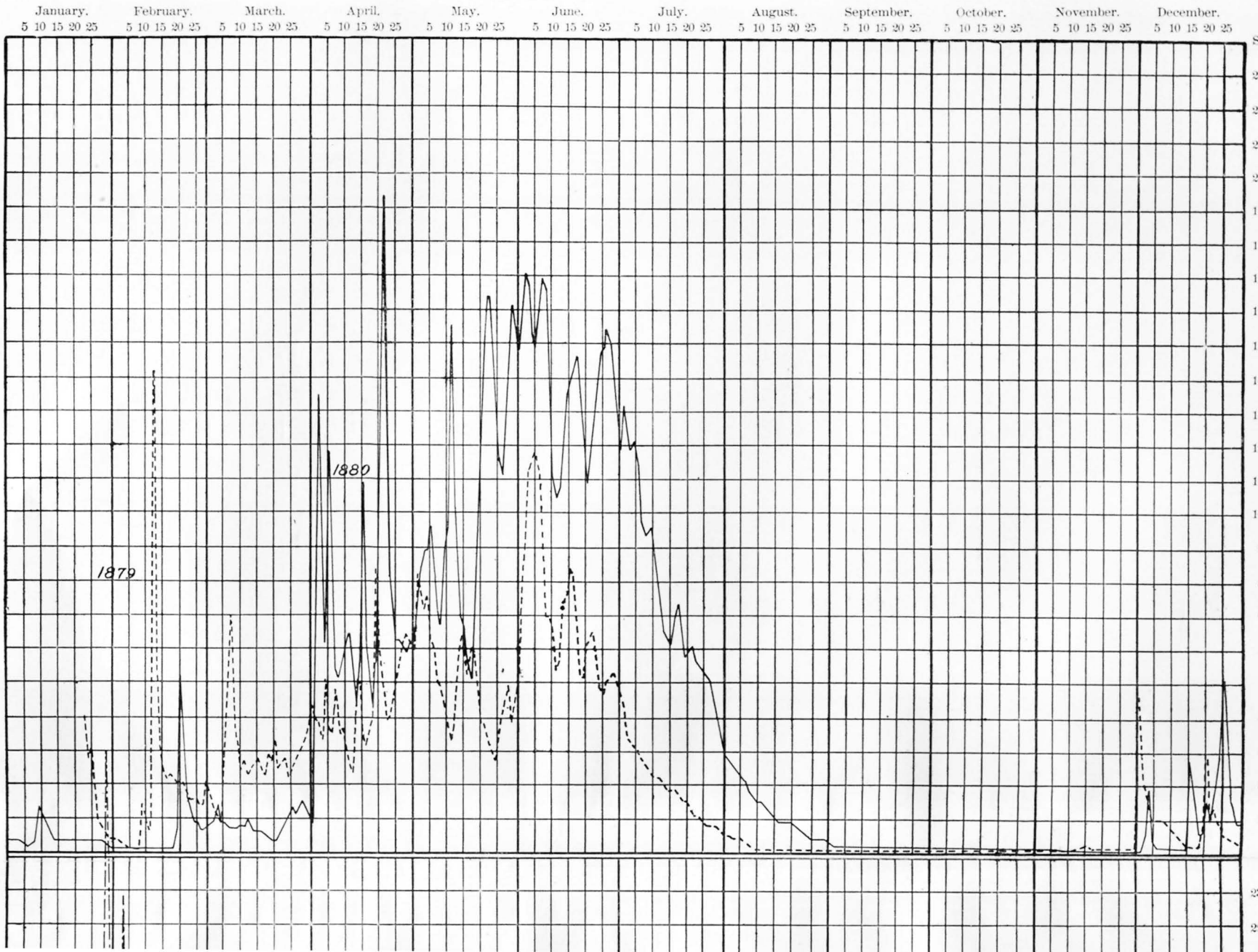


FIG. 228.—Diagram of the daily gauge height of the Tuolumne River, California, 1890 and 1891.

Sierra Nevada, the waters being used for irrigation in the vicinity of Modesto. The gaugings of this river were made near the railroad bridge


January.
February.
March.
April.
May.
June.
July.
August.
September.
October.
November.
December.
5 10 15 20 25
Second-feet.
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
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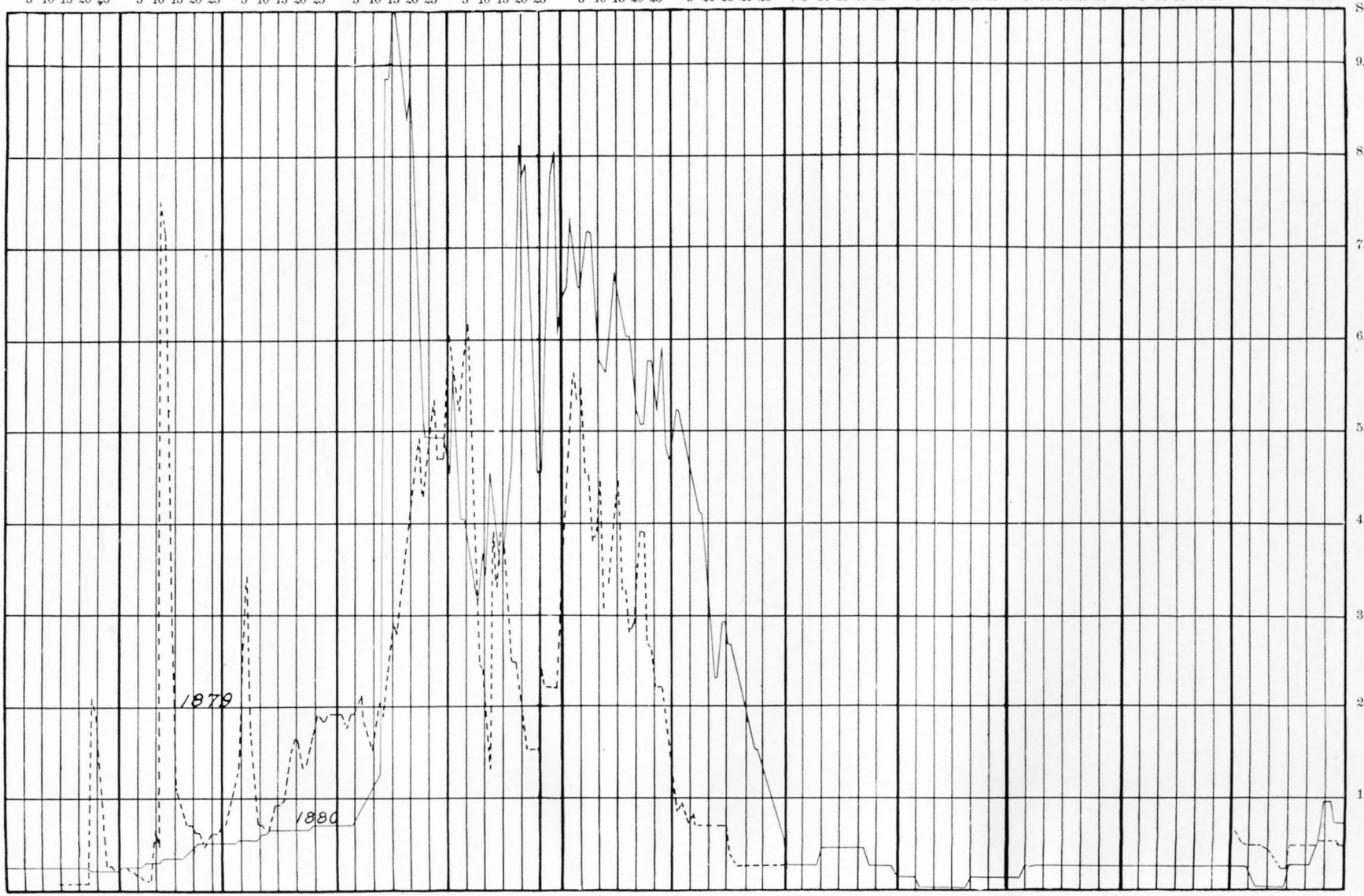
1880
1879
U. S. GEOLOGICAL SURVEY



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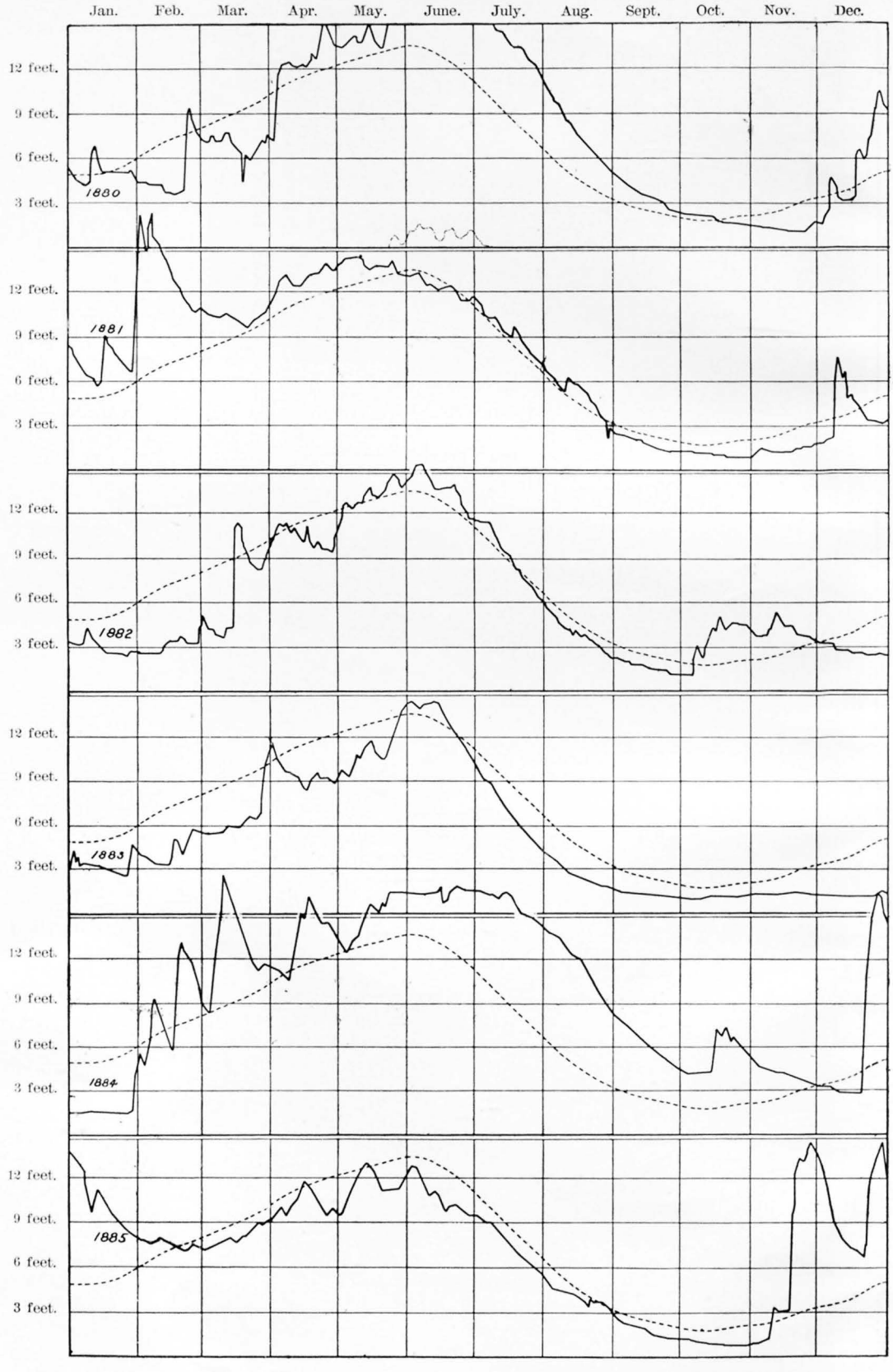
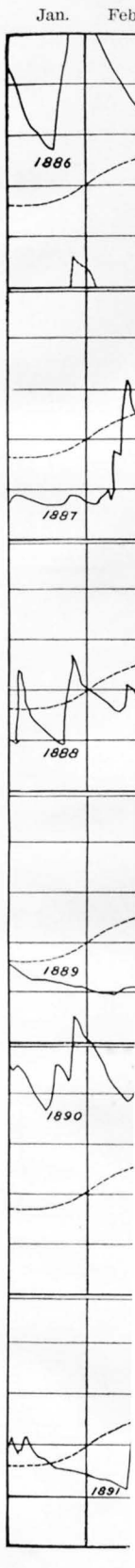




GAUGE HEIGHT OF THE LOWER SAN JOAQUIN RIVER AT CENTRAL PACIFIC RAILRO

south of the town, the record being kept for many years by the railroad company. The discharges are shown on Pl. LXXXVI, those for 1879 and 1880 on the upper half of the page, and for 1881 and 1882 on the lower half. The discharges of these years show the characteristic fluctuations, 1879 being low, 1880 high, and 1881 and 1882 in general intermediate.

The daily gauge height of this river for 1890, and a part of 1891, is shown on Fig. 228, the discharges not having been computed. This serves, however, to show the relative fluctuations during the various months of these years and the irregularity in the character of the stream.

MOKELUMNE RIVER.

The Mokelumne River enters the Sacramento Valley at about one-third of the distance from Stockton to Sacramento. It is considered a tributary of the San Joaquin, for although flowing toward the Sacramento, when within about 2 miles of that river its waters turn abruptly toward the south. The flow was measured on the edge of the valley above Clements, giving the discharges shown on Pl. LXXXVII. In this case, as in that of previous rivers, 1879 and 1880 are shown together on the upper half of the page, and 1881 and 1882 on the lower half. The difference in discharge between 1879 and 1880 is not as strongly marked as in the case of the rivers farther south, and when the discharges for the four years are plotted on the same sheet the result is a confused mass in which no one year is particularly prominent for the quantity of its discharge.

The excessive floods of early spring, as in 1879 and particularly in 1881, are the most noticeable features of these diagrams. The rapid fluctuations in quantity, so characteristic of the streams of this basin, are exhibited on this river. The culmination of the floods in the latter part of May and their gradual decline in June is clearly shown.

LOWER SAN JOAQUIN RIVER.

The height of the San Joaquin has been observed for a number of years by the Southern Pacific Company at its bridge. These daily gauge heights have been plotted, and are shown in condensed form on Pl. LXXXVIII, giving the fluctuations in height from 1880 to the present time. The average height of the river for each day in the year during the series of years through which observations were made is indicated by the dotted line, the irregular line showing the daily variations in each year from this average. In examining these in detail it will be seen that the flood of 1884 is, as in other cases, far above the normal.

In the diagram for 1886, at the top of the plate the discharges for floods in January and May, are so great as to bring the line above the upper margin of the plate. The amount by which this line overruns is shown by the dotted lines immediately below these places. In 1887, 1888, and 1889, the height is in general below the average, but in the fall of the latter year the water rose suddenly and continued at an un-

precedented height during that winter, the volume during each month almost equaling that of the flood discharge of May or June. This great flood continued through July, and then declined, reaching the normal at the end of the year, the beginning of 1891 being marked by low water.

THE GREAT BASIN.

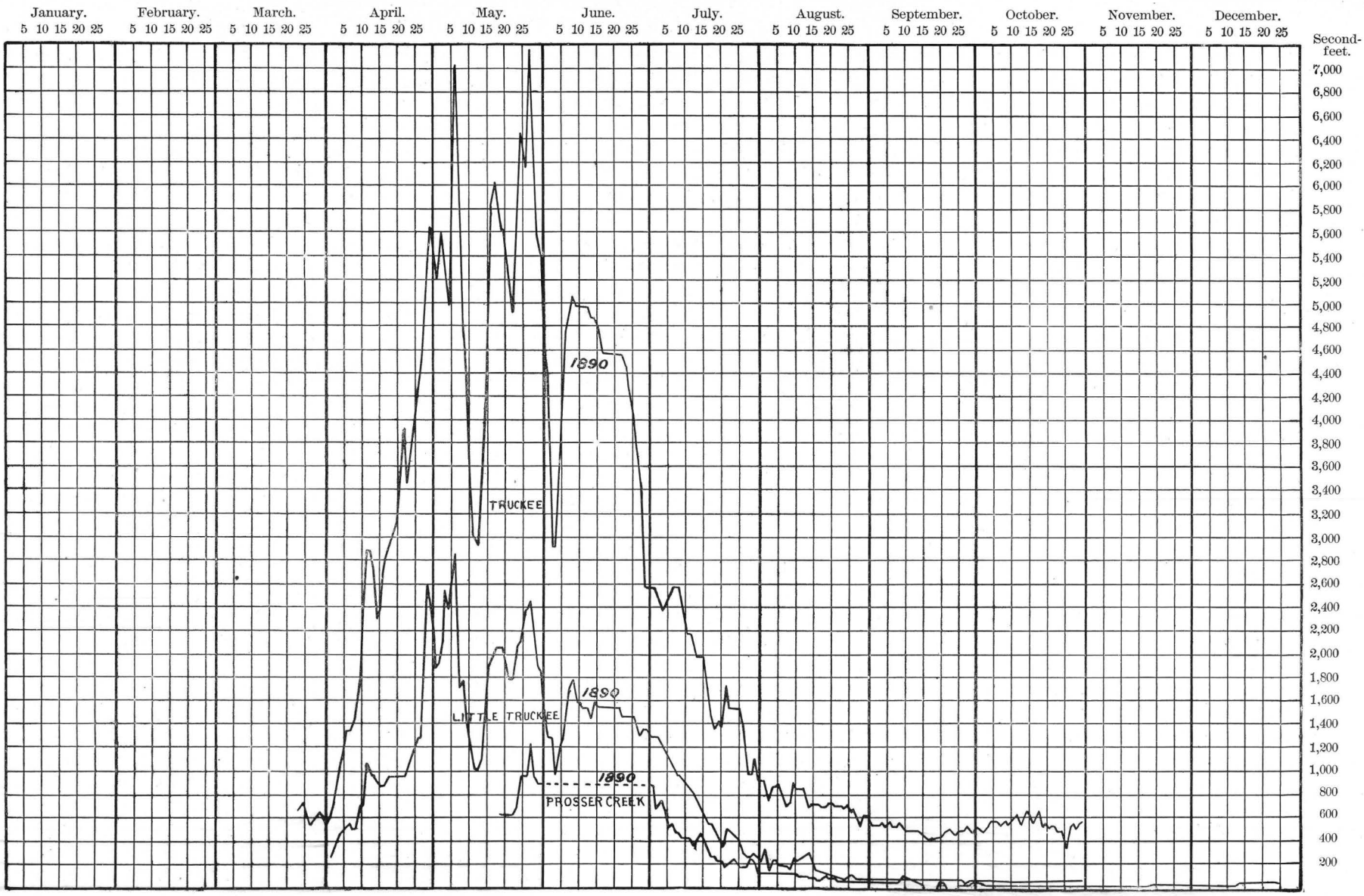
This term is applied to that vast extent of country lying between the Rocky Mountains and the Sierra Nevada, and embracing an area of 228,150 square miles, from which no water escapes to the ocean. The rain which falls within this area collects in the streams, and these in turn unite, forming large rivers in certain parts of the basin; but in spite of their size they are destined sooner or later to disappear, either by evaporation from their broad sandy channels or from the surface of some saline lake. The larger rivers are on the extreme eastern or western sides of this basin, for it is here only that lofty and continuous ranges of mountains are found. On the north the divide between the drainage of the Columbia is not sharply defined by great mountains, nor is it on the south adjoining the Colorado.

Stream measurements have been made by the Geological Survey on the principal streams on both sides of the Great Basin. On the western edge the Truckee, the principal river of the Pyramid Lake drainage basin, has been measured in several places, and also the Carson, whose waters disappear in Carson Sink. On the eastern edge of the Great Basin, in the Salt Lake Basin, measurements have been of the principal streams, the Bear, Weber, Provo, and others, and in the Sevier Basin of the Sevier River mainly at the point where it enters the Sevier Desert. The results of these measurements are given in the following pages in the order stated. The gauging stations have been described in the preceding annual report of this Survey. In the case of the Bear and Sevier rivers a somewhat detailed description of the topography is given, in so far as it relates to the questions of water supply and irrigation.

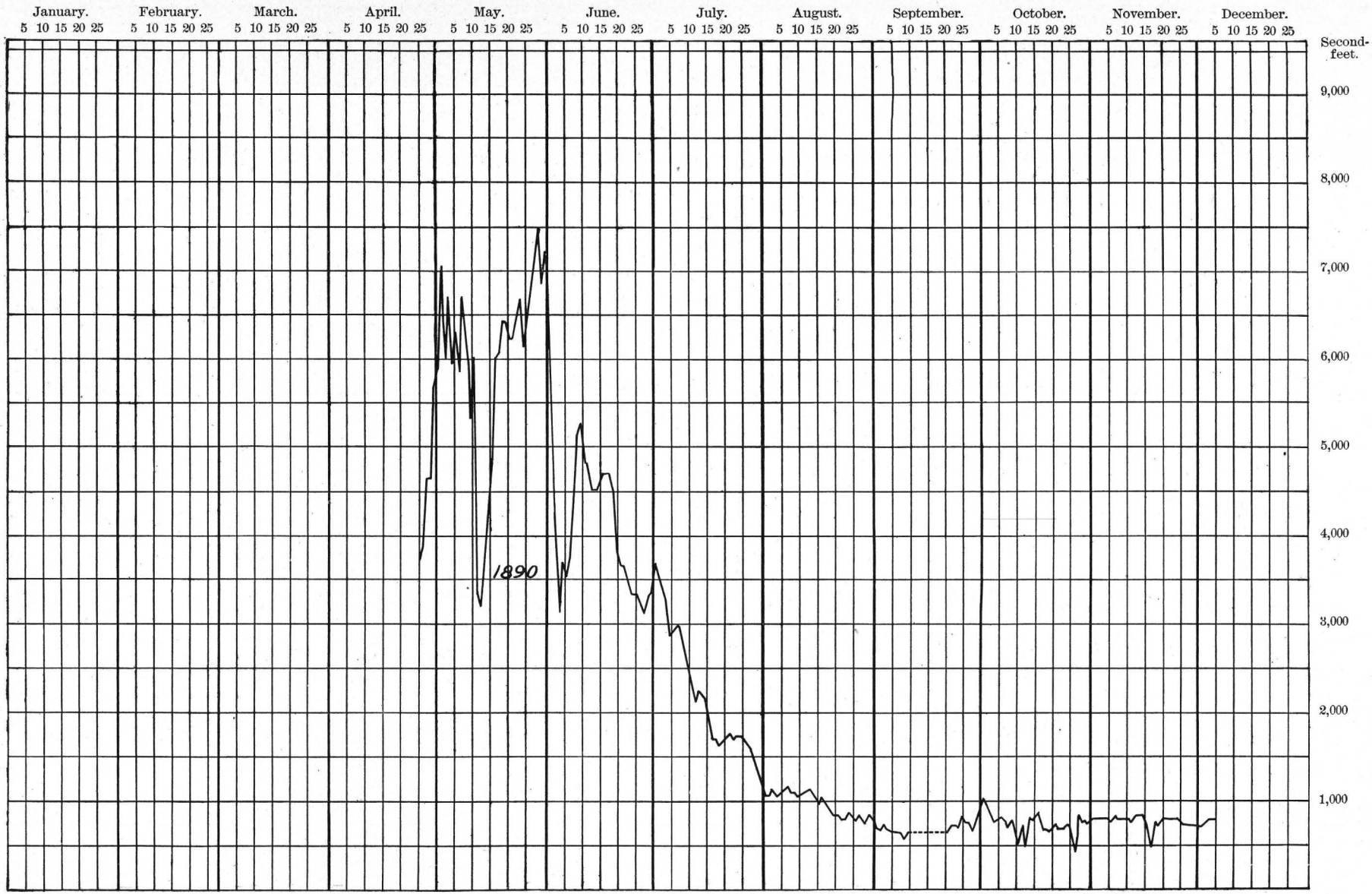
TRUCKEE RIVER.

On Pl. LXXXIX is shown the discharge for the greater part of 1890 of Prosser Creek, the Little Truckee, and the Truckee below Boca, California. Prosser Creek and the Little Truckee flow into the Truckee a short distance above this town, and consequently the discharge below Boca includes that of these two streams. As might be expected, these discharges follow each other closely, since, the drainage basins being small, similar climatic conditions prevail over all.

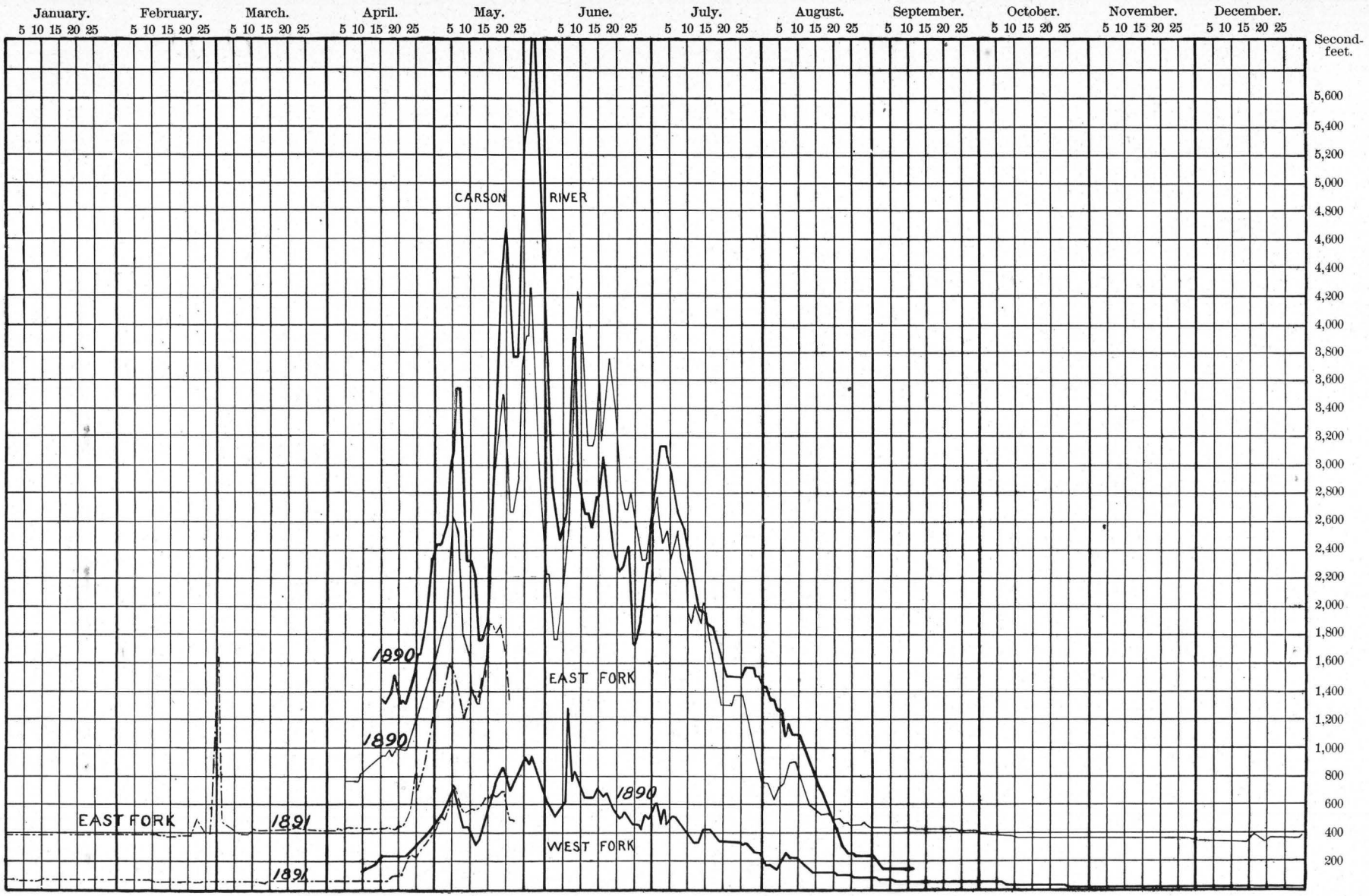
Measurements were made of the Truckee at two points farther down the river—one at Laughtons, about 6 miles above Reno, and the other at Vista railroad station, about 8 miles below Reno, at the lower end of the Truckee meadows. The discharge at these two points follow each other so closely that a single illustration is sufficient. Pl. XC shows



DAILY DISCHARGE OF PROSSER CREEK, LITTLE TRUCKEE, AND TRUCKEE AT BOCA, CALIFORNIA.



DAILY DISCHARGE OF THE TRUCKEE RIVER AT VISTA, NEVADA.



DAILY DISCHARGE OF THE CARSON RIVER NEAR EMPIRE, NEVADA, AND EAST AND WEST FORKS OF THE CARSON.

the quantity of water discharged during all but the early months of 1890, and by comparing this with Pl. LXXXIX the similarity is shown between the behavior of the river at Boca and at Vista.

CARSON RIVER.

The discharge of the main Carson, 5 miles east of Carson City, near Empire, Nevada, for 1890, is shown on Pl. XCI, in connection with the discharges of the East and West forks. The station at Empire was abandoned in the fall of 1890, but daily readings of gauge height for the East and West forks have been received to June, 1891, thus allowing computations of discharges to be made up to that time. In this diagram the large amount of water received from the East Fork is a prominent feature, the discharge of the West Fork being relatively small. It is apparent from the diagram that the discharge of the main river is in many cases, especially in the latter part of August and in September, less than the total of the two forks, this being due to the large diversions of water for irrigation made from these streams in the valleys through which they flow.

SALT LAKE BASIN.

BEAR RIVER.

The headwaters of this river, as shown by the map (Pl. XCII), are in the high peaks about 60 miles east of Salt Lake City. Here, at an elevation of from 9,000 to 11,000 feet, are small glacial lakes and basins which originally held a large amount of water, but by erosion the lower rims have been cut, allowing this water to escape. The torrential streams from these glacial lakes flow down the highly inclined slopes, and unite in the deep, narrow valleys at the foot of the peaks. Most of these valleys consist of alternations of narrow passes and broader meadow lands, where the streams become almost stagnant and meander through small marshes. At the lower end of each of these open spaces a dam could be built at small expense, all the materials being close at hand, making ponds from a quarter to a half mile in width and 1 mile or even more in length. These valleys have all the advantages of reservoir sites, the only objections to their use being the great distance which the stored water must travel before reaching altitudes sufficiently low to mature the more valuable crops.

The water flowing northward from these valleys crosses the line between Utah and Wyoming and entering the latter State continues in the same general northerly direction, passing through rolling pasture lands. These lands are too high for agriculture, but are adapted to grazing, and along the course of the streams are many ranches at which forage is raised as winter feed for cattle. Diversions of the waters of the Upper Bear and its tributaries are made at intervals in this high country, but the ditches are small. At Evanston, however, several

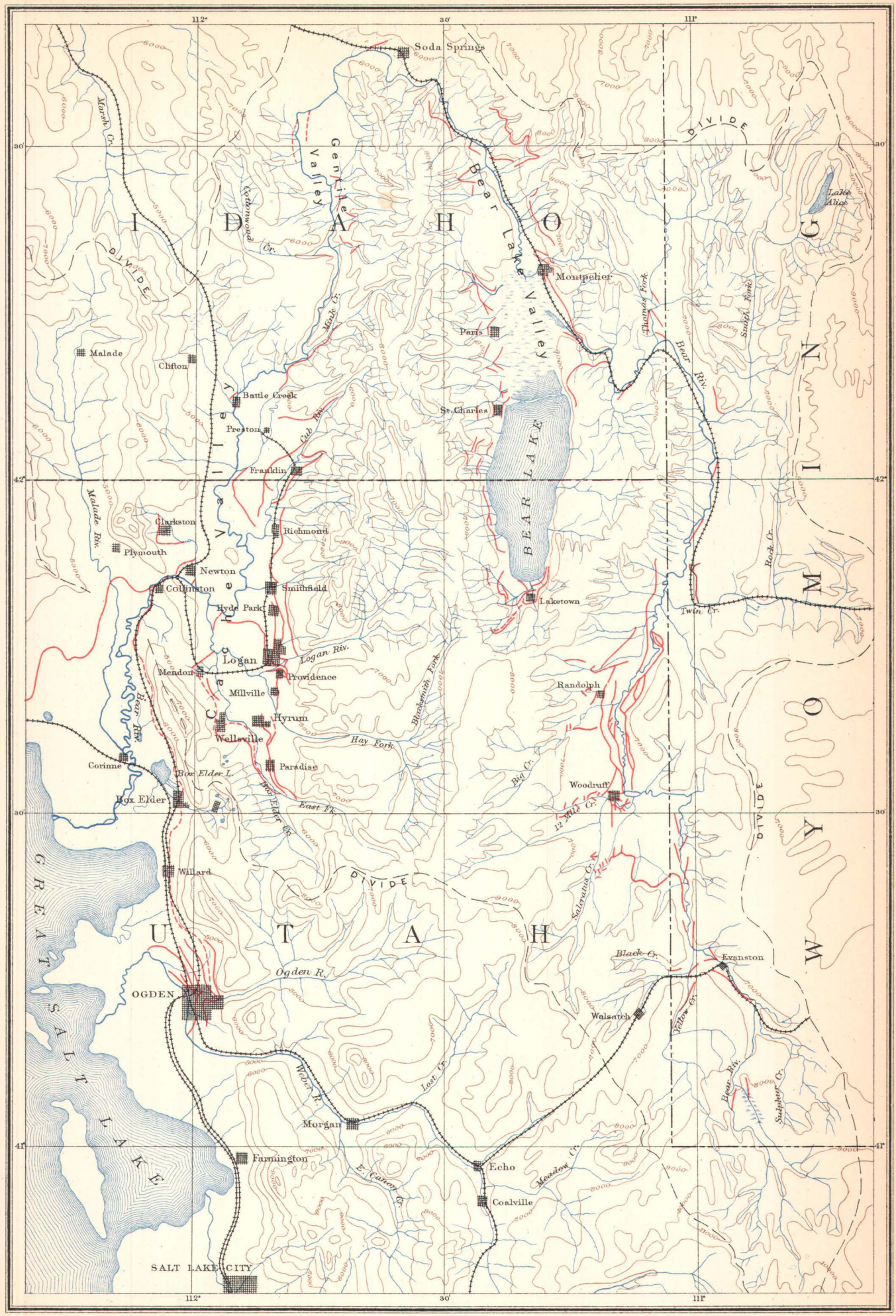
canals of notable size take water from the Bear River to supply the town and adjacent hay lands.

Northward from Evanston, in Wyoming, the valley continues open, the stream falls rapidly, and at short intervals ditches are taken out, the water being used mainly for the purpose of raising hay. Most of the tributaries which enter the Bear in this portion of its course have large drainage areas, but these consist for the greater part of gently rolling hills, and do not in ordinary seasons contribute perennial streams. The snow which falls upon these hills evaporates to a large extent without melting, there being few gulches or ravines into which it can drift and pack. The rainfall also upon these gentle slopes does not usually gather into large streams. On the other hand, in the case of exceptional storms, coming with such rapidity that they can not saturate the ground, large bodies of rain water flood these rolling lands and cause torrents in the ravines. Thus it is that the water supply of this high land, while in general larger than that of the arid region, is not available for the needs of agriculture in the regions below.

From Evanston northward the river passes through a valley which narrows in places and finally turns abruptly to the west. Near this locality is a site suitable for a reservoir; also at the junction with Salt Creek is another small reservoir site, having an average width of a quarter of a mile and a length of nearly 1 mile. From the mouth of Salt Creek the river runs almost due west for 7 miles, the first 2 miles being through a narrow canyon, which opens into a valley three-quarters of a mile in width. Here the river crosses the line from Wyoming into Utah. The valley continues open to and below the town of Woodruff, at which point the open land is about a mile and a half in width. The river then turns almost due north, continuing for about 25 miles in the Territory of Utah.

This valley, from Woodruff northward, continues to widen, until at Randolph it is nearly 3 miles from side to side. At the mouth of Saleratus Creek, which enters above Woodruff, is a wide valley, varying in width from $1\frac{1}{2}$ to 3 miles, and upon which water is now taken to a small extent from the Bear River, the headworks of this canal being in Wyoming. Near the mouth of Saleratus Creek the Randolph Canal, reported to be 16 feet in bottom width, is diverted, and follows along the west side of the valley. Below Randolph the river flows slightly to the east again. The valley continues nearly 3 miles in width, with wide meadow lands, then narrows to a width of about a mile and a half. Continuing northwardly and crossing into Wyoming, it widens out to from $3\frac{1}{2}$ to 4 miles. At this point are great ranches, some of the finest grazing lands of the State of Wyoming being at this locality, one ranch in particular extending about 8 miles along the river.

This portion of the river in Wyoming flows in a valley from 1 to 3 miles wide, with the same rich bottoms along its course. At intervals ditches divert water to cover the lower bench-lands on which hay



DRAINAGE BASIN OF THE BEAR RIVER

and other forage plants are raised. Near the mouth of Smith Fork the valley narrows on the west, and the bench lands almost if not quite disappear. A gauging of Bear River was made above the mouth of Smith Fork by Henry Gannett on August 24, 1877, and the stream was found to carry but 112 second-feet. The preceding season had been unusually dry and the discharge was probably less than the average for that season.[1] On Smith Fork, which has a drainage area of 314 miles, are several favorable reservoir sites, covering from 100 to 250 acres, and located 25 miles or more above the mouth, but there is little agricultural land along this stream and few ranches. The discharge of this fork in the fall of 1889 was estimated to be about 200 second-feet.

At the head of Smith Fork is a natural reservoir, known on the maps as Lake Alice, formed by a mass of loose material which has slid from the mountain into a narrow gorge, blocking the outlet of a long, narrow valley. This natural dam has made a lake nearly 2 miles in length by a quarter of a mile in width at the widest point, the water slowly escaping by percolation through the mass of loose material.

Below Smith Fork the first important tributary of the Bear is Thomas Fork, which flows southward along the line between Wyoming and Idaho, the mouth of this fork being in the latter State. The valley of Thomas Fork is but about 2 miles wide, and contains a large area of fine agricultural land, with but little water, the conditions here being the reverse of those prevailing on Smith Fork. Along the latter is little agricultural land, but an abundance of water, while along the Thomas Fork there is an abundance of land and a scarcity of water. It has been proposed to take water from Smith Fork and carry it around the point of the mountain into Thomas Fork Valley. A canal of a bottom width of 12 feet has already been begun.

From the mouth of Thomas Fork Bear River runs southwesterly and then northwesterly, passing through the range of low hills which bound Bear Lake on the east. In this portion of the river are many small areas of meadow land from a quarter to a half mile in width. A ditch is taken out, covering a wide strip of meadow on which hay is raised, and several others are projected to take water from the river upon land above the town of Montpelier.

BEAR LAKE.

The Bear River, emerging from the boundary hills between Wyoming and Idaho, enters the Bear Lake Valley at an elevation of about 5,800 feet. In the northern end is Bear Lake, a beautiful sheet of water 20 miles in length by 7 in width, surrounded on all sides except the north

[1] See Report of Henry Gannett, topographer, p. 697, in the Eleventh Annual Report of the U. S. Geological and Geographical Survey of the Territories, embracing Idaho and Wyoming, being a report of progress of the exploration for the year 1877. F. V. Hayden, Washington, 1879, 720 pp.

by ranges of steep hills. On the north end of this lake is the great marsh or slough which is indicated on the Land Office maps as the Upper Lake. In the fall of 1889, when visited, there had been a succession of dry seasons and the marsh had almost entirely disappeared, only a small area of open water at the south end, adjoining the lake, being left. In other portions of the marsh the ground was perfectly hard; roads crossed it in various directions; the greater portion of the area was covered with hay ranches, and dotted here and there by houses and hay stacks. Although the inhabitants of the valley can not enter and patent this land because of the fact of the official designation as a lake, yet they have made entries on the county records which are considered among themselves as binding. North of the marsh the valley continues nearly level for some miles, then the rolling hills on either side gradually close in and the river again enters narrow defiles.

Bear River does not flow directly into Bear Lake, but in times of high water floods the marsh, and from thence the water backs into the lake. In time of drought the water in turn flows from the lake into the marsh, and in many tortuous channels finally enters the lower portion of the river at the north end of the valley. There is no well defined passage through the marsh, the river where it enters dividing into channels and, spreading through this low land, finally converges upon its lower reaches. The lake and marsh thus have a modifying effect upon the régime of the river, cutting it into two portions, the Upper Bear River, above Bear Lake Valley, and the Lower Bear, below that point, the action of the upper river being felt only indirectly in the lower.

Bear Lake lies across the boundary between Utah and Idaho, the most southerly portion of the lake being in Utah, the northern in Idaho. On the south and east of the lake are strips of fertile land already populated by a community of farmers and fishermen. To the north in the broad valleys are many towns, some of which are of considerable size, depending for their prosperity upon the agricultural resources of that region. The elevation is too great for many of the crops that are grown in the valley of Salt Lake, frosts occurring in August and even in the latter part of July. The lands both along the lake and north of it are irrigated by canals taken from the streams which flow into Bear Lake Valley, principally from the mountains on the west. All of the ordinary flow of these streams is utilized, and the seepage water alone, excepting in times of flood, escapes into the lake and marsh at the north. Very little water is taken from Bear River itself. There are, however, a few canals taken from the upper river above the point at which it enters the valley and carried out upon the bench lands upon the eastern side of the valley south of the town of Montpelier.

The lake is separated from the marsh to the north by a long, low ridge of sand, thrown up by the waves to a height of from 2 to 5 feet above the ordinary water level. This sand ridge is about 5 miles in

BEAR RIVER CANYON, UTAH.

length and from 100 to 300 feet in width. It is pierced in two places by narrow passages, through which the water flows from the lake into the marsh, or from the marsh to the lake, depending upon the relative elevation of each.

In the fall of 1889 the Bear Lake and River Canal Company was by means of plow and scraper raising this natural embankment by scraping up the sand from the shore of the lake and dumping it on top, the object being, it was asserted, to increase the storage capacity of the lake by blocking the natural outlet. It was obvious, however, that such construction could be of little if any use toward this end, but was undertaken as a preliminary step toward the attempt to acquire some right or title to the use of this lake as a storage reservoir.

LOWER BEAR RIVER.

North of Bear Lake Marsh the river flows northwesterly and then westerly to Soda Springs through very narrow valleys with occasional strips of meadow land. The bounding hills are of irregular rounding outlines and are suitable only for grazing. Around Soda Springs are large areas of level land, wild and uncultivated, the town itself depending for support upon the springs, which attract to it a number of summer tourists. Beyond Soda Springs to the north and west stretch broad lava fields, extending to and beyond the Snake River. The Bear River on entering this lava flow is deflected toward the south, and for a time flowing upon it, finally cuts a deep channel and continues in a gorge.

From Soda Springs down to the north end of Gentile Valley the valley proper is underlaid by lava, but in places contains some irrigable land. On the east side the mountains come down to the river; on the west side is the lava plain. As gauged August 17, 1877, by Henry Gannett at Soda Springs, Bear River was found to carry 1,000 second-feet.[1]

In the northern part of Gentile Valley a company or association of irrigators has begun work toward constructing a ditch on each side of Bear River to irrigate a broad lava plain or bench. In some places, however, the soil of this is so thin that the lava is exposed to view, and in others the surface is so broken as to be unfit for irrigation. Thus it appears to be an unpromising locality for advantageous employment of water.

Gentile Valley is a prosperous agricultural region. Unlike Cache Valley and most of the valleys of Utah, each person lives on his own farm and not in a village. The houses are usually well kept and have been constructed with care, several of them being of brick. Nearly all the water for this valley is taken directly from lateral creeks which flow from the mountains on each side, there being but one completed ditch taking water from Bear River. In the valley the river has a very slight

[1] Eleventh Annual Report of the Hayden Survey, p. 698.

fall, this being the chief obstacle to the diversion of canals. A large portion of the valley, especially the lowlands along the river, is devoted to meadows. The rolling lands away from the river are planted in wheat, as are also a few of the foothills, on which are grass and alfalfa. Warm Creek and Bridge Creek, both rising in springs, empty into the river from the east, the first about 2 miles above the lower canyon, the other 4 miles above. The spring at the head of Warm Creek flows about 50 second-feet and supplies four ditches.

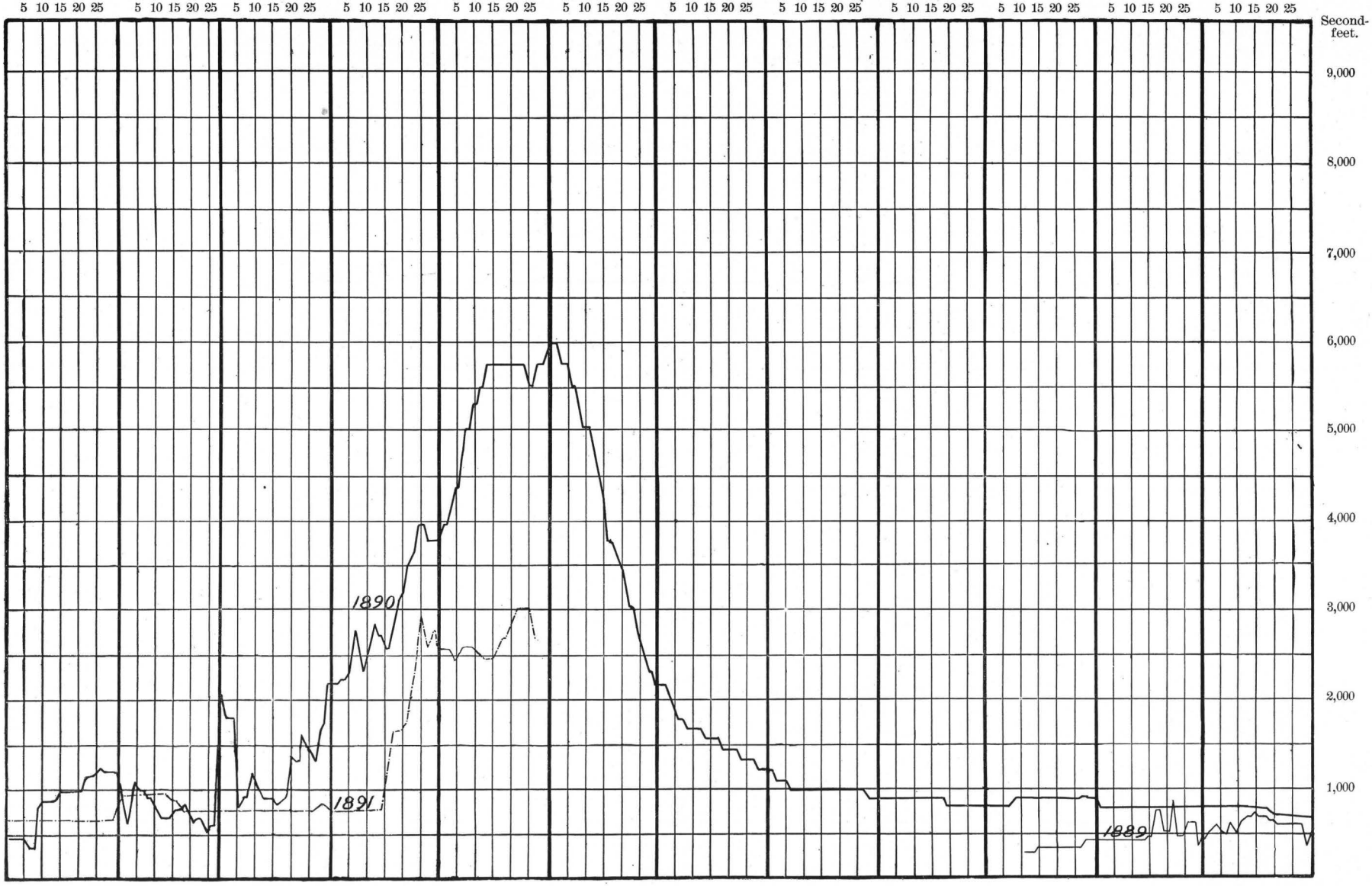
In the lower end of Gentile Valley Cottonwood Creek enters upon the west. The land along it is for the most part rough and nonirrigable. This creek is unlike the creeks emptying into Bear River in Gentile Valley on the east side. The volume varies greatly in the spring and summer and in dry or wet seasons, since it does not head in large springs, but depends upon the water from mountain slopes far to the west. In the summer of 1889 it was very low, and even the few ranches depending upon it suffered for water. The scarcity of that year was ascribed in part to the growing use of water on small hay ranches high up on the stream. It is doubtful if reservoirs can be constructed on account of the gravelly, open character of the soil and rocks.

Below Cottonwood Creek, on the east side, is Mink Creek, supplied by three large springs about 6 miles from Mink Creek Settlement, and discharging about 75 second-feet, this quantity of water being in excess of the needs of the tilled lands. The waters are clear and cold and therefore are not as desirable for irrigation as those of Bear River would be. The cultivated areas are on the hillsides, as there is very little level land.

CACHE VALLEY.

Cache Valley has been termed the "granary of Utah." It is one of finest of the large valleys of that Territory and contains many towns and villages dependent upon agriculture for support. The northern end of this valley lies in Idaho, the line between Utah and Idaho crossing the valley from east to west. At the north the land is high, sloping in a series of terraces toward the south. On this high ground several ditches have already been dug, winding about among the hills and deriving their water from the creeks entering the valley from the northeast. The Bear River is relatively at too low an elevation to cover the highest of this ground.

In the gorge north of the Cache Valley, about $3\frac{1}{4}$ miles from its mouth, there is an excellent site for a reservoir, a 30-foot dam making a pond 1·7 miles long, the first mile being on an average of 1,500 feet wide and the upper portion 800 feet wide. The elevation of the river at this proposed dam site, referred to the datum of the Utah and Northern Railroad, is 4,687 feet. Above this point the bottom land rises for 2 miles at the rate of 18 feet per mile, and then for a half mile at the



DAILY DISCHARGE OF THE BEAR RIVER AT BATTLE CREEK, IDAHO.

rate of 30 feet per mile. From the proposed dam down-stream is a rapid fall for 3¼ miles to the mouth of the canyon, where the elevation, referred to the same datum, is 4,620, the first mile falling at the rate of 25 feet, and then at about 18 feet per mile. From the mouth of the canyon southerly down river the fall is 19 feet per mile to Riverdale settlement, 2¼ miles below. From there down the fall varies from 24 feet to 6 feet per mile to Battle Creek railroad bridge and gauging station, which is 8½ miles below the canyons, the elevation of the water there being 4,477 feet. The diagram of discharge at this point is shown on Pl. XCIV, and the monthly means are given in the tables appended.

From the railroad bridge the fall varies from 3·8 feet to 6·8 feet per mile, for about 5 miles, to an elevation of 4,450. At about this place the rapids disappear and the fall becomes more gentle, being from 1·0 to 2·5 feet per mile as far down as Franklin and Benson road bridge, nearly 10 miles below Battle Creek bridge, at which point the elevation is 4,436. For 3 miles below this bridge the fall continues at 2·5 feet per mile, then decreases to 0·5 per mile, varying from this to 1·5 through the rest of the Cache Valley, excepting at two or three places where small riffles occur, the fall there increasing to the rate of 5 feet per mile. From the Franklin-Benson bridge for 35 miles down, following the river, the fall averages 1·11 feet per mile, the elevation being at that lowest point 4,397 feet.

This shows that the river falls sufficiently to enable a canal taken out at the reservoir site before noted to cover a large part, if not all, of the high-lying bench lands on the west side of the valley, lands of wonderful fertility, but which are now useless for the lack of water, and also that sufficient elevation can be obtained in the gorge of Bear River to enable a canal to be taken out to cover the bench land in the vicinity of Preston. A large portion of these flats, however, is now irrigated by a ditch from Cub Creek, and another canal is being constructed to take water from Mink Creek.

Cache Valley, with the exception of a part of the west side, is perhaps the best watered of any valley of the Territory. Besides the Bear River, which flows through it from north to south, but from which very little water is used, there are a number of large tributaries rising in the high mountains to the west of Bear Lake. The principal of these are Cub Creek, Logan River, Blacksmith Fork, and Box Elder Creek. On the west side are also one or two streams, but these, though supplying a considerable area, are of less importance, and a large area is left unwatered. On the headwaters of the Logan River and Blacksmith Fork are a number of localities at which storage reservoirs could be built, but these are of a small area and only of local importance. The results of measurements made of the discharge of Logan River have been given in the previous annual report.

The necessities of many of the inhabitants of the west side of Cache

Valley have forced them to attempt water storage, and it is instructive to note the progress in this direction. A brief description of the reservoir built by the residents of the town of Newton may be instructive, not that there is anything remarkable about this, but because it is in many ways typical of a number of small reservoirs in various parts the arid region.

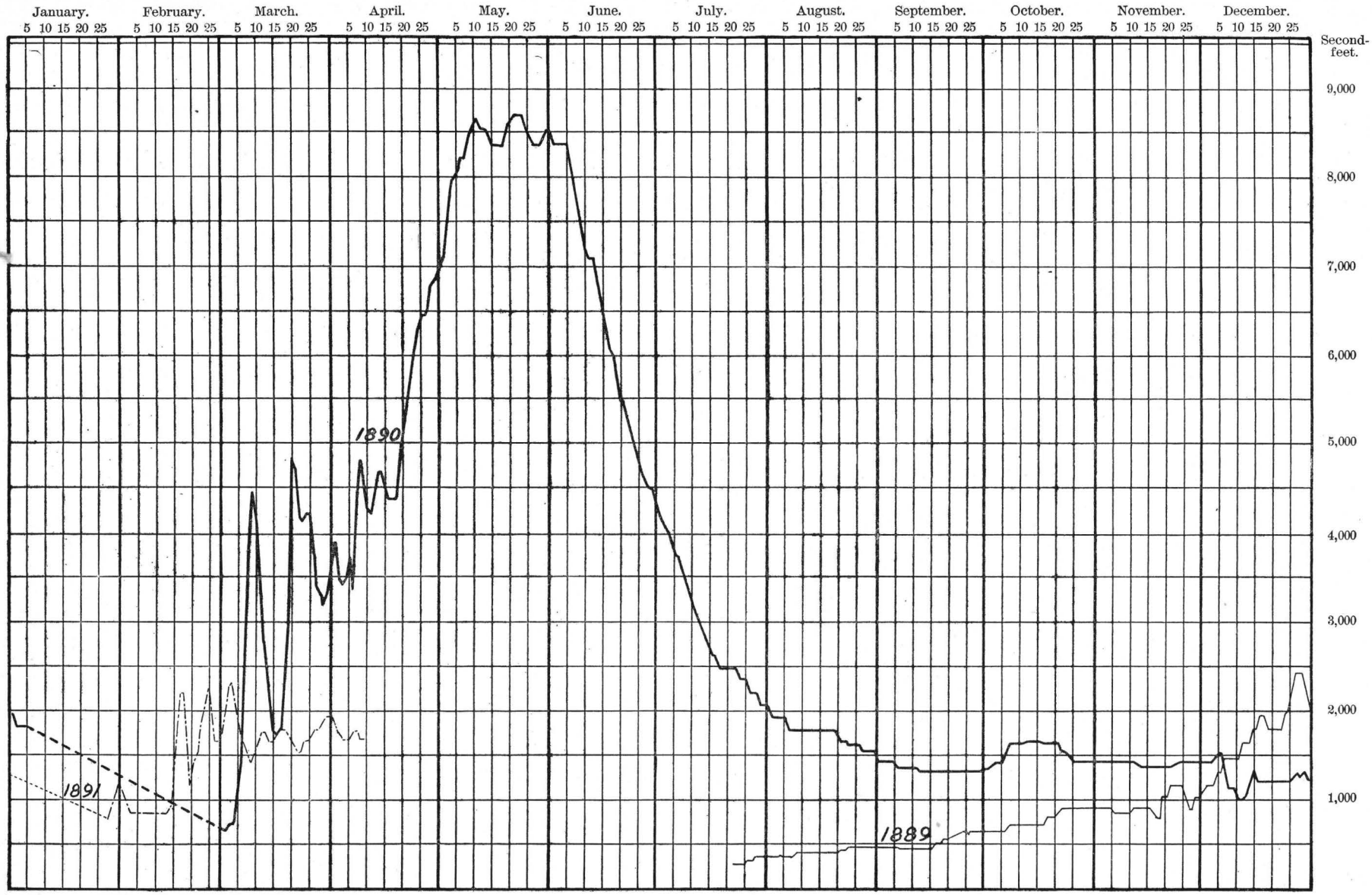
Newton Reservoir is situated in the southwestern part of Cache Valley, about 3 miles north of the village of Newton, from which it derives its name, and upon the lands adjoining which the waters are used. The reservoir is on a somewhat rolling and broken plain, into which Clarkston Creek has cut, forming this basin. When full the water surface is 2 miles long, has an average width of about 250 feet and an area of 147 acres, with an average depth of water of about 6 feet, the capacity of the reservoir being thus from 800 to 900 acre-feet.

The waters are confined by two dams, one on each side of a hill at the north end of the reservoir, the smaller of these dams being used as a waste weir. The main dam is about 500 feet long and 30 feet high at the highest point. It is constructed of earth, the outside slope being about 4 to 1 and the inside one being 3 to 1. The steeper inside slope is formed of a series of steps, these steps or terraces being held up by sheet piling of 3-inch plank. The dams could be raised 10 or 15 feet at a moderate cost and the capacity of the reservoir thus largely increased. The drainage area of Clarkston Creek is 40 square miles, more than half of which is mountainous.

The first dam was built by the people of Newton eighteen years ago, and has continued to be owned solely by the landowners and water-users of that village. All of their cultivated lands, to the extent of 1,000 acres, are irrigated solely from this reservoir, and without it the village would be deserted and the lands return to their original desert condition, as the water of Clarkston Creek is entirely consumed by the farmers of Clarkston during the irrigation season. With the present capacity of the reservoir no more than 1,000 acres can be cultivated. Practically the whole of this acreage is in wheat. An "irrigating head," that is, the quantity that an irrigator can readily distribute on his land, or a stream of 3 to 6 second-feet, is allowed to run for two hours for each acre for the first watering, and for the second an "irrigating head" for one and a half hours per acre, two waterings being usually sufficient for a crop of wheat.

To construct the reservoir $7,000 was originally contributed in cash, labor, or in material, and there have been subsequent assessments to an unknown amount, three dams being carried away in succession and rebuilt. For Clarkston Creek to fill the reservoir usually requires from two to three weeks, but in 1889, an exceptionally dry year, with light snowfall, the gates were shut the 1st of March and the reservoir was barely filled before irrigation began.

The second irrigation is usually finished about July 1, and the reser-



DAILY DISCHARGE OF THE BEAR RIVER AT COLLINSTON, UTAH.

voir is then entirely drained. It has happened that the reservoir has been refilled during the summer by storm waters, but this is very exceptional and is not to be depended upon. In September, 1889, at the time the reservoir was empty, the creek, then at a minimum, was discharging about 5 second-feet through the site.

In the lower part of Cache Valley Bear River turns rapidly to the west and passes out through a deep, narrow canyon, known as "the Gates," entering the Salt Lake Valley. In this canyon (see Pl. XCIII), in the fall of 1889, one of the largest canals of the West was begun, it being designed to carry 2,000 second-feet. The head works are placed in the upper end of the canyon, where a low dam raises the water into the canals, these latter being built along the side of the canyon partially in open cut and partially in tunnel. One branch runs almost directly west across the Malade River and covers the large plain north of Corinne, and the other branch is intended to continue down on the east side of the valley through the various towns and farms along the foothills, finally ending in the city of Ogden.

At the time at which the work upon this canal was begun there was, owing to the exceptionally dry season, considerably less than 1,000 second-feet in the river. This fact was well known, and uneasiness was felt by the older appropriators of water all along the river as to the probable action of the company building these canals, and their feelings were voiced in a protest made at the Idaho State convention and in appeals to the Federal authorities.

It is obvious from a broad, comprehensive knowledge of this river system, from a consideration of the climate of its upper courses and the wasteful utilization of the water for hay meadows in high altitudes, that the effort should be made, if the water is to be used to the best advantage, to discourage larger occupation of the lands at the headwaters. There should also be an attempt made to prevent the imposing upon these lands of inefficient, imperfect, or defective systems of water utilization and of canal or reservoir construction. The water supply of the whole region being limited, the high-lying areas should not be developed to the injury of better lands or of older water rights.

The settlers, however, are pushing up into these high altitudes, where no crops except hay can be raised, and there they are using enormous quantities of water in a wasteful manner, turning it out without system or economy upon tracts of grazing land, converting these into meadows where only the coarser grasses can grow. This water, which in former times following the course of the river came into the lower altitudes, was used by the older settlers upon crops of far greater value.

There are two gauging stations on this river, one at Battle Creek, Idaho, below the railroad bridge formerly used by the Utah and Northern Railroad, the other at Collinston, Utah, in the lower end of the canyon below Cache Valley, being thus below the head works of the new canal just mentioned. The daily discharges at these localities are shown on Pls. XCIV and XCV respectively.

These diagrams are very similar in general appearance, that for the lower station showing the increase in water received from the many tributaries entering the Bear in Cache Valley. The most notable feature in both cases is the smaller discharge for the year 1891. Comparing these with the diagrams of discharge of rivers in California and Nevada, a striking feature is the comparative steadiness of the flood discharge in May and June, the river gradually reaching a maximum, remaining at or near this point for days or weeks, and then declining slowly and steadily, and without those great fluctuations so characteristic of the streams before mentioned. Much of this regularity of flow is due doubtless to the fact that a large part of the flood comes from a great distance and from many tributaries, the irregularities of any one being to a certain extent neutralized by those of others, and also to the influence of Bear Lake midway in the course of the river.

THE OGDEN AND WEBER RIVERS.

These rivers rise in the Wasatch Mountains southwest of the Bear drainage, and flowing in a general westerly direction enter the Salt Lake Valley a short distance below the point where the Bear flows into Salt Lake. Their catchment areas are thus in many ways similar in topography and climate to those of the more southern tributaries of the Bear, and the fluctuations of their waters present many points of similarity. The gauging stations of these rivers are in the canyons above the heads of irrigating ditches, thus obtaining the full discharge of each stream.

On Pls. XCVI and XCVII the discharges of these streams are given, that of the Weber being continued till June, 1891. It is noticeable in this case, as in that of Bear River, that the discharge for 1891 is smaller to a marked degree than that of 1890. The steadiness of the spring flood is also remarkable, being similar to that of the Bear, though less regular. These rivers have, however, no large lakes to act as equalizers of the discharge, the water coming directly from the snows on the lofty mountains.

UTAH LAKE DRAINAGE.

Utah Lake is a body of fresh water, very shallow, with an extreme length of 22 miles and greatest width of 7 miles, the water supply coming almost entirely from the Wasatch Mountains, with very little from the low-lying foothills on the north and south, or from the Lake Mountains on the west. The principal river flowing into the lake is the Provo, which enters on the east side near the city of the same name. North of this is the American Fork River, and south of it the Spanish Fork, also Hobble Creek, Payson Creek, and Salt Creek, which comes from the valley to the south. In the summer and fall these streams are very small, in some cases their beds are almost dry, but in spring they are rivers of considerable size, and occasionally take the

character of mountain torrents, bringing an enormous quantity of water to the lake. Along the shores of the lake, especially on the west side, are many springs, some hot or warm, but the amount of water which these underground sources contribute is small in comparison with that which flows on the surface.

The daily discharges of the American Fork and Spanish Fork rivers during the low water of 1889 and flood of 1890 are shown on Pl. XCVIII, the American Fork occupying the upper part of the diagram, and the Spanish Fork the lower. In the case of the former stream the gauging station was destroyed by a flood due to the bursting of a dam, but the probable discharge, obtained from considerations of other data, is shown by the dotted line, making a complete year. The American Fork drains an area of about 66 square miles, while the Spanish Fork receives water from an area of 670 square miles or over ten times as much. The diagram shows, however, that the discharges are nearly equal, that of the American Fork being somewhat smaller. An exact comparison of the relative run-off of these two streams can be seen by referring to the table on page 104 of the preceding annual report.

The discharge of the Provo River is given on Pl. XCIX for the low water of 1889 and through 1890 up to June, 1891. The smaller discharge of this latter year is noticeable, showing that the decrease of run-off characterized a large part of the country.

The water of these and other tributaries after entering Utah Lake if not evaporated is discharged toward the north by the Jordan River. This, when the water was at a much higher level, cut a deep notch in the edge of the basin through which it flows into Salt Lake Valley, this deep cut being located at what is now known as the "Point of the Mountain." The level of the water of the lake varies from month to month, rising in the spring, usually reaching its highest in May or June, and then falling steadily until the beginning of winter. Besides this fluctuation by seasons there is is a wide annual range, the average level for the year rising or falling through a series of years, the extreme range of water level since the settlement of the country being about 12 feet.

No systematic record of the discharge of Utah Lake through Jordan River has been kept, although the water in seasons of scarcity is apportioned to the various canals. The matter is of such fundamental importance to the county and city of Salt Lake, as well as to various canal companies, that it seems strange that no record has been made of the amount taken by the various canals or flowing to waste. On May 21, 1889, Mr. J. Fewson Smith ascertained by weir measurement that the discharge was 218 second-feet. In the latter part of June the discharge began to diminish, and by September the flow had declined to 48 second-feet. During the succeeding winter there was a heavy snowfall in the mountains, and in the summer following the supply in the lake and river was ample for ordinary needs, so that measurements were not made.

The fluctuations in the surface of this lake from month to month are shown in Fig. 229, beginning in 1883. This year was marked by the greatest rise as yet recorded, the unusual snowfall of the previous winter being rapidly melted by the warm rains of spring and bringing a great quantity of water to the lake, submerging the shores and causing large loss to the people of Utah County occupying the low lands. The top of the flood line for each successive year, to and including 1889, is seen to be less and less, the lake in no succeeding year reaching at its maximum a height equal to that of the preceding year.

As the shores, excepting on the west side, are very low and with gentle slope toward the lake, the inclination in places being less than 4 feet to the mile, this variation of surface increases and diminishes the water area greatly, the shore advancing or retreating over a strip of land from 1 to 2 miles or even more in width. It may be said that for every foot

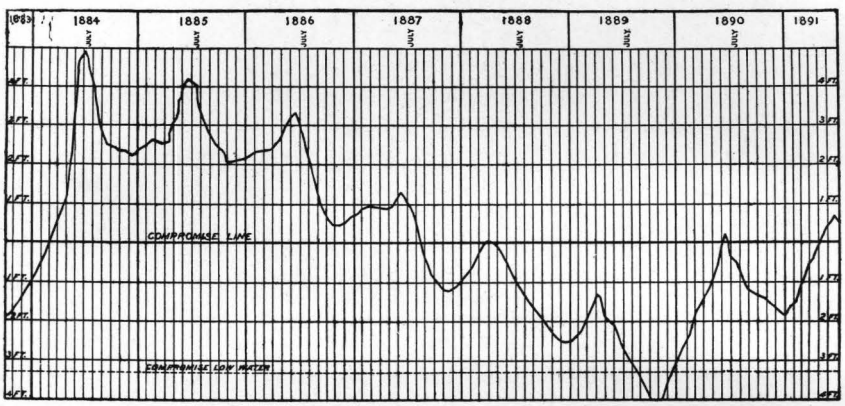
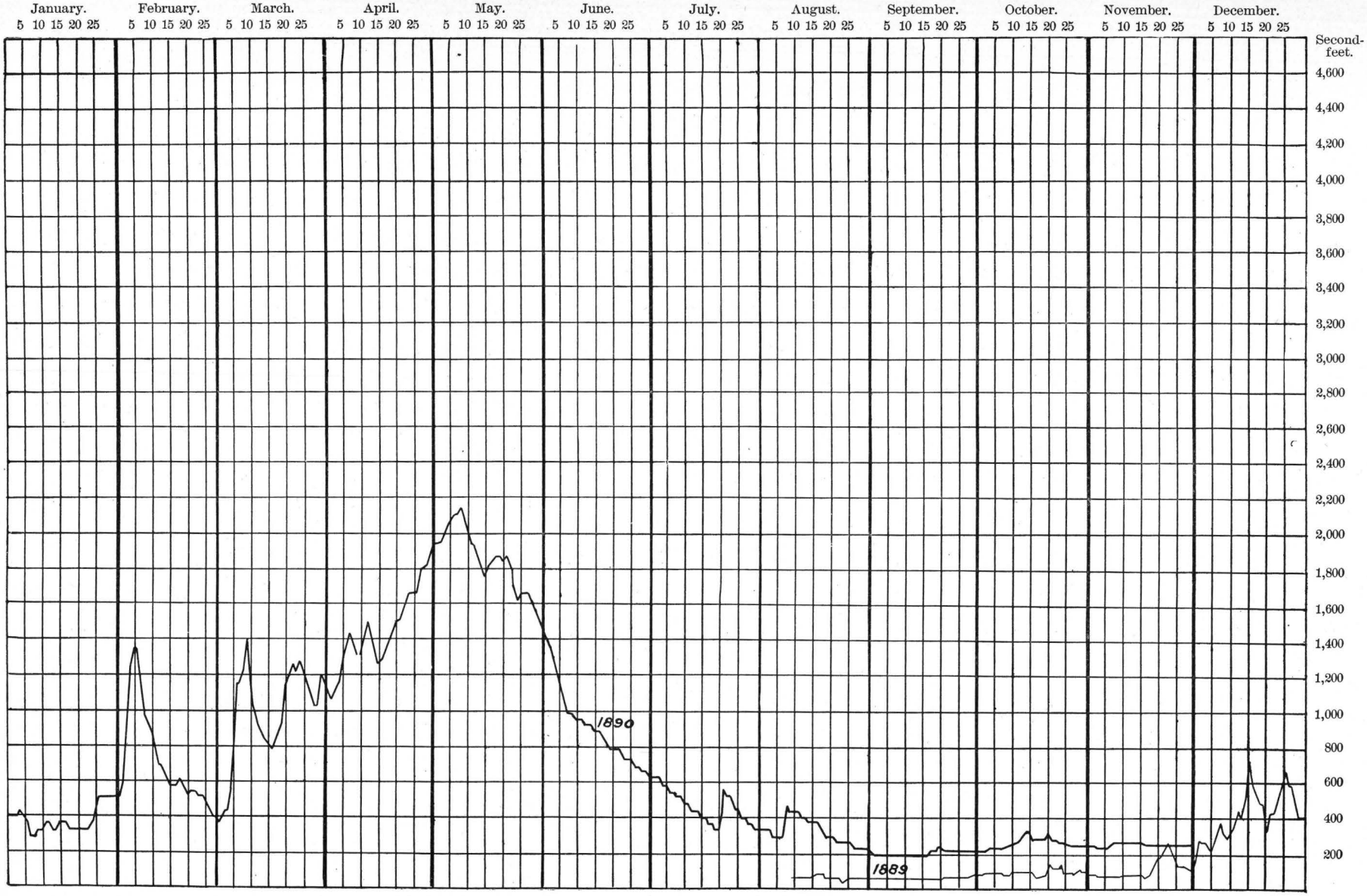


FIG. 229.—Diagram of fluctuations of Utah Lake.

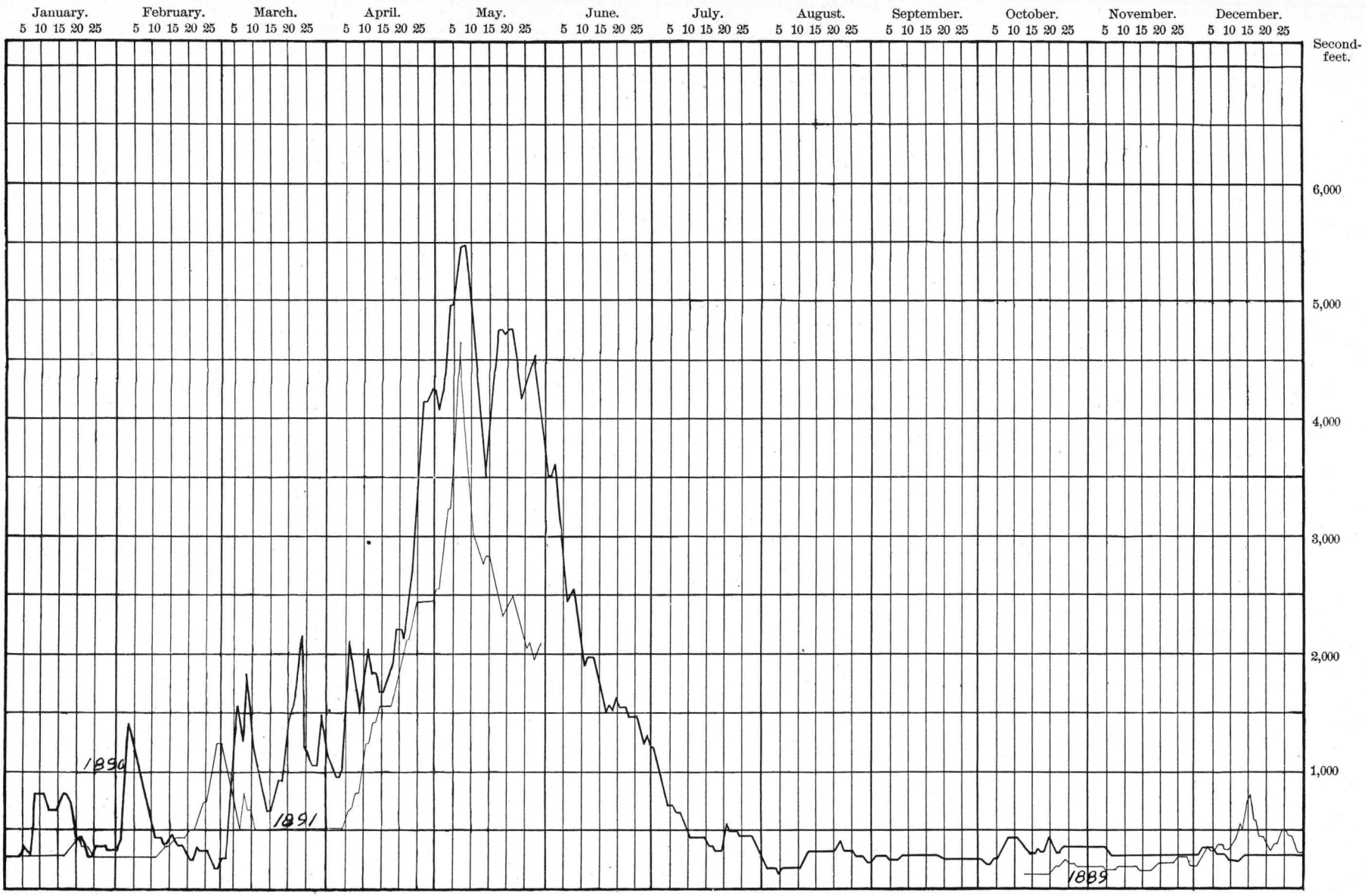
rise about 1,000 acres of pasture lands are submerged, and on the contrary, for every foot fall this amount of land is restored to use. These bordering lands are of great value to the people dwelling around the shores of the lake, for the arable and pasture lands of Utah County, being at the best somewhat restricted, are all utilized.

On the other hand, the waters of the lake discharged through the Jordan River are of prime importance to the inhabitants of Salt Lake County, for upon this water depends the larger portion of the cultivation of that broad and fertile plain. In 1874 a dam was built in the Jordan at the "Point of the Mountain," where the first decided fall or riffles of the water occur, its purpose being to raise the water to the height of the two highest canals. On the one side, in Salt Lake County, there is more land to be irrigated than water to cover it, and, on the other side, around Utah Lake, are enormous tracts of land whose value depends upon keeping the level of the lake to the minimum.

A survey of the lake was made in 1889 at a time when, owing to unusual droughts, the water was lower than it had been for nearly ten



DAILY DISCHARGE OF THE OGDEN RIVER ABOVE OGDEN, UTAH.



DAILY DISCHARGE OF THE WEBER RIVER ABOVE UINTA, UTAH.

years, and large bodies of land previously inaccessible from the soft and treacherous character of the surfaces could be traversed with ease. The map showing the result of this survey is on Pl. XCV of the preceding annual report of this Survey.

On the north and east the profile of the land bordering the lake showed a decided storm beach or ridge of sand from 2 to 5 feet above the average level of the water at that time, and from 100 to 200 feet in width. Behind this were marshes intersected by strips of open water from 1 to 5 feet deep, and filled with a luxuriant growth of tall weeds and bushes. This ridge holds back the seepage water which comes from the farms above, and retains the water in the marsh in places from 1 to 2 feet higher than that in the lake, but during the late spring and summer this usually either escapes to the lake or dries up.

In general the lake acts as an equalizer or safety valve for the great floods which come from the high, steep slopes of the Wasatch Mountains. In its natural condition it discharges freely during the summer and fall through the Jordan River, the velocity and discharge of that stream depending upon the height of the water in the lake. It is evident from the floods that have occurred in times past that the Jordan in its natural condition could not deliver during the autumn and winter all of the water which came in during one or two months of flood in the spring. From this it resulted that before the dam was built the lake has had a decided range from year to year.

As to the precise influence of the dam in the Jordan, observations are not as yet of a sufficiently detailed character to reveal this clearly. It is obvious, however, that while the dam influences to a certain degree the height of the water in the lake, and holds back during the summer a considerable amount of water, it can not in the long run obliterate or greatly modify the variation from year to year. Its influence will be in the direction of making the floods higher, but its removal would in nowise obviate the danger or probability of their occurrence.

The area of the lake at low water is approximately 80,000 acres, and the evaporation from the surface, the lake being shallow and exposed to the winds, is enormous in comparison to the amount discharged through the Jordan. In order to estimate the quantity of water thus passing into the air, it will be necessary to make some assumptions, from the fact that direct measurements of evaporation from this lake are very difficult. The amount of evaporation from pans 3 feet square has been obtained at certain places, as described in the preceding annual report of this Survey,[1] and estimates of the relative evaporation at Salt Lake City have been carried on by the Signal Service, U. S. Army.

The evaporation investigations of this latter organization were carried on in a uniform manner in various parts of the United States by means of a small instrument called the Piche evaporometer, described in the Monthly Weather Review for September, 1888.

[1] Eleventh Annual Report, U. S. Geological Survey, Part II, pp. 30-34.

The possible evaporation at Salt Lake City, as obtained by computations based upon the use of this instrument, is given in the table below, in connection with the results of measurement of evaporation from a pan in the reservoir at Fort Douglas, the military post outside the city. From a consideration of these figures and other data, a depth of evaporation, given in the sixth column, has been assumed for Utah Lake.

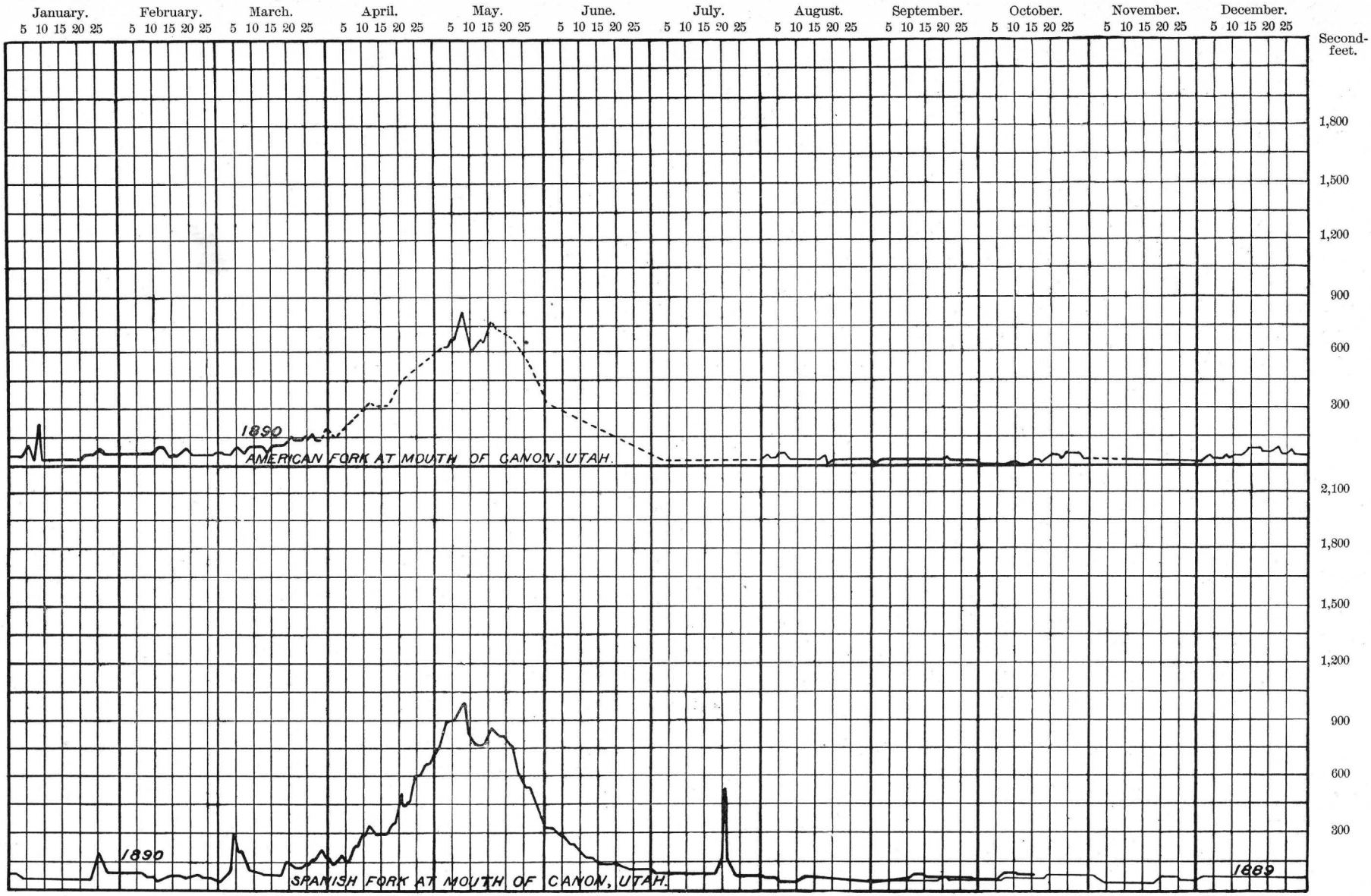
Monthly evaporation.

Months.	Salt Lake City. Piche.	Fort Douglas evaporating pan.			Utah Lake, assumed evaporation.		
		1889.	1890.	1891.	Inches.	Acre-feet.	Second-feet.
	Inches.	*Inches.*	*Inches.*	*Inches.*			
January	1·8	.....	*1·0	.....	1·0	6,666	108
February	2·7	.....	*1·5	.....	2·0	13,333	240
March	3·6	.....	*2·5	.....	3·5	23,333	380
April	7·2	.....	3·7	3·2	5·0	33,333	559
May	6·9	.....	4·1	4·8	5·0	33,333	542
June	8·9	.....	5·1	5·2	7·0	46,666	783
July	9·2	.....	7·6	7·6	8·0	53,333	866
August	10·7	10.5	6·5	6·5	8·4	56,000	911
September	9·6	5·7	4·6	5·2	7·0	46,666	783
October	6·5	4·9	2·1	2·5	5·4	36,000	586
November	5·0	1·0	1·2	1·4	2·0	13,333	224
December	2·3	.....	*1·1	.....	1·7	11,333	184
Total	74·4	.....	41·0	.....	56·0	435,429	†514

* Assumed. † Mean.

If, for example, during January the lake has a surface area of 80,000 acres and loses only 1 inch in depth, the total loss for the month would be 6,666 acre-feet, an amount sufficient to supply a stream flowing at the rate of 108 second-feet. In February, the area remaining constant, but the evaporation increasing to 2 inches, the loss would be 13,333 acre-feet, or 240 cubic feet per second. These quantities are given in the seventh and eighth columns, being computed on the basis of a loss in depth per month, as given in the sixth column, from a constant area of 80,000 acres. The mean loss by evaporation throughout the year, according to this conservative estimate, is 514 second-feet.

The mean discharge of the Provo, the principal feeder of the lake, for the year from July 1, 1889, to June 30, 1890, was 532 second-feet, and for the year from July, 1890, to June, 1891, was 472 second-feet. For the American Fork, from August 1, 1889, to July 31, 1890, the mean discharge was approximately 149 second-feet, and for the Spanish Fork, from September 1, 1889, to August 31, 1890, was 172 second-feet. These are results obtained by measurements in the canyons above the agricultural land of Utah County. Not all or even perhaps half of this water reaches the lake, as the greater part is diverted to the fields and there evaporated. Comparing, however, the total flow of the Provo with this computed evaporation, it is apparent that the whole discharge of this stream, including the floods, is necessary in order to counterbalance the loss by evaporation, and also that the united discharge of the Amercan Fork and Spanish Fork is only about 60 per cent of this loss.



DAILY DISCHARGE OF THE AMERICAN FORK AND SPANISH FORK AT MOUTH OF CANYONS, UTAH.

A comparison of these and other facts shows that the lake is in effect too large to be most effective as a storage reservoir. In other words, the efficiency of the lake as a reservoir would be greatly increased if its area could be reduced even to less that half of its present extent; for by so doing in years of scarcity, as those of 1888 and 1889, a large proportion of the water which reaches the lake, instead of being lost by evaporation, would be retained and held for use in canals which cover the land of Salt Lake County. On the other hand, considering this question from a theoretical standpoint, if the lake were only one-half its present area, the floods which come in years of exceptional precipitation would cause a far greater proportional increase of water surface than now takes place, for this water, being thrown into a smaller lake and being able to escape but slowly through the Jordan River, would of necessity encroach upon a far greater proportion of the surrounding lands.

Thus, while to obtain the maximum amount of water in years of scarcity it would be better if the lake were small, yet to take care of the floods, which will happen at intervals of from five to ten years, it is necessary that the lake have a flood area as large as it now has, or even what it would have at the highest water. From consideration of these points the segregation of the land around and under the lake was made to a contour line which should be 5 feet above the low-water mark of 1879.[1]

SEVIER RIVER.

The Sevier rises in the high plateaus of southern Utah, flows northerly about 300 miles, then turns abruptly to the west and southwest, finally losing its waters in Sevier Lake, an alkaline sink. All along its course the water is diverted for purposes of irrigation, the development of agriculture by this means being so great that during the summer the entire flow is utilized. On the head waters of this river are many reservoir sites, probably the largest and most valuable of any in the Territory. The river with gentle current winds through broad valleys, then plunges through deep, narrow canyons, alternately assuming the character of a tortuous, sluggish river and a mountain torrent. At the lower end of these open valleys the descent of the river is so small that there are frequently large marshes, and at the lower edge of the marsh the advantages for building a dam and holding back the surplus water in the river are unsurpassed.

A storage reservoir can be built at the lower end of one valley, and the water being discharged through the canyon can be taken out in the canals already built upon the lands of the valley next below. At the bottom of this valley another reservoir can be constructed, from which in turn the water discharging through the narrow gorge can be again taken into canals and utilized in turn upon the valley next succeeding. Thus a system might be provided which, if properly utilized, would en-

[1] Eleventh Annual Report U. S. Geological Survey, Part II, p. 183.

able a large proportion of the water to be used over and over again in the course of this river system.

The highest and most southern of these reservoirs is that situated at the middle of Plateau Valley, or, as it is sometimes called, Panguitch Hayfield, on the east fork of the Sevier near its headwaters. Here, at an elevation of about 7,200 feet, is a small lake and marsh. The altitude is too great for crops to mature, but in this hayfield a number of ranches have been fenced where forage is raised as winter feed for the herds which in summer range through the valley and over the adjoining summits. The disadvantage of reservoirs at this place is the comparatively small drainage areas above them and their distance from the tilled lands.

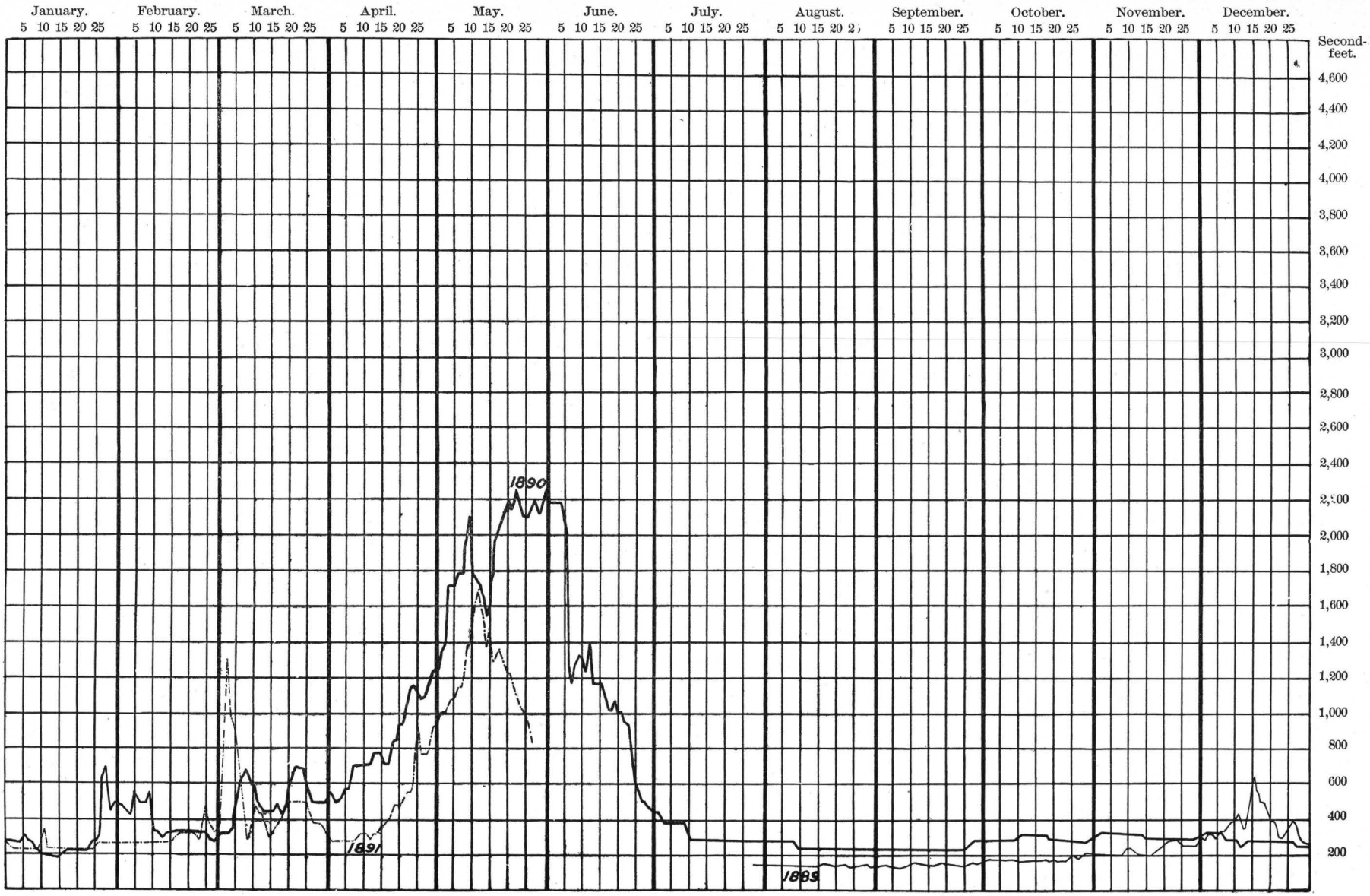
The next location in order is about 15 miles northeasterly from that above mentioned at the lower end of the Plateau Valley, and at a point where the East Fork of the Sevier enters its first canyon. The elevation is 7,000 feet, and the area drained into this proposed reservoir is larger, including that noted above. The situation is far more favorable, as the dam can be much shorter, and there is in the vicinity an abundance of material, both rock and earth, for constructing a dam.

If a company succeeds in building a reservoir at one of these places, an important question will arise, namely, as to how it will be possible to distinguish the water which is thus acquired by storage from that which would naturally flow in the river. In other words, what steps can be taken to prevent others from receiving the benefit of this stored water; as, of necessity it must be turned back into the river channel, which it will follow for 50 miles or more.

Bordering this upper Plateau Valley on the east side in the summits are also a number of small lakes admirably adapted for storage on a small scale, but which it seems unnecessary to describe, as their aggregate capacity is less than any one of the reservoir sites on the main stream.

The best place for water storage on the whole river is probably that on Otter Creek at its junction with the East Fork. Here is a marsh at the lower end of Grass Valley, at an elevation of 6,500 feet, about one-half mile in width, extending up the valley for a mile or more. The average fall of the water surface here is from 6 to 9 inches to the mile. Otter Creek discharges through a narrow notch about 180 feet wide, where a dam can be built at very small expense. The drainage area above this point is large; but should it prove insufficient to fill a reservoir basin of the capacity proposed it is possible at small expense, by building a canal from the east fork of the Sevier, to carry the entire flood waters of this stream with its enormous drainage area into this reservoir. There is already a small ditch on the site of such a canal, so that it is evident to the casual observer that here exist all the advantages for storage on a large scale.

The facilities at this point are well known and have frequently been



DAILY DISCHARGE OF THE PROVO RIVER AT PROVO, UTAH.

examined and discussed, and unfortunately, perhaps, for the canal owners below, they are fully appreciated by the persons who claim to own the greater portion of the land in the proposed site. The elevation in this basin is too great for most crops, but large quantities of hay are raised and the marsh affords excellent pasturage for cattle.

Below this marsh, on the East Fork, where it enters the canyon, are several other excellent opportunities for building a dam at the lower end of stretches of level land on which water can be impounded. There is a choice of sites here, and careful surveys and soundings for bed rock will be necessary before a final decision can be made.

All the localities mentioned above are on the East Fork of the Sevier. The West Fork drainage also includes a large number of excellent localities, among which is Panguitch Lake, well known as a locality where by the expenditure of a comparatively small amount a dam can be built, increasing the contents of the lake and holding a large amount of flood waters. From 2 to 3 miles above and southwest of the lake are other points at which storage works could be constructed, the most notable being at or near the wonderful Blue Spring, which adds a large volume to Panguitch Creek.

The situation on the Sevier is typical of that which prevails in other sections of the country. The older settlers came at first into the lower valleys and took out small ditches upon the lands most favorably located, though these were not always of the best quality. As these irrigators acquired property and other inhabitants flocked in, the ditches were enlarged and new ones, taking water at points a little higher in the river, were built, the process being continued until all of the available water at that place was taken out. In the meantime other settlements higher on the river were being made, and these in turn built larger and better ditches. The younger men and newcomers, not finding sufficient land and water in the older communities, continued to go higher and higher on the river, taking out new canals, which in turn diminished the water supply of the river below. Now the very headwaters of the river are reached, and settlers are coming to altitudes too great for the raising of most crops, but where wood and water are abundant. There they turn out upon the high pasture lands the water of the springs and smaller tributaries, wastefully using large quantities in this manner and diminishing the flow of the river itself. Without some regulation the matter must adjust itself finally by the limiting or even decrease of agriculture in the lower and more fertile valleys.

The Sevier, after passing through the canyon below Marysvale, enters upon the main Sevier valley, near the head of which is the town of Joseph. Above Joseph a stream known as Clear Creek enters from the left or west side, which, even in the dry season of 1888 and 1889, discharged a considerable volume of water. In the latter part of July it amounted to about 25 second-feet. On the headwaters of this creek are numerous localities suitable for small storage reservoirs, but the drain-

age area is too small for the establishment of any comprehensive system which will be of widespread benefit to the valleys below. The locality is, however, favorable for small projects which can be executed by one or more canal companies.

At and below Joseph City the main canals supplying the Sevier Valley are taken out from the river, covering a large amount of fertile land. The elevation of this valley is approximately 5,000 feet, and the climate is such that all the grains and fruits of the temperate zone mature to perfection. Besides the water of the main river all of the smaller tributaries entering both from the east and from the west are utilized to their full extent, mainly by individual farmers or by neighborhood associations. At Richfield, the principal town of the valley, is a large spring, which contributes greatly to the prosperity of the place.

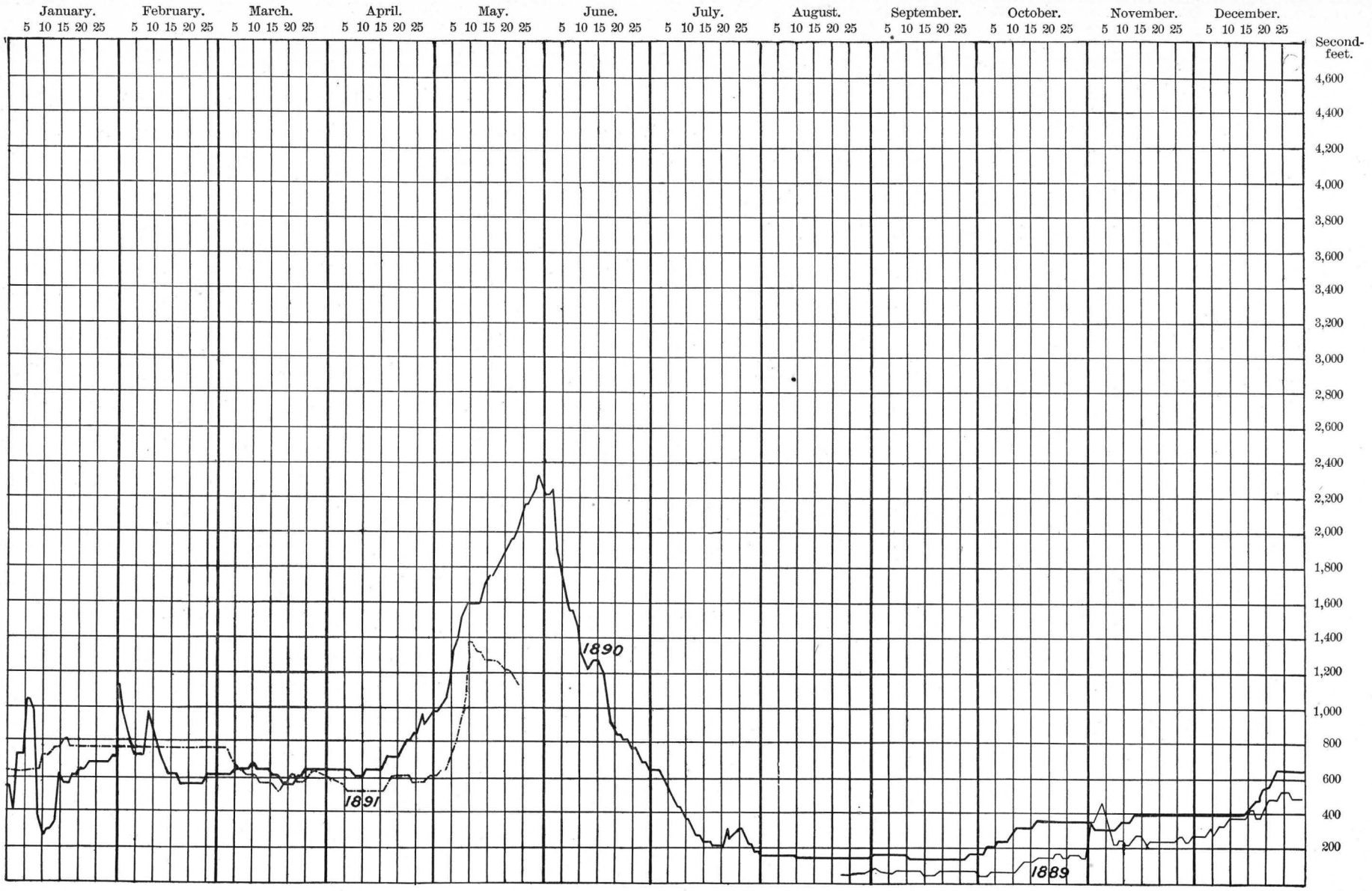
In flowing through the valley from Joseph northward to Gunnison all of the water is taken out of the river, and in 1889 there were three separate places along its course where the bed was dry. Below each of these places a certain amount of water returned to the river, to be caught in succession by tight dams built across the bed of the stream. In times of flood these dams are almost, if not entirely, swept away, but are replaced at the beginning of the dry season and made tight as the water diminishes in volume. Below Gunnison the Sanpitch River enters the Sevier, carrying, however, in the latter part of the crop season, a very small amount of water, if any.

There are in addition several very favorable localities for water storage on the Sanpitch and its tributaries, notably on Nine Mile and Twelve Mile creeks, most of which are, however, in use as ranches or hay meadows.

Below the junction of the Sanpitch with the Sevier the valley is still wide and contains large bodies of fertile lands, to which, however, little if any water can ever be taken. Below the settlement of Fayette the bounding hills approach each other, and finally the river enters a deep canyon, above the mouth of which is a favorable location for holding water. After passing through the canyon below Fayette there are intervals of comparatively open country and small flats of a few acres scattered along the river.

Near Juab, a station on the Utah Central Railroad, are several strips of marsh and pasturage which drain through Chicken Creek into the river. On this creek have already been constructed one or two small artificial ponds, where the water, which rises principally in springs, is collected and allowed to flow down as needed upon the small pieces of agricultural lands below. Again, along the river below Chicken Creek, are a number of localities where water might be held, notably at the railroad station called Wellington, also at Mills Station and at Church House.

At the town of Leamington the river finally leaves the broken, hilly country and begins to traverse the great plain of the Sevier Desert,



DAILY DISCHARGE OF THE SEVIER RIVER AT LEAMINGTON, UTAH.

cutting its way first through a great accumulation of gravels, the delta of the ancient river. At this point two canals have been taken out to supply the town of Leamington and the agricultural district below. About 40 miles farther down is the Deseret Reservoir. At this point the inhabitants of the towns of Deseret and Oasis have cut a channel for the river 460 feet long, shortening the course about a mile, so that the river, instead of pursuing a tortuous channel around a large loop, now pours through this cut-off across what was previously a narrow neck of land. The loop thus abandoned has been blocked up at both ends by earth dams and is now used as a reservoir, receiving its water by a long canal which runs up the river until it reaches a point sufficiently low for the water to be diverted into it.

There is at present constructed, running from this reservoir, a canal which passes out through a cut 22 feet deep and 24 feet wide on the bottom, which leads to the town of Deseret. A new canal is projected to take water from the middle of the old reservoir and irrigate other lands for the purpose of starting a new colony. The local engineers have estimated that, by raising the earth dams and building better regulating gates, sufficient water can be held in times of floods to supply the needs of this new community.

This reservoir will be an example of storage at low elevations near the land to be irrigated. The situation is such that it is almost impossible to provide a better system for these towns. The Sevier winds through so many long, fertile valleys in its course, the water being taken out by innumerable canals, that it is impossible for the irrigators living out on the desert to provide storage for themselves in the high mountains, for the question of the distribution of water which has flowed through five or six counties would involve interminable conflicts. Their only resource, therefore, is to attempt to hold some of the flood and seepage water which has come from the irrigated lands a hundred miles or more above.

From the above description of the river and the towns and communities depending on its waters for sustenance it will be seen that the most careful study must be made of all the conditions before a general system of storage can be inaugurated which will be beneficial to all. There is no doubt that reservoirs in the mountains at the headwaters will be of great value and advantage even to the people who live down in the Sevier desert, as by their presence in the mountains the summer flow of ground water must be increased. On the other hand, to directly benefit the lower towns it will be necessary to construct at points in the lower end of several of the populated valleys reservoirs which will hold at these points the local flood waters, and deliver them to the agricultural lands in the next valley below.

But before any such system of storage can be successfully carried into effect a general understanding will be necessary among the towns and counties interested, by which the whole body of irrigators shall

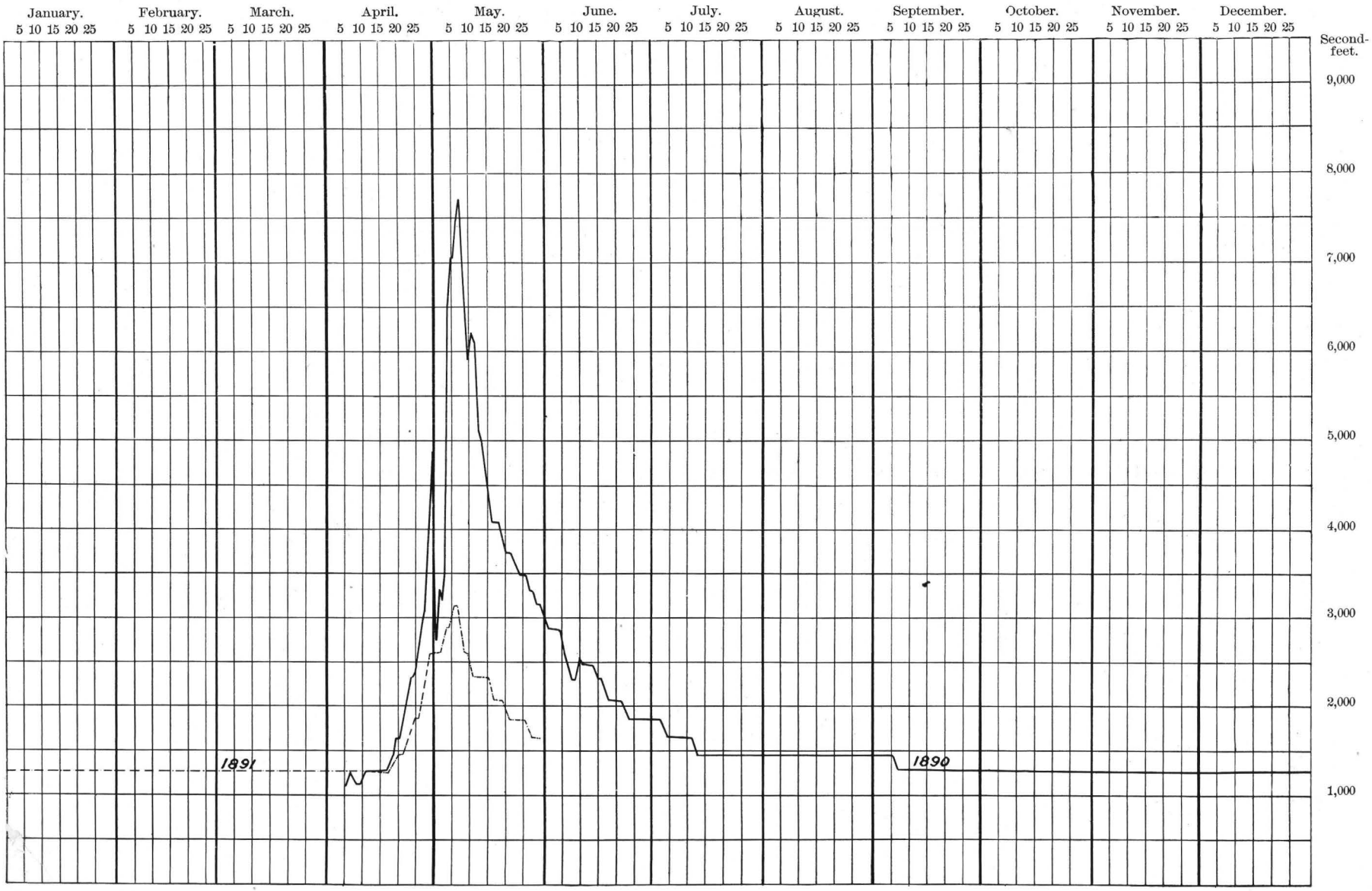
join in the system of water storage and then distribute the waters thus saved according to the judgment of all interested.

The discharge of this river at the Leamington gauging station from August, 1889, to June, 1891, is shown on Pl. C., the less discharge of this latter period being very noticeable. The amount of water passing this station is of course greatly affected by the large diversions of water all along the river, and in years of scarcity, as in 1891, the flood discharge must come mainly from the lower tributaries, that from the higher forks of the stream being used in the many large canals.

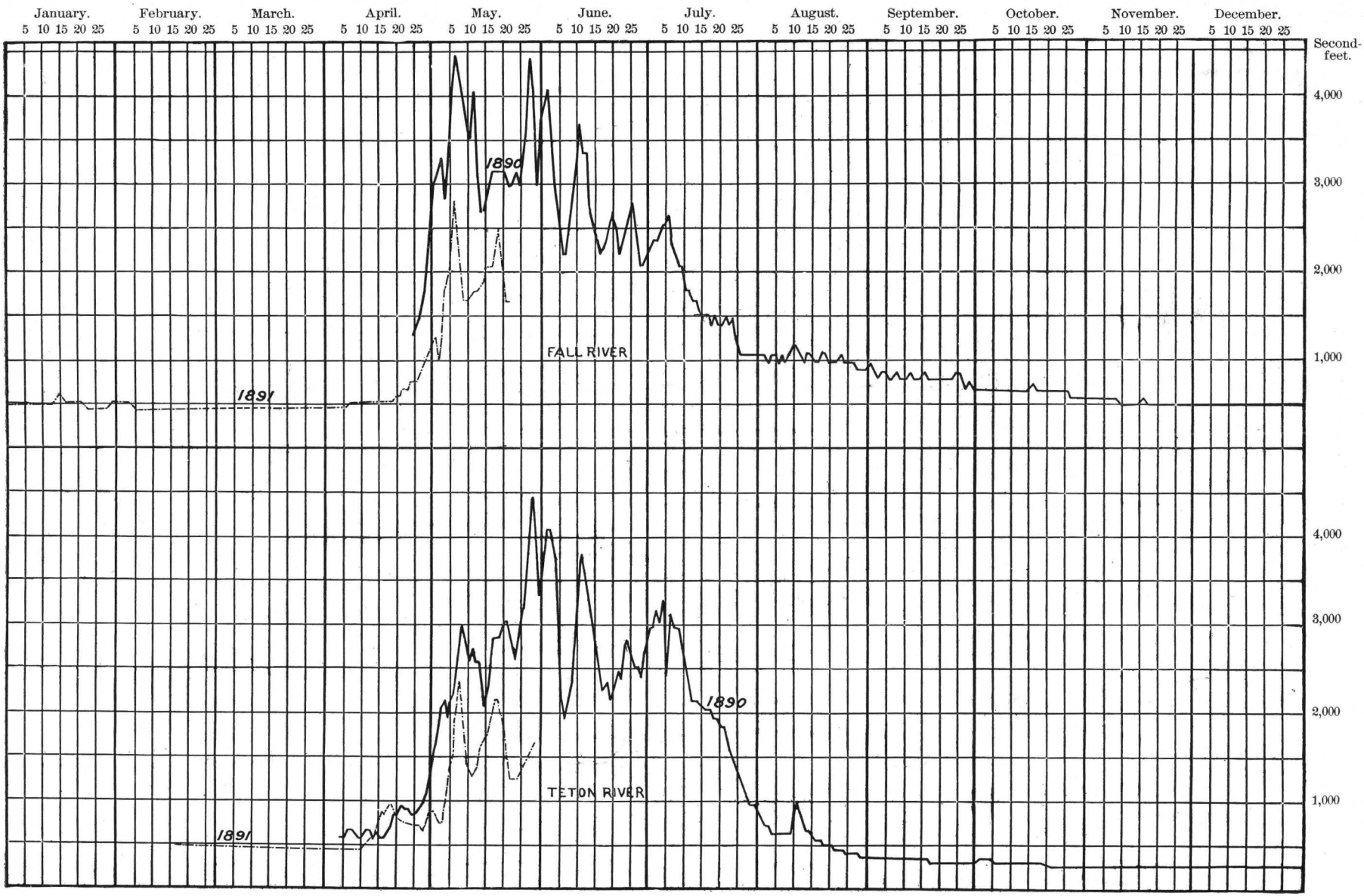
SNAKE RIVER DRAINAGE.

Stream measurements have been made of the principal tributaries of the Snake River in eastern Idaho, and also of lower tributaries in western Idaho and Oregon. A brief description of the topography of the country and of the gauging stations was given in the preceding annual report. The discharges at these stations are shown on Pls. CI to CVI. The discharges for Henry Fork, Falls River, and Teton, as well as for the Snake at Eagle Rock or Idaho Falls, are similar in general character, differing mainly in the quantity of water represented, but the diagrams for the Owyhee, Malheur, and Weiser exhibit distinctive characteristics, only to be explained by a careful study of the topography of the region.

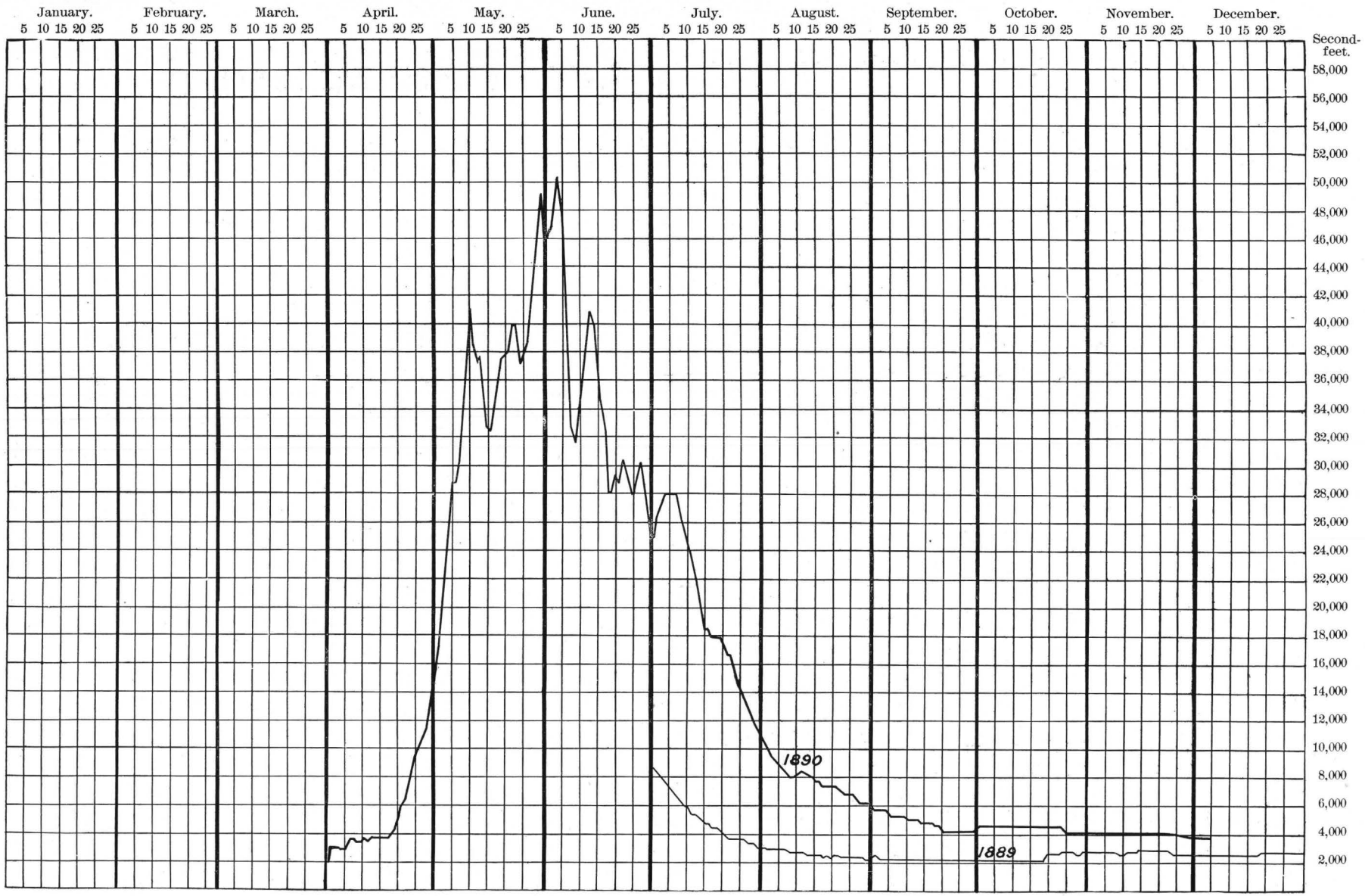
The diminished floods of 1891 are very noticeable, and these are not only less in quantity, but culminate at an earlier date. The diagram for the Weiser is peculiar for the number and extent of the fluctuations of high and low water and the irregularity of the time at which these occur.



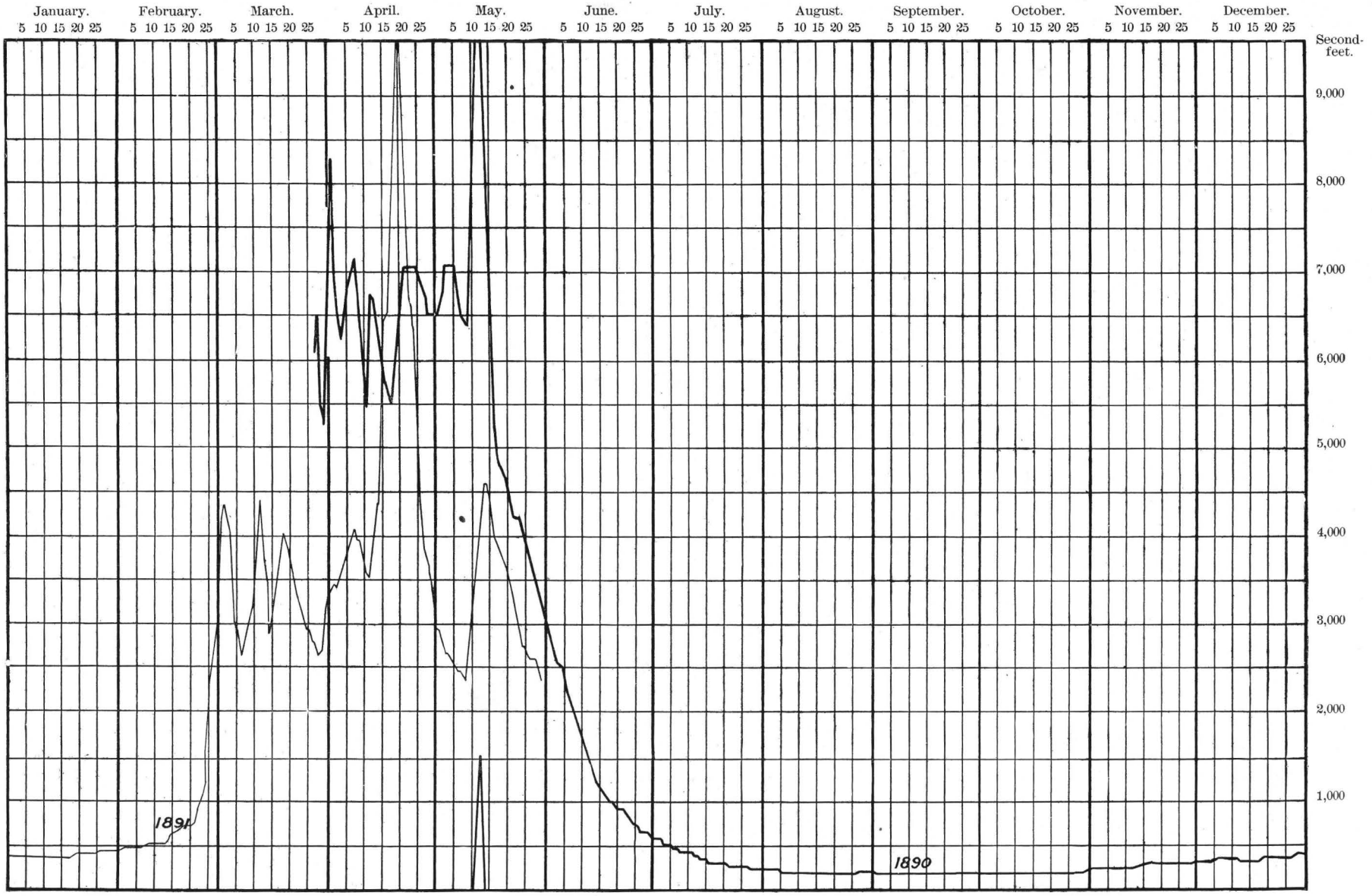
DAILY DISCHARGE OF THE HENRY FORK ABOVE FALLS RIVER, IDAHO.



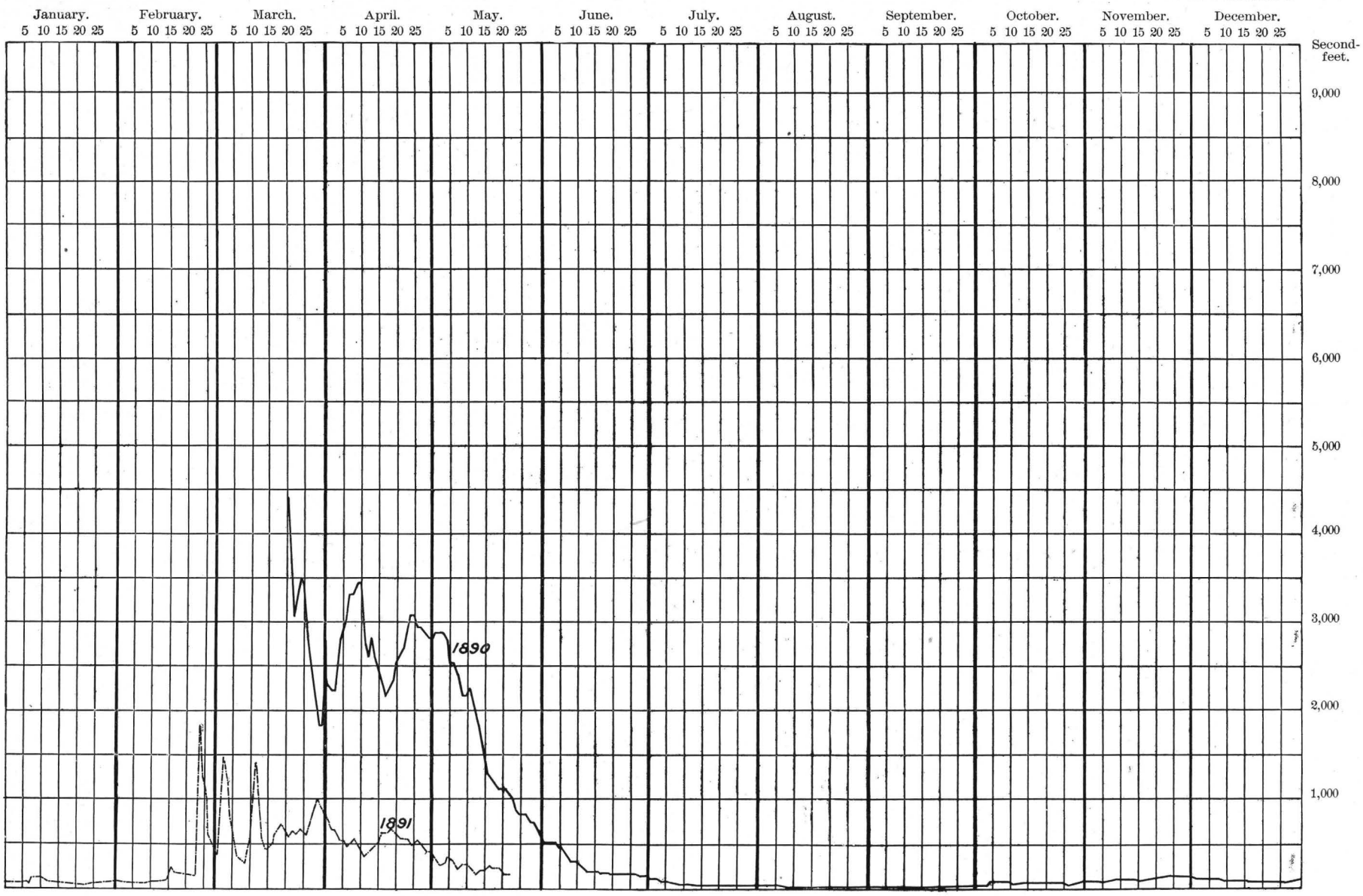
DAILY DISCHARGE OF FALLS AND TETON RIVERS ABOVE CANALS, IDAHO.



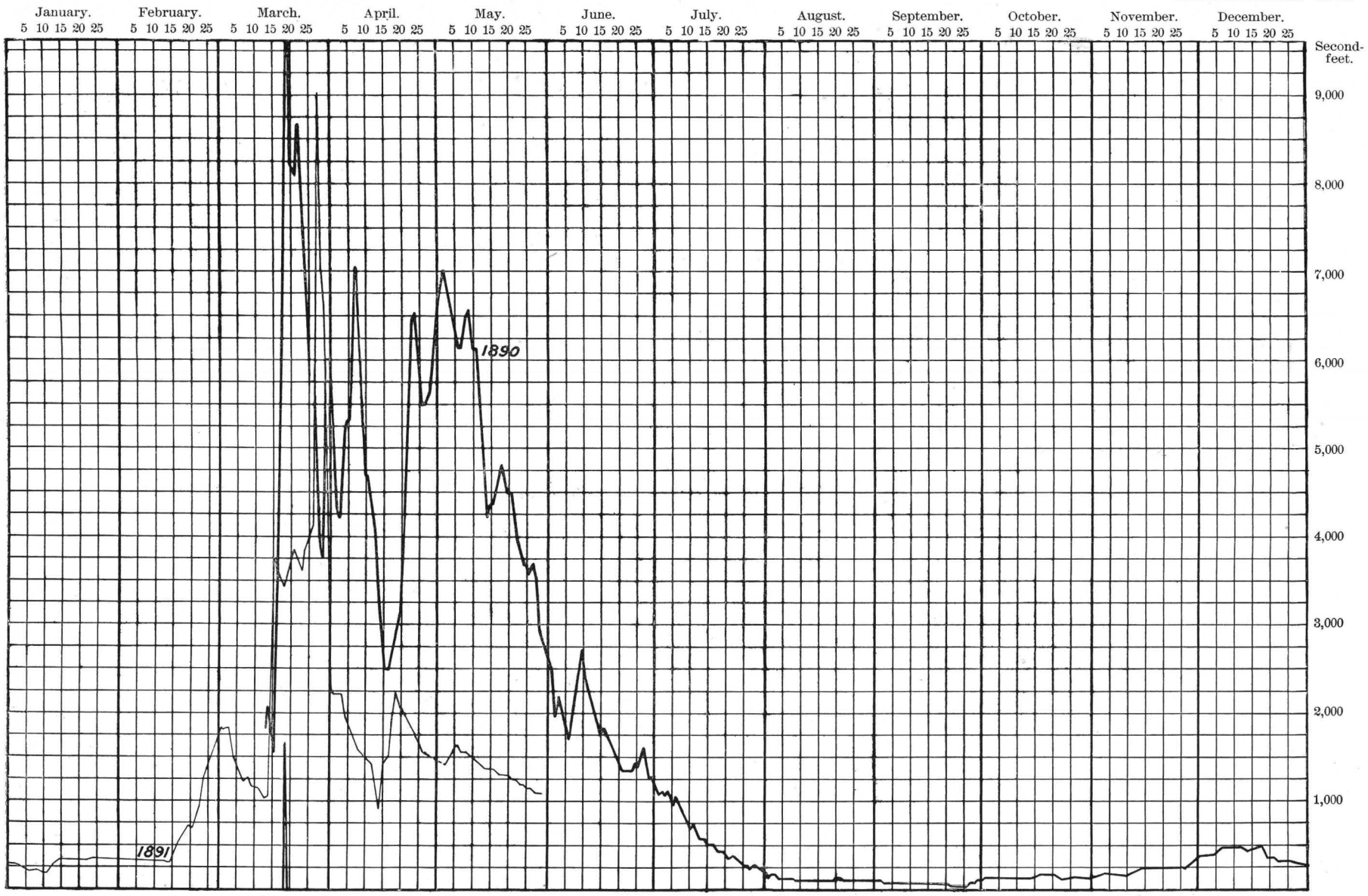
DAILY DISCHARGE OF THE SNAKE RIVER AT IDAHO FALLS, IDAHO.



DAILY DISCHARGE OF THE OWYHEE RIVER AT RIGSBY, OREGON.



DAILY DISCHARGE OF THE MALHEUR RIVER AT VALE, OREGON.



DAILY DISCHARGE OF THE WEISER RIVER ABOVE WEISER, IDAHO.

DISCHARGE TABLES.

The following tables give the monthly discharges for the rivers upon which observations of height have been made during the year ending June 30, 1891. These tables are similar in form to those published in the preceding annual report of this Survey,[1] being in fact continuations of many of them. At the head of each table is the name of the river and also the locality at which the measurements were made, together with the total drainage area in square miles above this point.

The first column gives the month, and in cases where observations were made during a portion of the month, the dates during which these were continued are shown immediately after the name of the month. In such cases the mean discharge is not that of the whole month, but of this fraction only. Under the head of "discharge" are given the maximum, minimum, and mean discharges for each month or portion of month in cubic feet per second. In several instances to complete a year estimates have been made of the mean discharge, these estimates being marked by an asterisk.

At the right of the mean discharge in second-feet are the total discharges for the entire month in acre-feet; that is, the number of acres that would be covered to a depth of 1 foot by a stream of this given size flowing continuously through the month, none of the water being lost. The last two columns on the page show the relation existing between this quantity of water and the area from which it may be supposed to have come. For purposes of comparison it is assumed that this water came in equal quantities from each square mile or acre of the drainage basin, although as a matter of fact this is recognized as impossible, since in nearly all cases the water running off a large drainage basin comes from comparatively restricted localities.

The first of these two columns gives the depth of run-off for each month in inches; that is to say, this quantity of water would, if put upon a plain of equal area, cover it to the depth given. The last column gives the run-off in second-feet for each square mile of the basin; or, in other words, each square mile, taking the average for the entire area drained, contributed a constant supply of the given number of second-feet.

[1] Eleventh Annual Report of the U. S. Geological Survey, Part II, Irrigation, pp. 93–106.

West Gallatin River, near Bozeman, Montana.

[Drainage area, 850 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
August 16 to 31	437	402	426	26,200	0·58	0·50
September	640	402	450	24,550	·54	·53
October	437	367	402	24,700	·54	·47
November	.....	.....	*400	23,800	·52	·47
December	.....	.....	*400	24,600	·54	·47
1890.						
January	.....	.....	*320	19,680	·43	·38
February	.....	.....	*320	17,760	·39	·38
March 23 to 31	320	320	320	19,680	·43	·38
April	1,255	280	460	27,400	·60	·54
May	3,195	1,300	2,092	128,600	2·84	2·46
June	3,800	2,060	2,641	157,300	3·47	3·11
July	2,165	890	1,388	85,362	1·88	1·63
August	890	570	761	46,800	1·03	·89
September	690	570	607	36,100	·80	·72
October	650	570	591	36,400	·80	·70
November	570	430	506	30,100	·66	·60
December	.....	.....	*450	27,650	·61	·54
1891.						
January	.....	.....	400	24,600	·54	·47
February	.....	.....	400	22,200	·47	·47
March	.....	.....	450	27,675	·61	·53
April	.....	.....	500	29,750	·65	·59
May	2,535	1,390	1,897	116,665	2·57	2·23
June	2,975	1,615	2,516	149,702	3·30	2·95

* Estimate.

Madison River at Red Bluff, Montana.

[Drainage area, 2,085 square miles.]

1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	.....	.....	*1,200	73,800	0·66	0·58
February	.....	.....	*1,200	66,600	·60	·58
March	.....	.....	*1,200	73,800	·66	·58
April 4 to 30	2,580	1,370	1,620	96,390	·87	·78
May	6,420	3,060	4,823	296,600	2·67	2·32
June	6,360	3,780	4,977	296,131	2·66	2·38
July	3,660	1,715	2,518	154,800	1·39	1·21
August	1,640	1,375	1,535	94,400	·85	·74
September	1,580	1,420	1,466	86,300	·78	·70
October	1,520	1,420	1,498	92,300	·83	·72
November	1,470	1,285	1,380	82,150	·74	·66
December	1,520	1,285	1,400	86,150	·77	·67
1891.						
January	1,580	1,240	1,406	86,469	·78	·67
February	1,580	1,265	1,436	79,698	·72	·69
March	1,790	1,470	1,631	100,306	·90	·78
April	1,960	1,640	1,774	105,530	·95	·85
May	4,260	1,790	3,389	208,423	1·88	1·62
June	4,620	3,780	4,167	247,936	2·20	2·00

* Estimate.

Missouri River at Craig, Montana.

[Drainage area, 17,615 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	.....	.....	*3,000	184,500	·20	·17
February	.....	.....	*3,000	166,500	·18	·17
March	.....	.....	*3,000	184,500	·20	·17
April 17 to 30	6,100	3,595	4,662	277,389	·29	·26
May	12,500	6,900	10,472	644,030	·68	·59
June	11,900	8,100	10,074	599,401	·64	·57
July	7,800	2,614	5,020	308,730	·33	·28
August	2,505	1,960	2,216	136,284	·15	·13
September	2,396	1,960	2,232	132,700	·14	·13
October	2,722	1,742	2,379	146,000	·16	·13
November	3,159	2,723	2,868	170,800	·18	·16
December	3,159	1,742	2,763	170,000	·18	·16
1891.						
January	3,823	1,742	2,967	184,270	·19	·17
February	.....	.....	*3,500	215,250	·24	·20
March	.....	.....	*4,000	246,000	·26	·23
April	9,130	4,570	5,794	344,743	·37	·32
May	12,050	7,150	9,015	554,422	·59	·51
June	16,355	11,000	13,645	811,877	·85	·77

* Estimate.

Sun River above Augusta, Montana.

[Drainage area, 1,175 square miles.]

1889.						
August 5 to 31	221	200	213	13,100	·21	·18
September	260	200	214	12,720	·20	·18
October	200	200	200	12,300	·20	·17
November	200	180	191	11,360	·18	·16
December	.....	.....	*175	10,760	·17	·15
1890.						
January	.....	.....	*175	10,760	·17	·15
February	.....	.....	*175	9,712	·15	·15
March	.....	.....	*175	10,760	·17	·15
April	1,580	160	371	22,050	·35	·31
May	4,085	1,990	2,804	172,500	2·75	2·38
June	4,000	1,850	2,342	139,500	2·23	1·99
July	2,440	450	961	59,100	·94	·81
August	480	315	371	22,800	·36	·19
September	365	260	304	18,090	·29	·26
October	480	240	315	19,395	·31	·27
November	390	275	322	19,160	·31	·28
December	340	240	267	16,430	·26	·23

* Estimate.

Yellowstone River at Horr, Montana.

[Drainage area, 2,700 square miles.]

1889.						
August 12 to 31	1,853	1,411	1,660	102,090	·71	·62
September	1,653	1,126	1,270	75,570	·52	·47
October	1,126	841	976	60,000	·42	·36
November	841	651	743	44,200	·31	·27
December	.....	.....	*650	39,975	·28	·24
1890.						
January	.....	.....	*550	33,825	·23	·25
February	.....	.....	*550	30,525	·21	·25
March 21 to 31	620	560	585	35,977	·25	·22
April	4,495	510	1,417	84,250	·59	·53
May	11,915	5,090	7,522	466,500	3·24	2·79
June	11,915	8,720	10,082	603,000	4·19	3·74
July	9,410	5,760	7,682	473,000	3·28	2·84
August	5,600	3,145	4,375	269,000	1·87	1·62
September	3,145	1,670	2,276	135,200	·94	·84
October	1,920	1 160	1,473	90,600	·63	·55
November	1,160	850	970	57,750	·40	·36
December	815	590	95	42,742	·30	·26
1891.						
January	590	470	488	30,012	·21	·18
February 1 to 14	.....	.....	*500	27,750	·19	·18
March	360	285	316	19,434	·13	·12
April	2,720	360	1,082	64,379	·45	·40
May	7,480	1,855	5,227	321,460	2·24	1·93
June	8,975	6,685	7,592	451,724	3·13	2·81

* Estimate.

Cache la Poudre Creek above Fort Collins, Colorado.

[Drainage area, 1,060 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1884.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
March 15 to 31	92	48	67	4,120	·07	·06
April	707	64	219	13,030	·23	·21
May	4,610	453	2,537	156,025	2·77	2·39
June	5,611	3,473	4,812	286,314	5·08	4·54
July	3,970	862	2,144	131,856	2·33	2·03
August	1,231	423	792	48,708	·86	·75
September	446	230	305	18,147	·32	·29
October 1 to 16	224	195	205	12,607	·22	·19
1885.						
April 4 to 30	822	241	447	26,596	·47	·42
May	1,592	954	1,419	87,268	1·55	1·34
June	3,857	2,235	2,910	173,145	3·07	2·75
July	3,186	1,076	3,186	195,939	3·46	3·01
August	1,116	369	656	40,344	·71	·62
September	386	214	272	16,184	·29	·25
October 1 to 10	210	202	203	12,484	·22	·19
1886.						
April 27 to 30	446	369	405	24,097	·43	·38
May	2,659	404	1,309	80,403	1·42	1·23
June	2,584	1,247	1,876	111,622	1·97	1·77
July	1,175	392	717	44,095	.78	·68
August	1,475	232	338	20,787	·37	·33
September	284	115	185	11,007	·19	·17
October	133	120	129	7,933	·14	·12
1887.						
May 18 to 29	2,380	1,150	1,822	112,053	1·99	1·72
June 14 to 30	1,970	1,050	1,401	83,360	1·47	1·32
July	1,260	410	735	45,202	·80	·69
August	430	240	307	18,880	·33	·29
September	300	110	175	10,412	·18	·17
1888.						
April	350	100	181	10,769	·19	·17
May	790	250	483	29,704	·53	·46
June	1,490	680	1,113	66,223	1·17	1·05
July	690	260	420	25,830	·46	·40
August	500	140	213	13,100	·23	·20
September	180	70	109	6,485	·11	·10
1889.						
January	342	71	151	9,280	·16	·14
February	198	69	106	5,880	·10	·10
March	125	41	46	2 830	·05	·04
April	342	48	113	6,730	·12	·11
May	1,886	215	649	39,900	·71	·61
June	1,960	837	1,338	79,500	1·41	1·26
July	844	271	514	31,600	.56	·48
August	455	67	187	11,500	·20	·18
September	75	56	67	3,990	·07	·06
October	92	55	69	4,240	·08	·06
November	122	46	88	5,240	·09	·08
December	89	33	64	3,940	·07	·06
1890.						
January	101	46	82	5,043	·09	·08
February	138	37	79	4,384	·08	·08
March	126	47	85	5,227	·09	·08
April	481	71	200	11,900	·21	·19
May	1,710	436	1,044	64,206	1·13	·99
June	1,804	1,016	1,280	76,158	1·35	1·21
July	1,025	336	649	39,950	·71	·61
August	404	150	287	17,650	·31	·27
September	183	58	103	6,130	·11	·10
October	118	55	80	4,925	·09	·08
November	89	41	61	3,630	·07	·06
December	.....	.....	70	4,305	·08	·07
1891.						
January	150	49	95	5,842	·10	·09
February	138	55	75	4,162	·07	·07
March	73	42	61	3,751	·07	·06
April	416	48	154	9,163	·16	·14
May	2,080	416	1,162	71,463	1·26	1·10
June	.....	.....	.....	.....	.....	.....

Arkansas River at Canyon City, Colorado.

[Drainage area, 3,060 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1888.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	.....	.....	*400	24,600	·15	·13
February	.....	.....	*500	27,750	·17	·16
March	.....	.....	*600	36,900	·22	·20
April	.....	.....	*1,000	59,500	·36	·33
May	1,570	1,280	1,440	88,500	·54	·47
June	2,760	1,120	2,090	124,300	·76	·68
July	1,870	850	1,350	83,000	·51	·44
August	1,100	800	932	57,300	·35	·30
September	850	430	605	36,000	·22	·20
October	.....	.....	*500	30,750	·19	·16
November	.....	.....	*500	29,750	·18	·16
December	.....	.....	*400	24,600	·15	·13
1889.						
January	.....	.....	*300	18,450	·11	·10
February	.....	.....	*300	16,620	·10	·10
March	.....	.....	*300	18,450	·11	·10
April 17 to 31	438	214	300	17,850	·11	·10
May	1,960	324	600	36,900	·23	·20
June	2,010	1,002	1,374	81,753	·50	·45
July	1,150	290	602	37,023	·23	·20
August	2,620	243	340	20,910	·13	·11
September	258	190	220	13,090	·08	·07
October	284	190	223	13,715	·08	·07
November	335	243	299	17,790	·11	·10
December	438	274	335	20,602	·13	·11
1890.						
January	494	18[illegible]	310	19,065	·12	·10
February	446	250	363	20,146	·12	·12
March	391	180	320	19,683	·12	·10
April	980	200	477	28,381	·17	·16
May	3,270	841	2,090	128,535	·79	·68
June	3,260	2,068	2,611	155,354	·95	·85
July	2,132	920	1,571	96,616	·59	·51
August	1,425	580	670	41,205	·25	·22
September	625	455	519	30,850	·19	·17
October	605	505	531	32,650	·20	·17
November	555	480	522	31,060	·19	·17
December	580	455	502	30,900	·19	·16
1891.						
January	505	325	431	26,506	·16	·14
February	580	365	474	26,307	·16	·15
March	685	530	586	36,039	·22	·19
April	1,600	580	857	50,992	·31	·28
May	3,370	1,340	2,012	123,738	·76	·66
June	4,230	1,600	3,291	195,814	1·20	1·07

Rio Grande at Del Norte, Colorado.

[Drainage area, 1,400 square miles.]

1889.						
October 11 to 31	345	214	278	17,097	·23	·20
November	364	290	319	18,980	·25	·23
December	364	200	281	17,281	·23	·20
1890.						
January	1,000	326	552	33,948	·45	·39
February	896	745	796	44,178	·59	·57
March	842	404	487	29,950	·40	·35
April	1,380	404	913	54,323	·73	·65
May	5,930	1,990	4,331	266,356	3·57	3·09
June	5,555	2,550	3,807	226,516	3·03	2·72
July	2,260	862	1,515	93,172	1·25	1·08
August	930	450	612	37,638	·50	·44
September	450	326	383	22,800	·31	·27
October	862	307	470	28,900	·39	·34
November	610	345	478	28,500	·38	·34
December	670	475	565	34,750	·46	·40
1891.						
January	1,320	670	990	60,885	·81	·71
February	1,410	1,193	1,294	71,817	·96	·92
March	1,460	930	1,280	78,720	1·05	·91
April	3,160	796	1,410	83,895	1·12	1·01
May	5,650	1,860	3,285	202,027	2·70	2·34
June	5,555	2,190	4,146	246,687	3·31	2·96

Rio Grande at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
January	495	379	431	26,506	·07	·06
February	576	420	473	26,251	·07	·07
March	1,042	537	784	48,216	·13	·11
April	4,420	970	2,261	134,530	·36	·32
May	5,075	2,443	3,430	210,945	·56	·49
June	5,660	1,390	2,922	173,859	·47	·42
July	1,105	236	471	28,966	·07	·07
August	253	181	206	12,669	·03	·03
September	264	184	212	12,614	·03	·03
October	324	243	283	17,404	·05	·04
November	507	253	366	21,777	·06	·05
December	610	364	542	33,333	·09	·08
1890.						
January	617	260	437	26,875	·07	·07
February	670	344	553	30,691	·08	·08
March	1,044	330	682	41,943	·11	·10
April	3,220	842	2,083	123,938	·33	·30
May	6,071	2,660	4,960	305,040	·82	·71
June	5,740	2,768	4,107	244,366	·65	·59
July	2,640	920	1,593	97,969	·26	·23
August	1,134	636	814	50,061	·13	·12
September	1,044	496	545	32,400	·09	·08
October	606	523	562	34,600	·09	·08
November	699	550	616	36,650	·10	·09
December	660	636	648	39,850	·11	·09
1891.						
January	666	550	586	36,039	·10	·08
February	1,000	550	616	34,182	·09	·09
March	1,450	735	917	56,395	·16	·13
April	5,690	735	2,370	141,015	·38	·34
May	8,550	4,520	5,965	366,847	·98	·85
June	6,340	4,325	5,040	299,880	·80	·72

Rio Grande at El Paso, Texas.

[Drainage area, 30,000 square miles].

1889.						
May 10 to 31	4,705	2,060	3,116	191,634	·120	·104
June	4,460	660	2,638	156,961	·098	·090
July	930	.....	237	14.575	·009	·007
August	.....	.....	0	0	0	0
September	.....	.....	0	0	0	0
October	.....	.....	0	0	0	0
November	.....	.....	0	0	0	0
December	252	.....	71	4,366	·003	·002
1890.						
January	280	126	196	12,054	·008	·007
February	458	108	290	16,095	·010	·010
March	1,140	45	424	26,076	·016	·014
April	4,108	470	2,190	130,305	·081	·073
May	7,200	3,495	5,771	354,916	·221	·190
June	7,200	2,925	4,404	262,038	·164	·147
July	2,355	235	854	52,521	·033	·028
August	2,497	170	734	45,141	·028	·024
September	660	40	176	10,470	·006	·006
October	616	40	65	4,000	·003	·002
November	610	40	284	16,950	·011	·009
December	610	430	535	32,900	·020	·018
1891.						
January	715	140	451	27,736	·017	·015
February	2,640	470	809	44,899	·028	·027
March	4,635	470	1,866	114,759	·072	·062
April	8,625	1,040	4,265	253,767	·159	·142
May	16,620	8,340	11,852	726,528	·454	·396
June	8,340	5,045	6,714	399,483	·249	·224

Truckee River at Vista, Nevada.

[Drainage area, 1,519 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
April 26 to 30	5,610	3,730	4,496	267,512	3·30	2·96
May	7,510	3,200	5,990	368,385	4·55	3·94
June	6,710	3,115	4,162	247,639	3·06	2·74
July	3,730	1,185	2,198	135,177	1·67	1·45
August	1,152	750	952	58,548	·72	·63
September	825	570	682	40,579	·50	·45
October	1,030	490	742	45,633	·56	·49
November	825	400	765	45,517	·56	·50
December	.....	.....	*750	46,125	·57	·49
1891.						
January	.....	.....	*700	43,050	·54	·46
February	.....	.....	*650	36,075	·44	·43
March	.....	.....	*650	39,975	·50	·43
April	3,115	570	1,523	90,618	1·12	1·00
May	3,285	1,990	2,765	170,047	2·10	1·79
June	2,730	1,280	1,905	113,347	1·39	1·25

* Estimate.

East Carson River at Rodenbahs, Nevada.

[Drainage area, 414 square miles.]

1890.						
April 7 to 30	1,565	752	1,026	61,047	2·76	2·48
May 4 to 31	4,260	1,315	2,654	163,221	7·38	6·41
June	3,900	1,745	2,430	144,585	6·55	5·87
July	2,780	750	1,789	110,000	4·98	4·32
August	875	437	597	36,750	1·66	1·44
September	437	400	415	24,700	1·12	1·00
October	390	385	386	23,740	1·07	·93
November	385	380	384	22,850	1·04	·93
December	400	375	379	23,300	1·06	·92
1891.						
January	395	385	388	23,862	1·08	·94
February	715	377	402	22,311	1·01	·97
March	1,650	390	783	48,154	2·18	1·89
April	590	410	452	26,894	1·22	1·09
May	1,884	1,010	1,445	88,867	4·02	3·49
June	1,884	565	1,328	79,016	3·58	3·12

West Carson River at Woodford, California.

[Drainage area, 70 square miles.]

1890.						
April 9 to 30	448	145	284	16,898	4·56	4·06
May	924	318	657	40,405	10·83	9·40
June	1,284	448	614	36,533	9·79	8·77
July	606	252	380	23,370	6·27	5·43
August	240	90	135	8,300	2·23	1·93
September	86	70	75	4,080	1·09	1·07
October	78	54	67	4,120	1·10	·96
November	58	46	49	2,915	·78	·70
December	58	42	53	3,261	·87	·76
1891.						
January	62	46	52	3,198	·86	·74
February	58	42	48	2,664	·71	·69
March	68	50	61	3,758	1·01	·87
April	384	62	127	7,556	2·02	1·82
May	740	300	534	32,820	8·79	7·62
June	456	260	338	20,111	5·38	4·83

Bear River at Battle Creek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
October 11 to 31	430	300	355	21,832	·09	·07
November	830	430	487	28,976	·12	·11
December	735	350	565	34,747	·14	·13
1890.						
January	1,255	270	875	53,812	·22	·19
February	2,040	600	809	4,490	·18	·18
March	2,040	780	1,271	78,166	·32	·28
April	3,960	2,170	2,978	177,191	·74	·66
May	5,980	3,960	5,199	319,738	1·33	1·60
June	5,980	2,300	4,074	245,000	1·02	·91
July	2,170	1,200	1,582	97,293	·40	·35
August	1,200	880	1,000	61,500	·26	·22
September	880	780	843	50,150	·21	·19
October	880	780	854	52,500	·22	·19
November	880	780	783	46,600	·19	·17
December	780	690	748	46,000	·19	·17
1891.						
January	690	690	690	42,435	·18	·15
February	.....	.....	780	43,290	·18	·17
March	880	780	790	48,585	·20	·17
April	2,950	780	1,623	96,509	·40	·36
May	3,030	2,440	2,652	163,098	·68	·59
June	2,870	1,660	2,245	133,578	·56	·50

Bear River at Collinston, Utah.

[Drainage area, 6,000 square miles.]

1889.						
June	.....	.....	*800	47,600	·15	·13
July 24 to 31	385	340	362	22,263	·07	·06
August	450	385	417	25,645	·08	·07
September	610	450	509	30,285	·09	·08
October	825	610	728	44,772	·14	·12
November	1,000	780	848	50,456	·16	·14
December	1,925	955	1,395	85,792	·27	·23
1890.						
January	.....	.....	*1,500	92,250	·29	·25
February	.....	.....	*1,000	55,500	·17	·17
March 2 to 31	4,850	1,100	3,188	196,062	·61	·53
April	6,680	3,600	4,953	294,703	·92	·83
May	8,220	6,890	7,924	487,326	1·52	1·32
June	7,940	4,440	6,234	270,923	1·16	1·04
July	4,230	2,060	3,250	199,875	·62	·54
August	2,060	1,545	1,754	107,871	·34	·29
September	1,425	1,310	1,344	80,050	·25	·22
October	1,665	1,365	1,544	95,000	·30	·26
November	1,425	1,365	1,403	83,500	·26	·23
December	1,545	1,000	1,243	76,500	·24	·20
1891.						
January	.....	.....	1,000	61,500	·19	·17
February	2,200	825	1,308	72,594	·22	·22
March	2,340	1,425	1,766	108,710	·34	·29
April 1 to 11	5,000	1,665	2,729	162,375	·51	·45
May	5,000	4,020	4,569	280,993	·88	·76
June	4,720	2,480	3,595	213,902	·67	·60

Estimate.

Ogden River at Powder Mills, Utah.

[Drainage area, 360 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
August 9 to 31	60	40	50	3,075	·16	·14
September	70	50	52	3,094	·16	·14
October	145	70	89	5,473	·28	·24
November	253	60	105	6,247	·33	·29
December	735	145	421	25,891	1·35	1·17
1890.						
January	510	289	382	23,493	1·22	1·06
February	1,364	399	680	37,740	1·97	1·89
March	1,401	362	978	60,147	3·13	2·72
April	1,919	1,068	1,449	86,215	4·49	4·02
May	2,178	1,475	1,818	111,807	5·82	5·05
June	1,438	624	910	54,145	2·82	2·53
July	624	326	458	28,167	1·47	1·27
August	473	215	312	19,188	1·00	·86
September	235	195	206	12,260	·64	·57
October	326	215	265	16,290	·85	·74
November	267	235	255	15,180	·79	·71
December	.....	.....	*240	14,760	·77	·67

* Estimate.

Weber River in canyon above Uinta, Utah.

[Drainage area, 1,600 square miles.]

1889.						
October 13–31	290	130	181	11,131	·13	·11
November	290	160	208	12,376	·14	·12
December	815	200	430	26,445	·31	·27
1890.						
January	815	290	457	28,105	·33	·29
February	1,400	200	547	30,358	·36	·34
March	2,130	200	1,091	67,096	·79	·68
April	4,280	970	2,184	129,948	1·52	1·36
May	5,465	3,470	4,528	278,472	3·26	2·83
June	3,635	1,220	2,017	120,011	1·41	1·27
July	1,220	290	549	33,763	·40	·34
August	450	200	280	17,220	·20	·18
September	290	240	265	15,750	·18	·17
October	450	200	331	19,850	·22	·21
November	340	290	298	17,720	·21	·19
December	340	240	290	17,830	·21	·18
1891.						
January	450	290	303	18,634	·23	·19
February	1,220	290	461	25,586	·30	·29
March	1,220	450	625	38,437	·45	·39
April	2,420	520	1,502	89,369	1·05	·94
May	4,655	1,940	2,752	169,250	1·98	1·72
June	2,225	1,135	1,621	96,449	1·13	1·01

Provo River above Provo, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
July 27–31	150	149	150	9,225	·27	·23
August	149	144	145	8,917	·26	·23
September	174	144	150	8,925	·26	·23
October	200	174	180	11,070	·32	·28
November	280	200	224	13,328	·39	·35
December	630	240	384	23,616	·69	·60
1890.						
January	700	200	305	18,751	·55	·48
February	564	280	377	20,923	·61	·59
March	700	240	519	31,990	·94	·81
April	1,240	500	840	49,980	1·46	1·32
May	2,180	1,316	1,926	118,450	3·47	3·01
June	2,260	440	1,184	70,448	2·06	1·85
July	440	280	314	19,311	·56	·49
August	280	240	252	15,498	·45	·39
September	280	240	244	14,520	·43	·38
October	330	280	304	18,700	·55	·48
November	330	280	303	18,020	·53	·47
December	330	240	293	18,020	·53	·46
1891.						
January	280	240	255	15,682	·46	·40
February	500	280	311	17,240	·50	·48
March	1,316	280	492	30,258	·89	·77
April	930	280	478	28,430	·83	·75
May	1,704	851	1,226	75,399	2·21	1·92
June	1,470	851	1,190	70,805	2·07	1·86

Spanish Fork in canyon, Utah.

[Drainage area, 670 square miles.]

1889.						
September	70	45	50	2,975	·08	·07
October	70	50	62	3,813	·11	·09
November	70	45	63	3,153	·09	·08
December	70	50	67	4,120	·12	·10
1890.						
January	230	50	68	4,182	·12	·10
February	95	50	76	4,218	·12	·11
March	355	50	143	8,794	·25	·21
April	770	150	387	23,026	·64	·58
May	1,040	355	777	47,785	1·34	1·15
June	355	110	205	12,197	·34	·31
July	590	82	114	7,011	·20	·17
August	82	50	64	3,837	·11	·10
September	95	50	63	3,750	·10	·09
October	95	50	64	3,938	·11	·10
November	50	50	50	2,975	·08	·07
December	50	50	50	3,075	·09	·07

Sevier River at Leamington, Utah.

[Drainage area, 5,595 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
August 23 to 31	60	40	48	2,952	·01	·008
September	80	48	53	3,153	·01	·009
October	160	48	111	6,826	·02	·019
November	444	210	274	16,303	·05	·049
December	526	280	395	24,292	·08	·071
1890.						
January	1,058	280	625	38,437	·13	·11
February	1,140	567	713	39,571	·13	·13
March	690	567	630	38,745	·13	·11
April	976	608	726	43,197	·14	·13
May	2,329	976	1,705	104,857	·35	·31
June	2,206	649	1,250	74,375	·25	·22
July	649	185	346	21,279	·07	·06
August	185	150	153	9,409	·03	·03
September	185	150	157	8,345	·03	·03
October	362	185	310	19,050	·06	·06
November	403	321	373	22,100	·07	·07
December	649	403	509	31,320	1·05	·09
1891.						
January	772	649	735	45,202	·15	·13
February	772	772	772	42,846	·14	·14
March	772	526	618	38,007	·13	·11
April	608	526	503	29,928	·10	·09
May	1,386	608	1,114	68,511	·23	·20
June	1,140	567	952	56,644	·19	·17

Henry Fork in canyon, Idaho.

[Drainage area, 931 square miles.]

1890.						
January	.....	.....	*1,200	738,000	1·49	1·29
February	.....	.....	*1,250	69,375	1·40	1·35
March	.....	.....	*1,300	79,950	1·61	1·40
April 6 to 30	4,920	1,120	1,875	111,562	2·25	2·01
May	7,710	2,750	4,580	281,670	5·67	4·92
June	2,890	1,860	2,270	135,065	2·72	2·44
July	1,860	1,450	1,550	95,325	1·92	1·66
August	1,450	1,450	1,450	89,175	1·80	1·56
September	1,450	1,280	1,314	78,183	1·57	1·41
October	1,280	1,280	1,280	78,720	1·59	1·38
November	1,280	1,280	1,280	76,150	1·55	1·37
December	1,280	1,280	1,280	78,720	1·59	1·38
1891.						
January	1,280	1,280	1,280	78,720	1·59	1·38
February	1,280	1,280	1,280	71,040	1·43	1·38
March	1,280	1,280	1,280	78,720	1·59	1·38
April	2,600	1,280	1,516	90,505	1·83	1·63
May	3,180	1,640	2,184	134,316	2·71	2·33
June	2,215	1,450	1,801	107,160	2·16	1·94

*Estimate.

Falls River in canyon, Idaho.

[Drainage area, 594 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
April 25 to 30	2,480	1,250	1,730	102,935	3·25	2·92
May	4,440	2,630	3,342	205,533	6·49	5·63
June	4,050	2,030	2,706	161,007	5·08	4·56
July	2,630	1,030	1,669	102,643	3·20	2·81
August	1,140	840	971	59,717	1·82	1·63
September	930	660	774	46,000	1·45	1·30
October	750	570	660	39,950	1·26	1·09
November	570	480	541	30,360	·95	·86
December	480	480	520	29,520	·93	·81
1891.						
January	590	450	509	31,304	·99	·86
February	.....	.....	*450	24,975	·79	·76
March	.....	.....	*450	27,675	·87	·76
April	1,140	450	606	36,057	1·14	1·02
May	2,790	1,030	1,765	108,547	3·43	2·98
June	2,180	1,370	1,681	100,019	3·17	2·85

* Estimate.

Teton River at Chase's ranch, Idaho.

[Drainage area, 967 square miles.]

1890.						
April 5 to 30	1,295	545	740	44,030	·85	·77
May	4,445	1,545	2,730	167,895	3·26	2·82
June	4,065	1,925	2,812	167,314	3·26	2·91
July	2,950	935	2,130	130,995	2·54	2·20
August	935	510	678	41,700	·81	·70
September	510	450	462	27,500	·53	·48
October	510	450	475	29,200	·57	·49
November	450	450	450	26,700	·52	·46
December	510	450	459	28,200	·55	·47
1891.						
January	.....	.....	*400	24,600	·48	·41
February 17 to 28	475	450	465	22,807	·56	·47
March	450	450	450	27,675	·54	·47
April	935	450	630	37,485	·72	·65
May	2,360	720	1,402	86,223	1·66	1·45
June	2,360	1,295	1,661	98,829	1·91	1·72

* Estimate.

Snake River at Eagle Rock or Idaho Falls, Idaho.

[Drainage area, 10,100 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1889.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
July	8,646	3,174	5,184	318,816	·59	·51
August	3,130	2,286	2,594	159,654	·30	·26
September	2,508	2,286	2,300	136,850	·25	·23
October	2,730	2,286	2,425	149,137	·28	·24
November	2,952	2,508	2,737	162,851	·30	·27
December	2,730	2,508	2,601	159,961	·30	·26
1890.						
January	.....	.....	*2,000	123,000	·23	·20
February	.....	.....	*2,000	111,000	·21	·20
March	.....	.....	*2,000	123,000	·23	·20
April	15,000	2,900	5,702	339,269	·63	·57
May	49,350	16,900	35,606	2,189,769	4·06	3·52
June	50,450	24,930	34,870	2,074,765	3·85	3·45
July	28,800	10,700	19,970	1,228,155	2·28	1·98
August	10,350	6,250	7,875	484,312	·90	·79
September	5,950	4,350	4,934	293,800	·54	·48
October	4,600	4,350	4,552	280,000	·52	·45
November	4,350	3,900	4,207	250,000	·47	·42
December	.....	.....	3,900	239,850	·45	·39

* Estimate.

Owyhee River at Rigsbys, Oregon.

[Drainage area, 9,875 square miles.]

1890.						
March 26 to 31	7,350	5,190	6,140	377,610	·72	·62
April	8,225	5,395	6,558	390,201	·74	·66
May	11,230	3,010	5,913	363,649	·69	·60
June	2,850	620	1,403	83,478	·16	·14
July	560	200	343	21,094	·04	·03
August	200	170	179	11,108	·02	·02
September	170	170	170	10,115	·02	·02
October	170	170	170	10,455	·02	·02
November	280	221	221	13,150	·02	·02
December	360	280	309	19,004	·04	·03
1891.						
January	400	360	320	22,140	·04	·04
February	3,265	450	932	51,726	·10	·09
March	4,335	2,600	3,313	203,649	·39	·34
April	10,000	2,900	4,984	296,548	·56	·51
May	4,600	2,075	3,114	191,511	·36	·31
June	2,150	500	1,267	75,386	·14	·13

Malheur River at Vale, Oregon.

[Drainage area, 9,900 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Max.	Min.	Mean.		Depth.	Per sq. m.
1890.	*Second-ft.*	*Second-ft.*	*Second-ft.*	*Acre-ft.*	*Inches.*	*Second-ft.*
March 20 to 31	4,445	1,840	2,912	179,088	·34	·29
April	3,450	2,180	2,770	164,815	·31	·28
May	2,890	590	1,627	100,060	.19	·16
June	520	120	254	15,113	·03	·02
July	90	25	43	2,644	·005	·004
August	25	15	17	1,011	·002	·002
September	15	15	15	893	·002	·001
October	62	15	44	2,705	·005	·004
November	150	70	118	7,010	·013	·012
December	115	62	83	5,105	·009	·008
1891.						
January	115	70	88	5,412	·01	·009
February	2,820	80	319	17,704	·03	·03
March	1,460	260	703	43,234	·08	·07
April	665	325	511	30,404	·06	·05
May	325	115	217	13,345	·03	·02
June	185	45	78	4,641	·01	·01

Weiser River in canyon, Idaho.

[Drainage area, 1,670 square miles.]

1890.						
March 13 to 31	11,220	1,550	5,773	355,039	3·99	3·45
April	7,060	2,470	4,792	285,124	3·20	2·87
May	7,060	2,610	4,882	300,243	3·37	2·92
June	2,470	1,280	1,792	106,624	1·20	1·07
July	1,130	220	590	36,285	·41	·35
August	190	100	138	8,487	·09	·08
September	140	80	103	6,135	·07	·06
October	190	140	166	10,200	·11	·10
November	400	160	222	13,200	·15	.13
December	480	280	396	24,350	·28	·24
1891.						
January	320	190	292	17,958	·20	·17
February	1,860	320	678	37,629	·42	·41
March	9,300	1,010	2,855	175,582	1·97	1·71
April	2,220	1,260	1,777	105,731	1·26	1·06
May	1,640	1,010	1,331	81,856	·93	·80
June	1,010	500	703	41,828	·47	·42

MONTHLY PERCENTAGES OF RUN-OFF.

The following table, giving the relative discharges of various streams during each month of the year, has been prepared for the purpose of aiding in approximations of discharge when but one or two measurements are available. The table shows the percentage of the average discharge for one month to the total for the year, and from these figures, based on actual measurements, certain inferences may be drawn. The years have been arbitrarily selected, the period being governed largely by the time at which gaugings were begun, and during which they were carried on. For example, in the first instance in the year from August 1, 1889, to July 31, 1890, the discharge during June was 27·4 per cent of the total discharge of the year, but taking the time from January 1, 1890, to December 31, 1890, the discharge for

June was 25·3 per cent for the year. In other words, it may be said that the June discharge was 25 to 30 per cent of the total for the year. One inference to be drawn from this instance is that rivers of this class discharge during the month of June a quarter or more of the amount for the whole year. This single instance suffices to explain the tables and their possible use.

In these tables the first column gives the name of the river upon which the measurements were made, the second column the locality of the gauging station, and the third column the year selected for the computation of percentages. The fourth column gives the mean discharge for this year in second-feet, while the succeeding twelve columns give the percentages of discharge for each month. The mean discharge, given in the fourth column, is of course 8·33 per cent, relative to the basis on which the monthly percentages are calculated.

Monthly percentages of run-off.

River.	Locality.	Time.	Monthly mean.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
			Second-ft.												
West Gallatin	Bozeman, Mont	Aug., 1889, to July, 1890	804	3·3	3·3	3·3	4·9	21·8	27·4	14·5	4·4	4·6	4·3	4·1	4·1
Do	do	Jan., 1890, to Dec., 1890	871	3·1	3·1	3·1	4·4	20·0	25·3	13·2	7·2	5·8	5·7	4·8	4·3
Madison	Red Bluff, Mont	do	2,068	4·9	4·9	4·9	6·5	19·4	20·0	10·1	6·2	5·9	6·0	5·6	5·6
Do	do	July, 1890, to June, 1891	1,967	6·0	6·1	6·9	7·5	14·4	17·7	10·6	6·5	6·2	6·3	5·9	5·9
Missouri	Craig, Mont	Jan., 1890, to Dec., 1890	4,307	5·8	5·8	5·8	9·1	20·2	19·5	9·7	4·3	4·3	4·6	5·5	5·4
Do	do	July, 1890, to June, 1891	4,699	5·3	6·2	7·1	10·2	16·0	24·2	8·9	3·9	4·0	4·2	5·1	4·9
Sun	Augusta, Mont	Aug., 1889, to July, 1890	666	2·2	2·2	2·2	4·5	35·1	29·3	12·0	2·7	2·7	2·5	2·4	2·2
Do	do	Jan., 1890, to Dec., 1890	715	2·0	2·0	2·0	4·3	32·8	27·3	11·2	4·3	3·5	3·7	3·8	3·1
Yellowstone	Horr, Mont	Aug., 1889, to July, 1890	2,808	1·6	1·6	1·7	4·3	22·4	29·8	22·8	4·9	3·8	2·9	2·3	1·9
Do	do	Jan., 1890, to Dec., 1890	3,178	1·4	1·4	1·5	3·7	19·6	26·4	20·2	11·5	6·1	3·9	2·6	1·7
Do	do	July, 1890, to June, 1891	2,663	0·1	0·4	1·2	3·4	16·4	23·8	24·2	13·8	7·1	4·6	3·0	2·0
Cache la Poudre	Fort Collins, Colo	Jan., 1889, to Dec., 1889	283	4·5	3·1	1·4	3·3	19·1	39·5	15·2	5·5	2·0	2·0	2·6	1·8
Do	do	Dec., 1889, to Nov., 1890	334	2·0	2·0	2·1	5·0	26·1	31·9	16·1	7·1	2·6	2·0	1·5	1·6
Arkansas	Canyon City, Colo	Jan., 1888, to Dec., 1888	859	3·9	4·8	5·8	9·7	14·0	20·3	13·1	9·0	5·9	4·8	4·8	3·9
Do	do	Jan., 1889, to Dec., 1889	433	5·8	5·8	5·8	5·8	11·6	26·4	11·6	6·5	4·2	4·3	5·7	6·5
Do	do	Jan., 1890, to Dec., 1890	874	2·9	3·5	3·0	4·5	20·0	24·9	15·0	6·4	4·9	5·1	5·0	4·8
Do	do	July, 1890, to June, 1891	997	3·6	4·0	4·9	7·2	16·8	27·5	13·1	5·6	4·3	4·4	4·4	4·2
Do	Pueblo, Colo	Jan., 1886, to Dec., 1886	1,441	2·3	2·9	3·5	4·6	17·6	32·2	10·0	8·6	7·9	4·6	3·5	2·3
Do	do	Jan., 1887, to Dec., 1887	1,323	2·5	2·5	3·2	3·8	15·8	21·9	21·1	10·8	7·1	5·0	3·8	2·5
Rio Grande	Del Norte, Colo	Oct., 1889, to Sept., 1890	1,189	3·9	5·6	3·4	6·4	30·3	26·6	10·6	4·3	2·7	2·0	2·2	2·0
Do	do	Jan., 1890, to Dec., 1890	1,242	3·7	5·3	3·3	6·1	29·0	25·5	10·2	4·1	2·6	3·2	3·2	3·8
Do	do	July, 1890, to June, 1891	1,369	6·0	7·9	7·8	8·6	20·0	25·3	9·2	3·7	2·3	2·9	2·9	3·4
Do	Embudo, N. Mex	Jan., 1889, to Dec., 1889	1,032	3·5	3·8	6·3	18·3	27·7	23·6	3·8	1·6	1·7	2·3	3·0	4·4
Do	do	Jan., 1890, to Dec., 1890	1,466	2·5	3·1	3·9	11·8	28·2	23·3	9·1	4·6	3·1	3·2	3·5	3·7
Do	do	July, 1890, to June, 1891	1,689	2·9	3·0	4·5	11·7	29·4	24·9	7·9	4·0	2·7	2·8	3·0	3·2
Do	El Paso, Tex	May, 1889, to Apr., 1890	755	2·1	3·1	4·6	24·0	34·0	28·8	2·6	·0	·0	·0	·0	0·8
Do	do	Jan., 1890, to Dec., 1890	1,327	1·2	1·8	2·7	13·7	36·2	27·7	5·4	4·6	1·1	0·4	1·8	3·4
Do	do	July, 1890, to June, 1891	2,384	1·6	2·8	6·5	14·9	41·4	23·5	3·0	2·6	0·6	0·2	1·0	1·9
Gila	Buttes, Ariz	Sept., 1889, to Aug., 1890	503	11·3	9·7	6·4	3·9	1·4	0·5	2·2	51·9	2·1	2·6	3·5	4·5
Salt	Arizona Dam	Aug., 1888, to July, 1889	2,654	18·7	8·2	27·4	12·4	3·4	1·5	1·6	1·1	1·1	1·0	2·6	21·0
Do	do	Jan., 1889, to Dec., 1889	2,576	19·3	8·4	28·3	12·8	3·4	1·5	1·6	1·3	1·7	1·4	1·9	18·4
Do	do	June, 1889, to May, 1890	2,738	15·1	30·7	19·6	5·6	2·8	1·4	1·5	1·3	1·6	1·3	1·8	17·3
East Carson	Rodenbah, Nevada	Apr., 1890, to Mar., 1891	969	3·3	3·5	6·7	8·8	22·8	20·9	15·4	5·1	3·6	3·3	3·3	3·3
West Carson	Woodford, Nevada	Apr., 1890, to Mar., 1891	206	2·1	1·9	2·5	11·5	26·6	24·8	15·3	5·5	3·0	2·7	2·0	2·1
Bear	Battle Creek, Idaho	Oct., 1889, to Sept., 1890	1,670	4·4	4·0	6·4	14·8	26·0	20·3	7·9	5·0	4·2	1·8	2·4	2·8
Do	do	Jan., 1890, to Dec., 1890	1,751	4·2	3·8	6·0	14·2	24·7	19·4	7·5	4·8	4·0	4·1	3·7	3·6
Do	do	July, 1890, to June, 1891	1,216	4·7	5·4	5·4	11·1	18·1	15·4	10·8	6·9	5·8	5·9	5·4	5·1
Do	Collinston, Utah	June, 1889, to May, 1890	1,969	6·4	4·2	13·5	21·0	33·5	3·4	1·5	1·8	2·1	3·1	3·6	5·9
Do	do	Jan., 1890, to Dec., 1890	2,945	4·2	2·8	9·0	13·8	22·5	17·8	9·2	5·0	3·8	4·4	4·0	3·5
Do	do	Apr., 1890, to Mar., 1891	2,810	3·0	3·9	5·2	14·7	23·5	18·4	9·6	5·2	4·0	4·6	4·2	3·7
Ogden	Canyon, Utah	Aug., 1889, to July, 1890	616	5·2	9·2	13·2	19·6	24·6	12·3	6·2	0·7	0·7	1·2	1·4	5·7
Do	do	Jan., 1890, to Dec., 1890	663	4·8	8·6	12·3	18·2	22·9	11·4	5·8	3·9	2·6	3·3	3·2	3·0
Weber	do	Jan., 1890, to Dec., 1890	1,070	3·6	4·1	8·5	17·0	35·3	15·7	4·3	2·2	2·1	2·6	2·3	2·3
Do	do	July, 1890, to June, 1891	773	3·3	5·0	6·7	16·2	29·7	17·4	5·9	3·0	2·9	3·6	3·2	3·1

American Fork	Bridge, Utah	Aug., 1889, to July, 1890	149	3·6	4·1	6·7	21·7	38·2	11·8	2·6	2·2	1·7	1·9	1·7	3·8
Provo	Canyon, Utah	July, 1889, to June, 1890	532	4·8	5·9	8·1	13·1	30·2	18·5	2·4	2·3	2·4	2·8	3·5	6·0
Do	do	Jan., 1890, to Dec., 1890	572	4·4	5·5	7·6	12·2	28·1	17·3	4·6	3·7	3·5	4·4	4·4	4·3
Do	do	July, 1890, to June, 1891	472	4·5	5·5	8·7	8·5	21·6	21·0	5·5	4·4	4·3	5·4	5·4	5·2
Spanish Fork	do	Sept., 1889, to Aug., 1890	172	3·3	3·7	6·9	18·8	37·6	9·9	5·5	3·1	2·4	3·0	2·6	3·2
Do	do	Jan., 1890, to Dec., 1890	172	3·3	3·7	6·9	18·9	37·7	9·9	5·5	3·1	3·1	3·1	2·4	2·4
Sevier	Leamington, Utah	Aug., 1889, to July, 1890	573	9·1	10·4	9·2	10·5	24·8	18·2	5·0	0·7	0·8	1·6	4·0	5·7
Do	do	Jan., 1890, to Dec., 1890	625	8·3	9·5	8·4	9·7	22·8	16·7	4·6	2·0	2·1	4·1	5·0	6·8
Do	do	July, 1890, to June, 1891	545	11·2	11·8	9·5	7·7	17·1	14·5	5·3	2·3	2·4	4·7	5·7	7·8
Henry Fork	Canyon, Idaho	Jan., 1890, to Dec., 1890	1,719	5·8	6·1	6·3	9·1	22·2	11·0	7·5	7·0	6·4	6·2	6·2	6·2
Do	do	July, 1890, to June, 1891	1,458	7·3	7·3	7·3	8·7	12·5	10·3	8·9	8·3	7·5	7·3	7·3	7·3
Falls	do	Apr., 1890, to Mar., 1891	1,194	3·6	3·1	3·1	12·1	23·4	18·9	11·6	6·8	5·4	4·6	3·8	3·6
Teton	Chase's ranch, Idaho	Apr., 1890, to Mar., 1891	1,021	3·3	3·8	3·7	6·0	22·3	22·9	17·4	5·5	3·8	3·9	3·7	3·7
Snake	Idaho Falls, Idaho	July, 1889, to June, 1890	8,335	2·0	2·0	2·0	5·7	35·6	34·9	5·2	2·6	2·3	2·4	2·7	2·6
Do	do	Jan., 1890, to Dec., 1890	10,635	1·6	1·6	1·6	4·5	28·0	27·3	15·5	6·2	3·9	3·5	3·2	3·1
Owyhee	Rigsbys, Oregon	Apr., 1890, to Mar., 1891	1,656	1·8	4·7	16·7	33·0	29·7	7·1	1·7	0·9	0·9	0·9	1·1	1·5
Malheur	Vale, Oregon	Mar., 1890, to Feb., 1891	698	1·0	4·8	34·8	33·1	19·5	3·0	0·5	0·2	0·2	0·5	1·4	1·0
Weiser	Weiser, Idaho	Mar., 1890, to Feb., 1891	1,652	1·5	3·4	29·1	24·2	24·6	9·1	3·0	0·7	0·5	0·8	1·1	2·0

IRRIGATION IN INDIA.

BY

HERBERT M. WILSON, C. E.

CONTENTS.

	Page.
Preface	369
Author's list	371
Introduction	375
CHAPTER I.—Finance and statistics	390
Value and necessity of irrigation	390
Land and crops	395
CHAPTER II.—Topography, meteorology, and forestry	399
Topography and geology	399
Meteorology	403
Forestry	404
CHAPTER III.—History and administration	406
History of irrigation works	406
Administration and legislation	407
CHAPTER IV.—Wells and inundation canals	415
Classes of works	415
Extent of irrigation	416
Financial and agricultural results	417
Objections to irrigation	419
Wells	423
Inundation canals	425
CHAPTER V.—Deltaic and perennial canals	428
Source of supply	428
Water duty and evaporation	428
Deltaic canals	435
Perennial canals	438
Ganges canal	439
Lower Ganges canal	443
Agra canal	445
Sirhind canal	447
Bari Doab and Western Jumna canals	450
Sidhnai canal	451
Soane canals	452
Cross section, slope, and alignment	455
Headworks	458
Weirs	460
Scouring sluices	467
Canal regulators	473
Well foundations	477
Escapes	479
Falls and rapids	481
Drainage works	484
Distributaries	490
Methods of applying water	495

	Page.
CHAPTER VI.—Storage works	498
Classes of works	498
Reservoirs	503
Mutha project	504
Nira project	506
Betwa project	515
Periar project	520
Tansa reservoir	525
Masonry dams	527
Materials, labor, and cost	530
Tanks	536
Ekruk tank	544
Ashti tank	545
Tank dams	550
Combined storage and canal systems	553
Palar anicut system	554
Zhara Karez irrigation scheme	556
River conservancy	557
Land reclamation	561

ILLUSTRATIONS

Pl.			Page.
	CVII.	Folding map of India	In pocket.
	CVIII.	Aden Tanks, Arabia	388
	CIX.	Persian wheel and paecottah	424
	CX.	Single mot	426
	CXI.	Gopalpur bifurcation, Ganges Canal	442
	CXII.	Sirhind Canal system	448
	CXIII.	Soane Canal system, Bengal	452
	CXIV.	Cross sections of modern weirs	462
	CXV.	Plan of headworks, Soane Canals	464
	CXVI.	Sidhnai Canal, section of river in line of dam	466
	CXVII.	Headworks and river training works, Ganges Canal	468
	CXVIII.	Narora Weir, Lower Ganges Canal, plan of well foundations	470
	CXIX.	Narora Weir, Lower Ganges Canal, plan of superstructure	472
	CXX.	Narora Weir, Lower Ganges Canal, detail of canal sluices	474
	CXXI.	Soane Canal, automatic sluice gate	476
	CXXII.	Headworks, Lower Ganges Canal, Narora	478
	CXXIII.	Sinking foundation wells, Nadrai Aqueduct, Lower Ganges Canal	480
	CXXIV.	Asafnagar Falls, Ganges Canal	482
	CXXV.	Rapids, Bari Doab Canal	484
	CXXVI.	Agra Canal, cross-section of Kushuk Fall	486
	CXXVII.	Solani Aqueduct, Ganges Canal	488
	CXXVIII.	Nadrai Aqueduct, lower Ganges Canal	490
	CXXIX.	Ranipur superpassage, Ganges Canal	492
	CXXX.	Sasoon superpassage, Sirhind Canal	494
	CXXXI.	Rutmoo level crossing, Ganges Canal	496
	CXXXII.	Drainage map, showing arrangement of distributaries	498
	CXXXIII.	Standard masonry outlet for distributaries, Punjab	500
	CXXXIV.	Plan of Mutha and Nira irrigation projects, Bombay	504
	CXXXV.	Plan and cross-section of Bhatgur Dam, Nira system, Bombay	506
	CXXXVI.	Bhatgur Dam, Nira system, Bombay	508
	CXXXVII.	Main and subsidiary weirs, Nira system, Vir, in great flood	512
	CXXXVIII.	Betwa project, plan of dam and headworks	516
	CXXXIX.	Betwa project, plan of regulator and scouring sluices	518
	CXL.	The Periar project, Madras	520
	CXLI.	Periar headworks, plan of dam and escape	522
	CXLII.	Natives building Tansa Dam, Bombay	526
	CXLIII.	Ekruk tank	544
	CXLIV.	Palar Anicut system, plan and cross-section	554
	CXLV.	Zhara Karez irrigation project, Beluchistan	556
	CXLVI.	Training works, Agra Canal, Okhla	560

Page.

FIG. 230. Paecottah 423
231. Mot 424
232. Persian wheel 425
233. Percolation and evaporation 431
234. Plan and profile, Ganges Canal, Hardwar to Roorkee 441
235. Thora Nulla Aqueduct, Soane Canal 453
236. Canal cross-sections 456
237. Three ancient weirs 460
238. Shutter on Soane Weir 465
239. Sidhnai Weir 466
240. Myapur Dam, Ganges Canal 468
241. Dropping the Soane automatic sluices 471
242. Details of Sidhnai Weir 472
243. Regulating gates, Ganges and Jumna canals 474
243*a*. Headworks, Ganges Canal 475
244. Regulating gates, Soane Canal head 476
245. Ogee and vertical falls, Ganges Canal 481
246. Soane canals, Bengal. Arrangement of branches and escape at Dunwar 483
247. Cross-section of Solani Aqueduct, Ganges Canal 485
248. Plan of Rutmoo Crossing, Ganges Canal 489
249. Kao Nulla siphon aqueduct, Soane Canal 490
250. Plan of distributing head, Mutha Canal, Bombay 494
251. Reinolds automatic weir gate 509
252. Vir headworks, Nira system, Bombay 510
253. Plan of headworks, Nira Canal, Vir 511
254. Plan of regulator head, Nira Canal 512
255. Kurra Aqueduct, Nira Canal 513
256. Nira Canal, Siphon superpassage, Jewhar Nulla 514
257. Cross section, Betwa Dam 518
258. Periar Dam and escape weir 522
259. Tansa Dam, Bombay 525
260. Tansa project, longitudinal section of dam 526
261. Foundation, Tansa Dam 526
262. Mixing mortar with churus 528
263. Carrying stones to build Tansa Dam 532
264. Profile of masonry dam, Molesworth's formula 534
265. Cross sections, earth and combined dams 538
266. Map showing Ashti Tank 546
267. Ashti Tank dam 547
268. Ashti Dam slips 553
269. Palar Anicut system 554
270. Training works, Lower Ganges Canal, Narora 559

PREFACE.

In the following account of some of the more interesting and prominent irrigation works in India I shall confine my detailed descriptions, as I did my observations, to the works which exist under conditions similar to those in the United States, and shall refer only briefly to the other though equally important features of the irrigation problem in India.

I examined only the principal canals, navigable and nonnavigable, and entirely neglected the deltaic and inundation canals, as there is little or no probability that such works will ever be constructed in the United States. Transportation by railways and wagon roads is so easy and general all over our country that there is little likelihood our canals will ever be made navigable; accordingly, though I saw and examined several navigable canals, little reference will be made to their features. The more important reservoirs and tanks were examined, especially those under construction. Little will be said of wells, though in the future improved methods of pumping will be used in the United States.

India stands preeminent for her gigantic engineering undertakings. No other country has so vast and so fertile an expanse of territory, with such convenient slopes for the construction of canals, and at the same time such an abundant water supply. In general there is great similarity between the climate and topography of the great northern plains of India and portions of our arid West, especially the eastern slope of the Rocky Mountains and the great California valley. Central India and the Deccan have many features in common with the central arid Territories, particularly portions of northern Arizona and southern Utah. The climate is as similar to that of our central Territories as is the topography. The average annual precipitation rarely exceeds 30 inches, while the precipitation during the autumn or rabi crop varies between 2 and 6 inches.

This autumn crop is the one that will be generally considered and discussed in this report, since during the time of its maturity the climatic conditions are very similar to those existing everywhere in the arid regions of the United States. Two crops are annually grown in India, one of which is sown in early spring at the beginning of the

monsoon or rainy season, and is called the summer or kharif crop. This crop depends little on irrigation for its maturing, as the greater proportion of the rain of the entire year falls during the summer. In the autumn, however, the rainfall is very light, and, as before stated, the temperature and precipitation are both similar to those in the West.

Though the conditions of government and people are so different in India from those in America, many useful examples and lessons may be drawn from the method of administration and legislation practiced there, as well as from the financial success or failure that has attended the construction of their works. The conditions under which Americans must undertake irrigation enterprises are not so different from those existing in India and southern Europe as would at first appear. Any works we may construct must depend for their utilization and revenue on immigration, as they will be largely undertaken in a sparsely inhabited country. In order to induce this immigration people must be convinced of the benefits and utility of irrigation. Conditions similar to these exist in portions of India where the most successful irrigation projects have been carried out. Irrigation works have frequently been undertaken in portions of India that were already over-populated. They have rendered the lands more fertile and sufficiently productive to support nearly double the population which it was previously capable of sustaining. This, too, has been accomplished despite the prejudices to be overcome, and the difficulties encountered in inducing people to make use of the water furnished; difficulties far greater than we would have to contend with in inducing immigration to our arid West. A few of the great canals of the Northwest Provinces and the Punjab were undertaken in districts that were sparsely inhabited. These canals are among those of India that have paid the largest interest on the original outlay. Within ten years from their construction the country was fully populated, although the immigration was often from remote portions of India.

Any imperfections which may appear in this account of works examined and in operation are in no way due to lack of assistance from the engineers in authority. It is impossible to speak strongly enough of the hospitality and kindness with which I was everywhere treated. In fact, owing to the limited time at my disposal, the greatest difficulty experienced was to leave the hospitable guides and entertainers, who were apparently willing to spend days in showing and explaining the works they had in charge.

LIST OF AUTHORS OF WORKS ON INDIAN IRRIGATION.

In the following list are arranged alphabetically by authors the titles of works which were referred to in the preparation of this report. This list does not pretend to be a complete list of works and pamphlets published on Indian irrigation:

Author.	Subject, etc.
Anderson, C. E.	Damage to Works of Agra Canal by Floods of September, 1875, to February, 1877. Allahabad, India, 1878.
Anderson, Col. J. C	Irrigation in Madras Presidency. Professional Papers, second series, No. 253. Roorkee, India.
Ashhurst, F. H.	Reconstruction of Bhin Tal Dam, Kumaon. Proceedings Institution Civil Engineers, vol. 75, pp. 232. London, 1884.
Bellais, E. S.	Inundation Canals in the Punjab. Proceedings Institution Civil Engineers, vol. 89, pp. 251. London, 1887.
Beresford, J. S	Proposed Standard Designs for Masonry Outlets. Nanai Tal, India, June, 1882.
	Duty of Water. Memoranda on Irrigation. Professional Papers, second series, No. 212. Roorkee, India.
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MAP OF INDIA

SCALE.
100 80 60 40 20 0 100 200 Miles.

LEGEND.

1. Bari Doab Canals.
2. Sirhind "
3. Western Jumna "
4. Eastern " "
5. Ganges "
6. Agra "
7. Lower Ganges "
8. Dun "
9. Betwa Canals.
10. Soane "
11. Midnapore "
12. Orissa "
13. Mutha System
14. Nira "
15. Ekruk Tank.
16. Ashti "

Irrigation Canals

AFGHANISTAN
BELUCHISTAN
RAJPUTANA
AGENCY
GUZERAT
CENTRAL PROVINCES
HYDERABAD
ASSIGNMENT
BUNDELKUND AGENCY
CHOTA NAGPORE
ORISSA
TRIBUTARY
MAHRATTA
STATES
MADRAS PRESIDENCY
ARABIAN SEA
BAY OF BENGAL
HIMALAYA Mts.
GREAT TIBET
LOWER BURMA
UPPER BURMA
Mouths of the Ganges

PESHAWUR
SRINAGAR
JAMOO
KASHMIR
LAHORE
AMRITSAR
SIMLA
QUETTA
MOOLTON
DOORKEE
DELHI
ALLYGURH
JEYSULMERE
JEYPORE
AJMERE
AGRA
LUCKNOW
KURRACHEE
Mt Abu
JHANSI
ALLAHABAD
PATNA
DARJEELING
Brahmaputra River
Ganges River
Sodre River
Indus River
Jhelum River
Chenab River
Ravi River
Sutlej River
Jumna River
Western Ghauts
Eastern Ghauts
Godavery River
Mahanadi River
Irrawaddy River
INDORE
BARODA
BOMBAY
POONA
NAGPUR
CUTTACK
CALCUTTA
HYDERABAD
MANDALAY
RANGOON
Vindhia Hills

66° 70° 74° 78° 82° 86° 90° 94° 98°
32° 28° 24° 20° 16°

WEST, MARVIN & BOWE LITH. PHILA.

IRRIGATION IN INDIA.

By Herbert M. Wilson.

INTRODUCTION.

The principal sources from which the information in the accompanying report was obtained were (1) conversation with engineers in charge of works and examination of their office material, (2) personal examination of the works themselves, and (3) books and official reports. In the following narrative I will endeavor to sketch hastily the route traveled and give a brief outline of works visited.

For a week before my departure I was busily engaged in reading all the books and reports on Indian irrigation procurable, in order to plan the trip so as to see the most in the least space of time, for I had but five months for the entire journey. I finally decided that the two months spent in India should be devoted to the northern and central portions, and the route was planned so as to see only such works as were within easy access of the railway lines.

Through the cooperation of the director of the U. S. Geological Survey I was enabled to leave Washington on December 1, 1889, well equipped with letters of introduction to the various secretaries of the public works departments of India, carrying also letters from the Secretary of State to our diplomatic and consular officers abroad. In New York letters of introduction to prominent English engineers were obtained from the secretary of the American Society of Civil Engineers and others, and on December 4 I sailed for Liverpool.

A few days were spent in London, where, through the courtesy of Mr. James Forrest, secretary of the Institution of Civil Engineers, a number of letters of introduction to Indian officials were obtained. From London I proceeded to Brindisi, Italy, and embarked December 30 for Bombay, arriving there on January 13, 1890.

In Bombay I called upon Mr. W. C. Hughes, secretary to government for the irrigation branch of the public works department, and he gave me letters to several of the engineers in the Bombay presidency, and kindly aided me in so arranging my tour in that presidency as to see only such works as were most accessible. From Mr. W. Clerke, chief engineer of the Bombay waterworks, I also received much valu-

able assistance and advice, and on January 18 I proceeded to Poona with the intention of visiting the Fife reservoir. In the absence of the chief engineer, Col. Cruikshank, R. E., Mr. Rebsch, executive engineer of the Mutha canals, devoted two or three days to showing me over the works under his charge.

We drove from Poona to Lake Fife, a distance of 12 miles up the valley of the Mutha River. The road here, as everywhere in India, was excellent, being well macadamized for the entire distance. On both sides were well cultivated fields, the principal crops grown being sugar cane, millet, and wheat, and the care with which the water was applied to these crops was the first object which attracted attention. I also observed that Indian peasants fully appreciated the value of fertilizers. The city officials of Poona make a handsome profit annually by removing excrement from the residences and mixing it with ordinary soil, the whole being sold by the cartload to farmers.

Lake Fife is a large artificial reservoir, formed by a dam three-quarters of a mile long and nearly 100 feet in height. The water is backed up the valley for nearly 15 miles, and the available storage capacity of the lake is about 63,000 acre-feet. The Mutha canals are taken from the dam at the lower end of the lake, one along the right, and the other on the left bank of the Mutha River. The right bank canal is nearly 100 miles long, and passes through the city of Poona, which it supplies with water; it is also used in irrigating the rich land lying between it and the river. The left-bank canal is much shorter, and also controls a large area of valuable land.

The topography of the Upper Mutha Valley seemed very familiar. Had I been suddenly transported in my sleep to northeastern Arizona the similarity of the topography of the two regions could not have more strikingly impressed me. At Lake Fife the Mutha River makes its exit through a narrow canyon similar to those of the mesa country in northern New Mexico and Arizona, and flows thence through a broad and gently sloping valley, which gradually widens till it becomes an extensive plain. The slope from the bottom of the stream toward the surrounding hills is regular, but rather steep, and suddenly terminates at the foot of cliffs which are similar in their abruptness and sharpness of outline to the mesa cliffs of our Southwest. The soil in the Mutha Valley is rather shallow, and wherever uncultivated is covered with a low, scrubby grass, dried and parched by the sun. At the canal edge the barren slopes are suddenly merged into endless green and well cultivated fields. The slopes of the hills are rocky and barren, covered with a growth of low trees, among which babul or mesquite is the most prominent.

After examining Lake Fife, Mr. Rebsch and myself proceeded down the line of the Mutha Canal, and followed some of the minor distributaries through the fields, watching their ramifications, until we reached the smallest private ditch used in irrigating the crops. The construc-

tion of these canals is similar to that found in the United States on small canals. The chief feature noticed was the substantial method of constructing all bridges, head gates, and other regulators. Here, as elsewhere in India, timber is seldom used, owing to its cost and the rapidity with which it is destroyed by insects and rot. All bridges on this canal are constructed of masonry, and the smallest regulating gates consist of masonry passages let into the banks of the canal and closed with iron shutters. The system of distribution of the water is very complete, every square foot of desirable land being under cultivation.

On January 21 I engaged a tonga, a sort of dogcart, drawn by a team of ponies, in which a three days' trip to Bhatgur reservoir and the Nira canals was made. The trip to Bhatgur was made in the night in order to avoid the heat. The road is macadamized the entire distance, and is lined on each side with a double row of trees, which furnish a dense and agreeable shade. The gradients are sufficiently easy for a railway, while all drainage passages, large or small, are crossed by masonry bridges. In order to avoid excessive grades a range of low hills about halfway in the journey is pierced by a tunnel nearly one-fourth of a mile long. This tunnel is about 20 by 20 feet in cross section, and is lined with masonry throughout.

At Bhatgur I was met by Mr. H. Beale, assistant engineer in charge of construction of the dam. During the day we went over the entire length of the dam and viewed all the works of construction. It was my good fortune to see the Bhatgur dam when it was about two-thirds completed and while the construction was being vigorously pushed. I was thus enabled to examine with care the details not only of the method of masonry construction, but also the management and character of the labor employed.

The topography above the Bhatgur dam is very similar to that at Lake Fife. The dam is constructed on a modern cross section, similar to those obtained by the Bouvier or Rankine formulæ. It is located in a rather wide part of the river, the object being to afford sufficient spillway for the large volume of water which comes down the river in the spring floods. Its length is 4,067 feet and its greatest height is 130 feet above the foundations. The river at this point is subject to maximum floods of 50,000 second-feet. This reservoir is used as a storage basin to supply the Nira canals, which are taken from the Nira River at Vir, a point 20 miles below the dam. During my visit to Bhatgur 1,500 laborers were employed on the work and completed about 5,000 cubic feet of rubble and concrete masonry per day and 1,000 cubic feet of finished dressed-rubble facing. Stone for the construction of the dam was quarried close to the abutments, and kunkar, a dirty lime which produces a very good hydraulic cement, was found within a short distance of the dam site. Sand was procured from the river bed and charcoal for burning was procured in the adjacent hills.

On the morning of the 22d I left Bhatgur, proceeding by tonga to

Vir, the head of the Nira Canal, where I was met by Mr. W. H. Le Quesne, executive engineer in charge of the Nira system. The next two days were spent in looking over the reports and detailed maps in the office, in examining the great diversion weir at the head of the Nira Canal, and in inspecting the first 12 miles of the latter. The Vir weir is constructed throughout of concrete, faced with dressed-rubble masonry, and is 2,340 feet in length and 40 feet in greatest height above the river bed. A few hundred yards downstream is a subsidiary weir, similar in construction to the first, but only 615 feet long and 20 feet in height. This lower weir backs the water up against the toe of the upper one, thus producing a water cushion, on which the great floods fall harmlessly. The maximum flood over this weir may be 160,000 second-feet, and this will bank up about 8 feet in depth over the crest of the main weir. Our trip down the canal was made in a row boat, and we were thus enabled to examine several aqueducts and a siphon on the way. The first 10 miles of the canal are for diversion line only, being required in making grade to get the canal out of the confining banks of the Nira River. At about the tenth mile the first distributary is taken off to the irrigable lands.

On January 23 I left Vir for Lonand, where I took the train for Poona. This trip is one of the most interesting in India, the road passing through the celebrated Bhore Ghauts, a range of rugged, bluffy hills which break down precipitately to the western ocean. The summit of these Ghauts forms the edge and top of the great interior plateau of the Deccan. The scenery along the entire descent is similar in every respect to that east of the line of the Oregon and California Railroad near Red Bluff. The road runs with heavy grades and sharp curves along the edges of nearly vertical trap cliffs, in a place that in almost any other country would be considered quite impracticable for railway construction. The expense of such a line in the United States would exceed $100,000 per mile. Owing to the very heavy rainfall, which averages 250 inches per annum, the greatest precautions have been taken for the passage of all drainage lines. Numerous viaducts are crossed in rapid succession, the frequency of their recurrence being rivaled only by that of the many tunnels, there being 33 of these in a few miles.

I had been very desirous of making a visit to the celebrated Tansa reservoir, near Bombay, in the company of Mr. Clerke, the chief engineer, and on arriving in Bombay, on the 24th, I found he had arranged a trip with the governor of Bombay, Lord Reay, a few of the municipal officers, the governor's staff, Mr. Baldwin Latham, and myself. We left by special train on the evening of the 24th, arriving at Atgoan on the following morning. From Atgoan we had a pleasant tonga trip of 7 miles to the site of the Tansa dam. Here I was as fortunate as at Bhatgur. I found the great dam more than half completed and construction being vigorously pushed. Two days were spent in inspecting the works, which

consist mainly of an enormous rubble-masonry dam 9,350 feet in length. When completed it will be 145 feet in maximum height. This dam is intended to furnish water for the city of Bombay. The rock for its construction is quarried at the dam site, but kunkar, for the production of cement, has to be brought long distances by rail or road cart. The aqueduct line, which carries the water to the city of Bombay, is partly in tunnel, partly in masonry conduit, partly in iron pipes. It has 7 inverted siphons crossing drainage valleys, the greatest being 11½ miles in length.

On January 28 I left Bombay for Calcutta, a distance of about 1,200 miles. This trip was full of interest. During the early part of the first day the Thule Ghauts were ascended, the difficulties of construction being quite equal to those on the line between Poona and Bombay. Railway travel in India, while inferior in comforts to the United States, is still decidedly superior to European modes of making lengthy trips. The cars, like those on European railways, are short, and on only a few are Bogie trucks used. These latter, however, are rapidly finding favor, and at no distant day will be universally employed on the Indian railways. Each compartment, of which there are two in every first and second class carriage, will hold from 5 to 6 persons. The seats are placed lengthwise of the train and are well cushioned. There is a hanging seat or bed suspended from the roof, similar to those seen in an Ameri. can immigrant car. This can be lowered at night and used as a berth. Each passenger must carry his own bedding, which in that warm climate consists of nothing more than a blanket and a pillow, and spreading these on the seats or hanging beds he can pass a comfortable night on the road. In the center of the car, between the two compartments, is a small closet and toilet room. A table may be set up in the center of each compartment on which to spread lunches. Men and women are never permitted to travel in the same compartment. Good meal stations are placed at convenient intervals on all lines of railway, and ample time is given for eating.

The main portion of central India between Bombay and the Gangeton plain is rather sparsely inhabited. The topography is mountainous, consisting of low, uneven, rolling country, similar to that along the southern New Jersey coast or in the wooded districts of Missouri and Indiana. A dense growth of jungle, consisting of low trees, mesquite, teak, etc., with an undergrowth of tall, stiff jungle grass from 5 to 10 feet in height, covers the entire country. The streams draining this region are, during the dry season, but little rills, flowing through very broad, wide, sandy beds, that serve to indicate the enormous size these rivers attain during the flood season. There is little irrigation practiced in this region. In some sections moderate areas are irrigated from tanks of various sizes. The sloping hillsides are terraced, like those of Japan and China, by the construction of embankments. These produce level benches, where the flood water is held back sufficiently long to enable it to soak into the ground On these benches small crops of rice, garden truck, and grains are cultivated.

The river Jumna is first crossed and the Gangetan plain entered at Allahabad, between which place and Calcutta the country is extremely level and fertile, having a strong resemblance to the broad, level prairies of the Mississippi Valley. Throughout this portion of the route fine fields of wheat, millet, barley, indigo, cotton, sugar cane, and poppy were passed in endless succession, while occasional groves of mangoes, cocoanut, and date palms relieve the prairie-like appearance of the country. The entire region is divided into innumerable small fields, each of a few acres, but no fences or houses were to be seen, though laborers dotted the fields. All live in villages, and from these they sometimes travel several miles to work.

I arrived in Calcutta on the morning of January 30, and called on Dr. W. King, the director of the Geological Survey of India, who gave me letters of introduction to some of the officials I was desirous of meeting. Mr. B. F. Bonham, American consul-general, treated me with the utmost courtesy and did everything in his power to aid me during my short stay. One day was spent at the office of the surveyor-general of India, Col. H. R. Thuillier, R. E., who kindly aided me in the examination of the methods of work of the topographic division and of the great trigonometric survey.

On the 31st I called on Col. J. M. McNeill, R. E., the secretary for government of the public works department of Bengal. With him I discussed the arrangement of my tour through his presidency, and from him I received letters of introduction to his various executive engineers. Col. McNiell kindly telegraphed to Mr. R. B. Buckley, superintending engineer of the Soane canals, to arrange a hasty trip over his territory, and on the following day I reached Arrah, where I called upon Mr. Buckley. That day was spent in examining the maps and office records of the Soane canals, and on the following morning I set out on a tour of inspection. Mr. Buckley kindly placed at my disposal his canal steamer *Kudra*, on which I lived for three days, and Mr. Buckley also telephoned over the canal lines, arranging for various engineers to meet and show me over points of interest.

I started early in the morning of February 2, and steamed up the canal against the current at the rate of about 8 miles per hour. Our rate of travel was rendered slow owing to the velocity of the stream and to the great number of locks which had to be passed. At Arrah the canal is 86 feet wide at bottom, about 9 feet deep, and discharges about 2,000 second-feet of water. From there to the headwaters at Dehree, a distance of 65 miles, the Arrah branch follows the general direction of the Soane River on its western side, gradually increasing in width toward the head, where it is 180 feet wide at bottom, 9 feet deep, and discharges about 4,300 second-feet.

At Nasregunge, a large village midway between Arrah and Dehree I was met by Mr. Inglis, the executive engineer of the Arrah Canal, who showed me over the heads of some of the distributaries, the es-

capes, and also the mode of applying the water to the fields. I reached Dehree at 8 o'clock on the following morning. During the absence of the executive engineer in charge of the head works at Dehree I was met by Mr. Williamson, the overseer of the shops at that point, who spent the day explaining the various works. These are of the most interesting and important nature, and consist of the great weir across the Soane River, $2\frac{3}{4}$ miles long and 14 feet in height, of the scouring sluices and regulators at the heads of the canals at each end, and of the general machine shops for the construction and repair of engines, dredges, and other metal works used on the canal system. The Soane River was then very low, scarcely discharging more water than was required to fill the main eastern and western canals. Thanks to this fact I was enabled to watch the operations of the automatic sluice-gates, which were lowered and raised for my inspection.

From Dehree we proceeded again by steamer down the Buxar branch of the main western canal, passing through immense fields of grain and vegetables where but a few years before had been but a desert waste. One work of particular note passed was the Kao Nulla siphon aqueduct, whereby the canal is carried over the bed of the Kao torrent and the latter in a semisiphon is passed under the aqueduct. A little farther on was a similar work by which the canal is carried in an aqueduct over the Thor Nulla. In the evening I arrived at the town of Buxar, where I met Mr. Horn, the executive engineer of the Buxar branch, and left the same night for Allahabad.

During the trip along the Soane canals many interesting scenes were noticed. Numerous canal boats loaded with grain or stone were passed. These were being taken to the railway or floated out on the Ganges River, whence they made the trip to Calcutta. The boats are peculiarly shaped, being higher at the stern than at the bow, varying from 15 to 25 feet in length, and about 10 feet wide. In the center is erected a pole, perhaps 12 feet in height, attached to which are numerous light strings, and each of these is drawn by a native on the towpath. On these canals it is not unusual to see ten or more men towing one boat.

The more important roads cross the canal in well constructed masonry or iron bridges. A peculiar accident has occurred to many of the former owing to the pressure of the earth embankments behind the abutments causing them to act as retaining walls. The pressure has in several cases caused the arches to spring upward at the center or key leaving a slight crack on top. These bridges have been constructed strong enough to perform their duties as bridges, but are not sufficiently strong to act as retaining walls.

The smaller roads and footpaths terminate at the canal banks, where catamaran-shaped ferryboats carry traffic across the canal. These boats are unique in construction. Each pontoon is composed of riveted sheet iron, and is 2 feet wide by 2 feet deep and 15 feet in length. Between the two is supported a wooden deck 6 feet wide, sufficiently large

to carry the ordinary two-wheeled bullock cart with its team. A chain is laid from one bank of the canal to the other, long enough to rest on the bottom of the canal so as not to impede traffic, and passing through a ring on the deck of the ferryboat. By pulling on this chain the occupants are enabled to draw the boat across the canal.

The canal banks are lined throughout with plantations of trees, the property of the canal government. These are cut and sold as may seem desirable to the canal officers, all trees thus removed being replaced by young growths. Among the more usual trees are the sissoo, somewhat like the teak in general character, and used in the construction of furniture, carts, etc., the sal, also used for furniture and fuel, some mangoes, and some mesquite.

Owing to the low velocity, about 3 feet per second, which it is necessary to give the navigable branches, considerable deposits of silt have been made near their heads; and lower down, where the water is clearer, reeds and rushes line the banks well out toward the middle of the stream. Large steam dredges are kept at work on the upper lines of the Soane canals, giving them much the appearance of the Suez Canal. These dredges have mostly been constructed at the shops at Dehree, and are of iron throughout, as are also the scows. Large steam passenger boats ply on the main canals, stopping at the various villages lining their banks and terminating their runs at the railway. These boats are crowded with people, which indicates a profitable passenger traffic.

Among the most interesting scenes observed were the enormous crowds of pilgrims, afoot, on camels, or on bullocks. These pilgrims make journeys between distant shrines, often occupying six months in the longer trips. Each devotee carries a pole across his back, from the ends of which are swung the few necessaries of food and clothing.

The locks along the canal are substantially constructed of brick masonry, sometimes singly and sometimes in pairs, and average in their lift from 7 to 12 feet. These locks are sufficiently long and wide to accommodate the big passenger steamers. Beside and around the locks is always constructed a waste weir and channel through which the greater part of the discharge of the canal used in irrigation and not required in operating the lock is passed. In this channel is necessarily a high fall with a drop equal to that of the lock. This fall is built of the most substantial masonry in order to withstand the jar caused by the great body of water passing over it.

On February 5 I arrived at Allahabad, the capital of the northwest provinces and Oudh, where, during the absence of the chief engineer and secretary for Government, Col. G. T. Skipworth, R. E., I was very courteously treated by Mr. H. W. Conduitt, the office assistant. He gave me some official reports, and letters to engineers in the northwest, and arranged for a visit to the Betwa, Ganges, and other canals by writing to the executive engineers in charge, informing them of the ap-

proaching visit and requesting them to render such assistance as might be required. On the same day I proceeded to Orai, where I was met by Mr. W. P. Vonder Horst, the executive engineer of the Betwa Canal. The 6th was spent in examining the office records and maps and making such notes and tracings as were deemed necessary. On the same evening we left by rail for Chirgaon, whence a short tonga ride took us to Paricha, the head of the Betwa Canal and the great Betwa Reservoir.

The Betwa Reservoir is constructed on the channel of the Betwa River where it emerges from the Northern Ghauts. The weir is located in a rather wide part of the river bed, crossing the stream in an irregular line, abutting in one place on a large island and at another on a broad rock in the middle of the river. The total length of this weir, including the islands on which it abuts, is about 4,300 feet, and its greatest height in the middle of the channel is 60 feet. The entire dam acts as an overflow weir, in order to give sufficient waste way to the enormous flood of 750,000 second-feet which may pass over it. Such a flood would bank 17 feet deep over the crest of the weir. In order to withstand the shock of this body of falling water two small subsidiary weirs have been constructed in the channel below the deepest portions of the weir, thus giving a water cushion on which the maximum height of the overfall is 21½ feet. The net storage capacity of this reservoir available for irrigation purposes is nearly 37,000 acre-feet.

The canal system heading immediately above the dam controls an area of about 950,000 acres, of which about 400,000 is excellent arable land. The balance is very poor and barren. This area of irrigable land is included between the Betwa, Pahug, and Jumna rivers, and at present about 135,000 acres are irrigated by the canal system. The flushing sluices on the end of the weir adjacent to the canal head and the regulators at the canal head are of great interest, owing to the pressure of nearly 60 feet under which the gates are operated.

From Paricha I proceeded by rail to Agra, and on February 9 went to Narora, where are located the head works of the lower Ganges Canal. In order to reach Narora it was necessary to go by rail to Aligarh, where a couple of hours were agreeably spent. From Aligarh I went by rail to Rajghat, which station was reached late in the evening. There, thanks to the thoughtfulness of Mr. E. A. Carswell, the executive engineer in charge of the Narora works, I was met by a hand car or trolley, in which I was pushed by natives 5 miles to the bungalow at Narora, where the following night and day were spent. I was received by Mr. Carswell with the same hospitality that had been accorded me by all the other officials with whom I had come in contact. The larger part of that evening and the next day were spent in examining the office reports and maps and in examining the head works and the river training system of the Lower Ganges Canal. These headworks consist of a great weir 4,135 feet in total length, 3,700 feet of which are

composed of an overfall weir 14 feet in height above the foundation, 315 feet consisting of sluice gates adjacent to the head of the canal. The head of the canal adjacent to the end of the weir consisted of 26 regulating gates, each 7½ by 11½ feet in the clear. The maximum flood coming down the Ganges which may pass over this weir may be as great as 230,000 second-feet.

The river training works are interesting and extensive. They are necessitated by the low character of the river bottom, in which the canal is constructed for some miles before its diversion line gets out of the bottom and reaches the summit of the bluff. Where these bottom lands are traversed the river is apt to change its channel, and if not controlled would cut its banks, thus destroying the canal. The regulating works are carried for 4 miles above the head of the canal and 15 miles below it, and consist of long earthen embankments or groynes, which jut straight out into the river channel at right angles to its course and are protected on their ends by rock paving and rock noses. Sixteen miles below the Narora weir the Lower Ganges Canal crosses the great Kali Nadi torrent, which in time of floods becomes an enormous river. The canal is carried across this torrent on an aqueduct which provides water way for a flood of 130,000 second-feet. The channel of the canal on the top of the aqueduct is 130 feet wide and 7 feet deep. Previous to 1885 there was in this place a short aqueduct calculated to pass a flood of 30,000 second-feet; but in that year it was destroyed by an unprecedented flood of nearly 130,000 second-feet, and has since been entirely remodeled and reconstructed.

On February 12 I left Narora for Lahore, the capital of the province of Punjab. In the absence of Col. F. J. Home, R. E., the chief engineer for irrigation in the Punjab, I presented my letters of introduction to Mr. Cockhorn, the office assistant, who had been instructed by Col. Home, in anticipation of my arrival, to furnish what aid he could. In the Punjab I was less fortunate than elsewhere. The works of that region are among the greatest and most interesting in India. I reached there in the midst of the busiest part of the field season. Most of the engineers were far out of reach of railways or other convenient modes of travel in charge of the construction of works, and as time was limited it was impossible to go far out of the way to meet them. Accordingly, I decided not to visit the works of the Western Jumna nor the Bari Doab canals, but to devote the remaining time to a thorough inspection of the Sirhind canals, which are the most modern and perhaps the most interesting of any of the canals of India.

I at once proceeded to Amrister in hope of meeting Maj. Ottley, R. E., the supervising engineer, from whom I expected information and assistance in the trip. Here, again, I was disappointed, and found no one who could give assistance or advice as how to visit them best. Accordingly I decided to go to Ludhiana, the nearest railway point to the canal. I reached there on February 14 and called on Mr. J. Demp-

ster, executive engineer in charge of the Sirhind canals. I did not receive much encouragement from Mr. Dempster, as he said that owing to not having been previously advised of the trip and the shortness of the time it would be nearly impossible to arrange conveniently to show me the canals. From Ludhiana to Rupar, where the headworks of the canal are, was a distance of about 60 miles, and to make this trip it would be necessary to engage an elephant and to procure the necessary traveling outfit. As I did not know where to find these, and Mr. Dempster was apparently too busy to aid in the search, I reluctantly abandoned the journey, and on the same day left by train to visit the Ganges Canal.

Next morning, February 15, I reached Roorkee, where I found that Mr. M. King, executive engineer, had made elaborate preparations for the trip over the line of the canal. I also found Col. G. T. Skipworth, R. E., chief engineer of the northwest provinces and secretary to government, and Mr. W. J. Wilson, his assistant secretary. They had made preparations for the annual inspection of the lines of the canal, but as they would not be prepared to set out on their trip for a few days, Mr. King had arranged to take me to the head works and return to Roorkee in time to accompany the inspecting party. A portion of the 15th was spent in examining the office records and maps, and early on the following morning Mr. King and I set out on a tonga drive along the banks of the canal bound for Hardwar, where are situated the headworks. Owing to the heat, though the distance was but 20 miles, two relays of horses had been sent out to hasten the journey. Two heavy bullock carts laden with camp equipage, etc., and an elephant which would be required in making journeys away from beaten roads, had also been previously forwarded to Hardwar. In the course of the drive along the canal banks we had an excellent opportunity for investigating the level crossing of the Rutmoo torrent at Dhanowri. We also examined the great aqueduct by which the Ganges Canal is carried across the Solani Valley and the superpassages which conduct the waters of the Puthri and Ranipur torrents over the Ganges Canal. These works were also examined on the return trip to Roorkee, when I was enabled to observe other points of interest that had escaped notice on the first inspection.

We spent the night at Hardwar and on the following day set out on the elephant to examine the various river training and regulating works, whereby the majority of the water of the Ganges River is guided into the Hardwar Channel, from which it is diverted into the canal. These training and regulating works extend for a distance of several miles above Hardwar and are unique from the fact that the supply of water being at all times abundant for the demands of the canal, no permanent dam has been thrown across the river. The bed of the river is here broken up into several channels and is very wide, but by means of a row of three temporary dams constructed of bowlders the majority of the water is turned into the Hardwar Channel. These temporary dams,

it has been found, can be more cheaply reconstructed annually after their destruction by the regular floods, than a great permanent weir could be built across the entire channel. Above the temporary bowlder dams a permanent masonry wall has been constructed on one minor channel besides a series of permanent bowlder embankments and bars, the latter to prevent the retrogression of grades. Groynes and other training works so confine the main body of water to the Hardwar channel that during times of greatest flood, when all of these works are submerged, little or no damage is done to the permanency of this channel. At Myapur, the head of the Ganges Canal below the training works, a permanent weir with the usual scouring sluices has been thrown across the Hardwar channel, thus training the water into the regulator at the head of the canal.

On the following morning we continued our inspection of the headworks and in the afternoon returned to Roorkee. The 18th was spent at Roorkee in a visit to the Thomason College of Civil Engineering, where Col. Brandreth, the president, kindly showed me over the building, and from whom numerous valuable reports and other information were obtained.

On February 20 I reached Okhla, near Delhi, at which place are situated the headworks of the Agra Canal. Here, thanks to the kindness of Col. Crofton, superintending engineer, who had written from Roorkee of the intended visit, I was met by Mr. C. G. Palmer, the executive engineer of the Agra Canal, with whom I visited the works under his charge. The headworks of this canal consist of a low weir, 10 feet in height and 2,573 feet in length from the right bank, the left wing resting on an island in the middle of the river. Wings and heavy earth embankments, 20 feet wide on top, are carried across the island and the east channel, and thence up the left bank to the railway bridge at Delhi.

This canal receives its water supply from the Jumna River, which, however, does not at all times carry sufficient water to fill it. Its supply is accordingly augmented by means of a cut from the Hindun River which empties the water of that stream into the Jumna above the diversion weir. In the weir there is the usual set of scouring sluices at the end adjacent to the canal head, and the customary regulating gates and lock for navigation purposes at the canal entrance. Like the Ganges River at Narora, the Jumna here requires the construction of great river training works similar in their general character to those on the Lower Ganges, but, in order to throw the greater portion of the water toward the right bank of the river where the canal head is, alligator groins have been run at right angles to the line of the weir, by means of which the water is trained in the desired direction.

After examining the office records and maps at Okhla, Mr. Palmer and I made a trip by tonga down the line of the canal to examine some of the works of interest. We passed several inlets by which the drain-

age of small streams heading in the hills to the southward is admitted to the canal. The water enters by stone culverts, and the core of the canal embankment at these places is usually constructed of rubble masonry. These inlets are generally controlled from a gate tower. Near the Ali Torrent the canal banks are protected on the upper side by a long earthen dam, forming a storage reservoir which catches the drainage of several small streams from the hills and passes this through an outlet or spillway into a superpassage of sheet iron carried over the canal. The water retained in the reservoir is allowed to settle, and when clear of silt is admitted into the canal, but in time of floods the superabundant discharge is carried over the spillway previously mentioned and discharged into the Jumna. Many hundreds of small tanks have been constructed all through this region of country, and one very large one is now under construction on the Surwa River about 15 miles above Baroda.

Among the most interesting sights from a scientific point of view to be seen in India are the ancient astronomical observatories erected by the old Arab astronomers at Delhi and Jeypur. At the latter place I had an opportunity to examine carefully the observatory of the Shah Jehan which covers a couple of acres of ground and is surrounded by a high stone wall. Within this inclosure are constructed many unique masonry instruments with which were conducted the observations of the ancient astronomer.

On March 3 I reached Bombay, and a few days afterwards left for home.

At Aden we stopped a day, thus giving sufficient time to examine the strange old reservoirs (Pl. CVIII), constructed in a gully above that town, which supply it with water. It is only once in several years that a sufficient rainfall occurs in this arid region to fill the tanks. There are several of them, one above the other far up the gully, and it was my good fortune to be there a few days after the occurrence of the first storm that had filled them in three years. They are most carefully constructed, lined throughout with hydraulic cement, thus preventing any leakage through their rock bottoms, and are closed by substantial dams with waste ways and masonry conduits leading from one to the other, so that the least possible amount of water will be lost by absorption. The total storage capacity of these tanks is about 12,000,000 gallons.

From Aden we proceeded direct to Suez, where I took the train for Cairo, arriving there on March 18. Here I called upon the American consul general, Mr. Eugene Schuyler, who informed me how best to see the irrigation works in the immediate vicinity. By him I was introduced to Col. Sir Scott Moncrieff, the minister of public works for the Government of Egypt, from whom valuable information and numerous reports relative to the irrigation works of that country were obtained. The next day the Barrage du Nil was visited, it being readily reached by a railway trip from Cairo occupying about an hour. Two

other trips to the Barrage were made, during which ample opportunity was had to examine the works. Construction was being rapidly pushed, and there were probably 6,000 workmen employed on them.

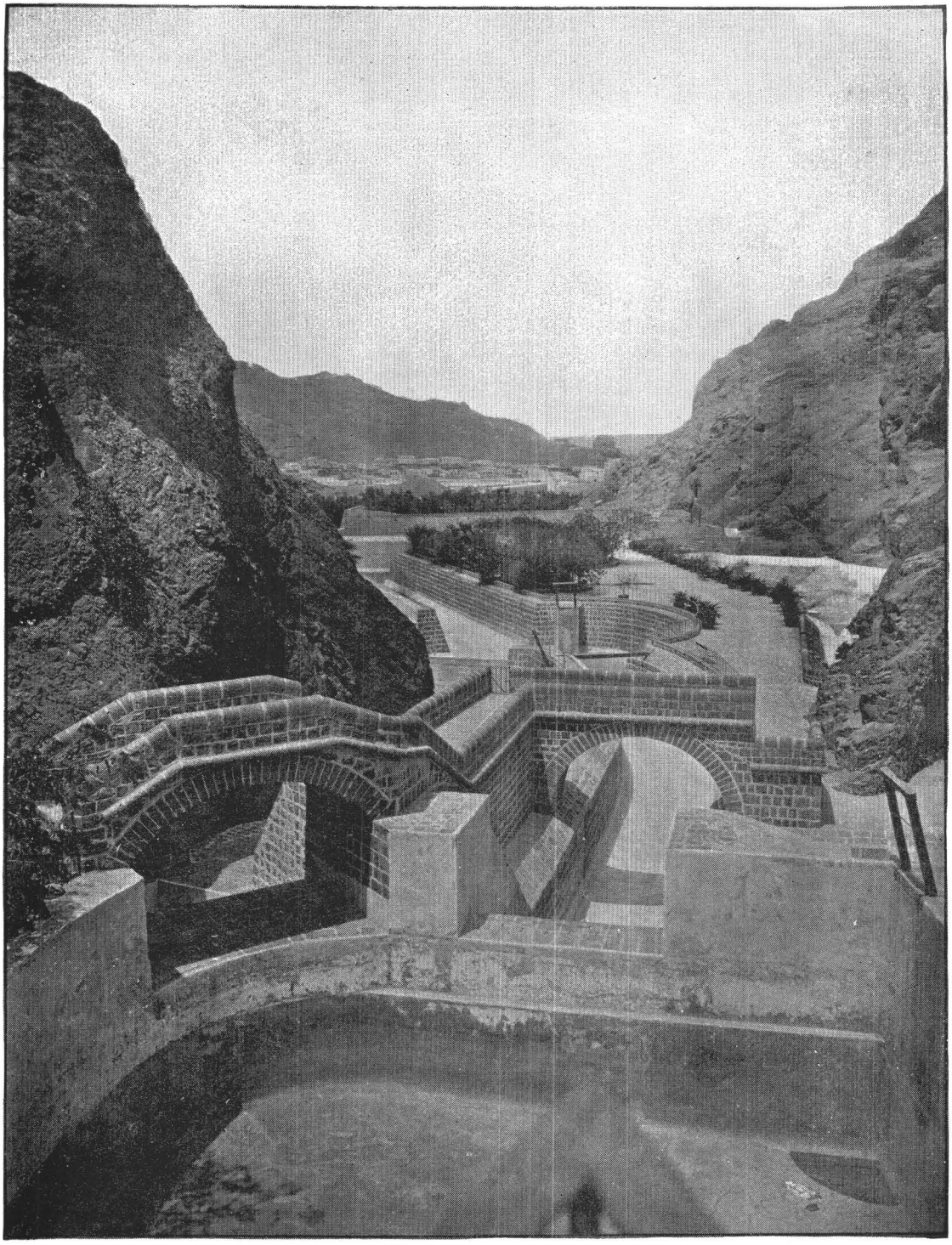
A few days later I proceeded to Brindisi, Italy, thence to Rome, where I arrived March 30. In Rome, thanks to the kindness of the American minister, the Hon. A. G. Porter, I called upon the minister of finance, under whose direction are the irrigation works of Italy. From him I received a letter to Signor Carlo Sospizio, the director of the Cavour Canal at Turin, and on the following day I reached Turin. Signor Sospizio was very courteous, and arranged to have one of his subengineers meet me the following day at Chivasso, where the headworks of the Cavour Canal are, and show me over them.

On April 2 I was met at Chivasso by Signor Canavotte Oreste, an assistant engineer. With him the following two days were spent in an inspection of the line of the Cavour Canal as far as the inverted siphon crossing the river Sesia. The trip was made from Chivasso in a carriage along the canal banks, as far as the aqueduct crossing the River Dora Baltea, below Saluggia. From this point the carriage was sent around the road to Saluggia and we examined the canal and aqueduct on foot, rejoining the carriage at Saluggia.

The weir across the River Po at the head of the Cavour Canal is a temporary one, constructed of brush and rocks, and is not over 5 feet in height. This weir has to be annually repaired, but this is less expensive than the construction of a permanent one would be. When the River Po is low, and does not discharge sufficient water for the wants of the canal, additional water is supplied by the subsidiary canal Farini, while the Canal Rotto adds some of the water of the Dora Baltea to it.

Above Saluggia, near Cigliano, is an interesting arrangement for lifting the water from a low to a high level canal. This consists of four levels of canals. Between the two lower ones is placed an extensive pumping plant, operated by turbines which receive their water from the upper of the two lower canals and tail into the lower canal, whence the water is distributed to low lying fields. The lower of the two upper canals supplies water by means of an immense wrought iron pipe, 3 feet in diameter, with a head of about 66 feet to the pumps below, and these force it, through another pipe of the same dimensions, a total height of 140 feet to the high level canal, whence it is distributed to the upper fields.

From Saluggia we proceeded by rail to Santhia near where the canal Cigliano passes over the Ivrea Canal and at the same time supplies it with water. The night was spent in Vercelli and in the morning we proceeded to Greggio, where the Cavour Canal passes under the river Sesia in a great siphon nearly 800 feet in length, which carries the entire capacity of the canal. This system consists of four channels or conduits constructed of masonry, oval in shape, the inside diameters of which are 9 by 15 feet.



ADEN TANKS, ARABIA.

On the following day I proceeded to Milan, thence over the celebrated St. Gothard route through Switzerland to Paris, where I arrived on April 6. In Paris, through the courtesy of the minister of public works, I received a letter to M. Caméré, engineer-in-chief of Ponts et Chaussées, located at Vernon, with whom I examined the various barrages which regulate the navigation of the Seine. At Paris the examination of irrigation works came to an end and I proceeded thence direct to the United States.

CHAPTER I.

FINANCE AND STATISTICS.

VALUE AND NECESSITY OF IRRIGATION.

In view of the interest in the subject of irrigation which has been recently developed in this country, it will be well to observe what benefits have been derived financially and otherwise from the irrigation works that have been in active operation in India during the last century, and also to note what Indian and English statesmen and engineers have to say on the subject of the extension of irrigation in India. Because of the similarities of the countries, climates, and the conditions under which irrigation works are operated in America and India, some useful lessons may be drawn from these comparisons. It has already been shown that the conditions of the utilization of the waters of irrigation works are quite similar in the two countries, and that the autumn crop in India is cultivated under circumstances almost identical with those under which our ordinary summer crops are grown in the arid regions.

The Indian financier divides the irrigation works into two great classes called major and minor works. Major works are generally those of more importance from an engineering point of view and have been in some cases almost entirely constructed by the British Government, while the minor works are of smaller pretensions and in many cases modifications or improvements of existing ancient irrigation systems. The portion of the major works that are constructed from capital provided from the general revenues of India are styled "protective works." "Productive works" are usually constructed from capital which has been borrowed, and it is expected that a sufficient profit will be realized from their operation to pay interest on the borrowed money. Many minor works are also productive works. In general, protective works are constructed as a protection against famines, and they act in the amelioration of these in two ways. Firstly, they are constructed during famine times to give employment to the people and furnish them money and food for their sustenance; and secondly, after their construction they are expected to furnish sufficient water for irrigation purposes to render them a protection against future famines. The majority of these famine protective works consist of storage reservoirs constructed in the more arid portions of India.

The reason for the success of the greater productive works of northern India is twofold. Firstly, these works are constructed in a country simi-

lar to that of the western United States, so barren and devoid of water that nobody could live there or produce crops of any sort until canals had been dug and water provided for irrigation. Accordingly, all those who immigrated to the neighborhood of these canals were at once compelled to use and pay for the water, otherwise they would have been unable to raise crops. It is owing to the fact that these works have been able to do their full duty and the total amount of water furnished by them has been in constant demand, that these works have paid interest. On the contrary, the protective works, which have usually proved financial failures, have been made in regions where in ordinary years the precipitation has been sufficient to produce good crops, but where during occasional years the crops suffer from lack of water, and it is then only that the irrigation works are called upon. Such works being only utilized occasionally, produce only moderate returns during occasional years. Were these works constructed in a less inhabited region and in one lacking sufficient precipitation to raise crops, they would doubtless then do constant duty, and it might reasonably be expected that they would become productive works. In some few cases, such as those of the Sidhnai Canal in the Punjab and the Betwa Canal and reservoir in the northwest, works originally constructed as protective works have received such a constant demand for their waters that they are now productive, returning moderate interest on the capital.

Anywhere in our arid West where irrigation works may be constructed it is reasonable to suppose, judging from analogy, that when a sufficient population settle below them these works will be called upon to furnish all the water they can provide, and if properly and carefully planned and estimated for should return fair interest on the original outlay. Only semi-humid regions, such as western Kansas, the Dakotas, Nebraska, and Oklahoma, have been subjected to famines. These occur every few years, and are the results of the country having been occupied by settlers during periods of fair rainfall. Following these good years came a season or two of minimum rainfall when the crops were parched. It is only because of the increased transportation facilities in our West and the extensive charities undertaken by the Government and people that settlers in that portion of our country have been saved from famine. It is in such regions as those in India that the Government has devoted the most time, attention, and money for the construction of irrigation works as a means of protection against such losses, and convincing arguments have been brought to prove that money expended in such protective works is saved to the Government.

The high price paid for labor as compared with that in India is the argument generally used to prove that similar profitable returns from irrigation enterprises in this country can not necessarily be expected, as the cost of construction here would be proportionately so much greater as to demand a higher return from the use of water in order to pay a corresponding rate of interest. It is not improbable that with

the increased amount of work done by an American laborer as compared with that of a Hindoo coolie, and with the aid of many mechanical devices, the discrepancy in cost is not so great. Moreover, returns derived from irrigation works in the two countries are more nearly equalized from the fact that we can impose a higher tax for the use of water than it is possible to demand of the poor farmers in India, where from 2 to 5 acres support a large family. The apparent low cost of Indian labor is at first glance against this argument. Men, women, and children are engaged alike in the construction of all works. As common laborers women and children receive about 4 cents per day, and men from 8 to 10 cents. Skilled masons and machinists receive from 18 to 22 cents per day, and carpenters and blacksmiths nearly the same.

In the interior towns of the Bombay Presidency contract prices are about as follows: At the Bhatgur dam uncoursed rubble masonry costs $1.75 per cubic yard, while at Tansa dam it costs $2.50 per yard. In the northwest provinces earth excavations in deep canal cuts cost 6⅔ cents per cubic yard, while surface excavation costs 2½ cents. In the Punjab, according to the revenue reports, water in the canals yields a return of from 70 cents to $1.25 per second-foot, while the water rate charged per acre irrigated was from 70 cents to $1.15. In Bombay, according to the revenue report of 1889, the water rate derived was $1.15 per acre irrigated, and ranged from 35 cents to $3, the latter figure being abnormal and paid for the irrigation of sugar-cane crops which require an enormous amount of water in their cultivation. Against these prices we are able to obtain in the central arid regions of America a revenue of from $1.50 to $3 per acre, which is equivalent for a duty of 80 acres per second-foot to from $120 to $240 per second-foot utilized. In California and other portions of the country where water is scarce and the crops valuable the rate is usually many times higher than the above.

In the province of Sind in the Indus Valley, including the southern Punjab, there is an enormous and thirsty waste of sandy desert where the annual precipitation is always below 10 inches, even falling as low as 3 or 4 inches. There nothing can be grown without the aid of irrigation, and the entire area under cultivation and the population supported thereby are entirely dependent on irrigation. The works in that region are chiefly inundation canals with a few perennial canals mostly taken from the Indus River. In the Sind alone over 1,500,000 acres are under cultivation, and yield an annual revenue of about $1,600,000.

In Bombay and the northwest provinces nearly double the population is now sustained that was supported previous to the introduction of modern irrigation works. According to Col. Baird Smith the whole of the region irrigated by the Eastern Jumna Canal would have been devastated by the famine of 1837–'38 without the aid of the irrigation which that canal afforded. With its aid the population was comfortably supported and the gross revenue derived from the use of the water

was $2,445,000, of which the Government received a yearly net income of $250,000, and this shortly after the completion of the work. In the same year the united Eastern and Western Jumna canals were estimated to have saved property to the value of $10,000,000, and as a result of this showing the British Government shortly afterward began the construction of the great Ganges Canal and other similar works. From the report of Maj. Baker, R. E., it appears from actual measurements made on the Western Jumna Canal in 1838 that the gross value of crops on lands irrigated by that canal was $7,500,000, of which $750,000 was paid to the Government as land and water rent; the remainder aided to feed and support the inhabitants of 500 villages during a period of devastating famine. Without irrigation this land would during that drought have been totally unproductive.

As an indication of the increased revenue derived from the use of water and the capability of the soil to pay that increase, it appears that in the presidency of Madras the rate of assessment in the tank region is about $2.30 per acre on irrigated land, as against 55 cents per acre on land not irrigated. It is difficult to show in a satisfactory manner what has been the actual result of the irrigation works in India as financial undertakings. The figures given convey little idea of the actual benefit derived from the canals, as much of this is collected as the land tax, which forms nearly half the total revenue of the Indian Government.

Another difficulty in reviewing the financial results of Indian irrigation works is found in the fact that in several cases capital shown by the Government accounts does not include the value of the old native works, upon which the British undertakings were founded. Recognizing these difficulties, Maj. Gen. Dickens presented to the select committee on public works a statement, of which the following is a summary, which was given as the nearest approximate to the truth that could be obtained. This statemant was for the year 1875–'76 only, and no allowance was made for the value of the old native works, which Gen. Dickens stated did not exceed $2,500,000. The total expenditure to date was $77,500,000; the total receipts were $6,150,000; and the working expenses were $2,000,000. This shows that the irrigation works of India, taken altogether, paid at that time a revenue direct and indirect of 5½ per cent to the state. This includes some works which were only partially in operation. Gen. Dickens anticipated that when in full operation they would eventually pay 6 to 7 per cent.

As an indication of the time which must necessarily expire after a canal work is opened and before it is doing its full duty and returning its full revenue, the Great Ganges Canal was fourteen years in operation before it paid 4 per cent on its simple capital, and Col. Crofton, the late inspector-general of irrigation in India, appears to think that ten years is by no means an unreasonable time to elapse after an irrigation work has been put in operation before it can pay interest on its cost. Gen. R. Strachey in 1865 gave it as his opinion that it was not likely that even

5 per cent would be realized in ten years on the capital stock on any but the smallest irrigation works, while Col. Baird Smith took it for granted, in reporting on the proposed Soane canal, that the works would not be self-supporting for sixteen years after they had been opened for irrigation.

The following quotations are from the reports of the select committee appointed in 1888 by the British Government to report on the measures of protection and prevention of famine. This report must bear great weight, owing to the high character of the members of the committee, both as engineers and men of experience in the construction and management of irrigation works and as statesmen of broad views, whose integrity can not be doubted. This committee consisted of Gen. Richard Strachey, James Caird, H. S. Cunningham, H. E. Sullivan, and J. P. Peile. Their remarks relative to the value of irrigation works were as follows:

It is not only in years of drought and as a protection against famine that irrigation works are of value. In seasons of average rainfall they are of great service and a source of great wealth, giving certainty to all agricultural operations, increasing the outturn per acre of the crops, and enabling more valuable descriptions of crops to be grown. The following instances may be quoted from the mass of evidence before the commission. The outlay on completed canals in the Punjab up to the close of 1877–'78 had been $11,300,000. The total area irrigated by them was 1,324,000 acres. The value of food grains raised on two works, the Western Jumna and the Bari Doab canals, was $14,400,000. It may, without exaggeration, be reckoned that one-half of these crops would have perished if unwatered or would not have been raised at all if the canals had been absent, so that in that one year alone the wealth of the Punjab was increased by these two canals by $7,200,000, an amount equal to about two-thirds the cost of the works, and but for the protection they afforded the Government would have lost heavily from the necessity of remitting revenue and otherwise providing for famine relief. The net revenue for the year in the Punjab was only $610,000, being about 5½ per cent on the capital outlay on works in operation, a result which obviously supplies a wholly inadequate test of their value to the country.

Up to the year 1878 the capital outlay on canals completed in the northwest provinces had been $21,800,000. The area irrigated that year was 1,461,000 acres, the value of the crop raised on which was estimated at $30,000,000. Half of the area irrigated was occupied by autumn crops which but for irrigation must have been wholly lost, and it may be safely said that the wealth of these provinces was consequently increased by $15,000,000, so that three-fourths of the entire first cost of the works was thus repaid to the country in that same year. The net revenue to the Government from irrigation in these provinces was $1,550,000 or 7¼ per cent on the whole capital outlay of $28,750,000, of which about $6,250,000 was still unproductive.

The results of irrigation are not so favorable in Bengal and Behar as in the above two provinces, chiefly because irrigation is there less necessary since the rainfall is more abundant. There is sufficient evidence of its value in Madras. The three great deltaic systems of irrigation, the Godaveri, the Kistna and the Cauveri, yield direct returns of 8, 6, and 31 per cent, respectively, on the capital spent on them. During the year 1876–'77, a year when every unirrigated district was importing a large part of the food of its population, the value of rice produced in the deltas of the Godaveri and Kistna rivers is calculated at the prices then prevailing to have been not less than $25,000,000. The ordinary rental of land in northern India is doubled

by irrigation, while in eleven districts of Madras the average rental rises from 40 cents to $1.70 per acre. In considering this question it should be borne in mind that there are othes causes of financial ill success of irrigation works; the one temporary, the other permanent. In the one case the works may fail to pay for a time because of the slowness with which the people adapt themselves to the new system of cultivation, a difficulty which arises in almost every new work, or because of errors in the details of the scheme which experience detects and which are easily remedied. In the other case the failure may be due to the inherent defects of the scheme and to the fact that the water costs more than it is worth. In the former case there may be reason to expect that the water will be eventually fully utilized and the deficit be converted into a surplus, though the accumulated excess charges during a series of years may amount to a large sum which receipts will only gradually wipe out. In the latter case, though there may be room for improvement and economy in the distribution and use of the water, it may be impossible ever to realize a surplus.[1]

According to the same authorities the net income of the whole works in operation in British India was in the year 1879–'80 $5,830,000, which amounts within a very small fraction to 6 per cent of the whole capital, including about $16,250,000 spent on works not yet brought into operation. If this part of the outlay be excluded the income is found to be more than 7 per cent on the capital actually utilized.

The following statement of the water rents derived from the use of the Western Jumna Canal in the Punjab between the years 1820 and 1850 will give a fair idea of the rapidity with which the income from the use of irrigation works increases. In 1820 the water revenue was $420 per annum; in 1830 it was $28,800; in 1840 it was $112,900. On the Eastern Jumna canals in the Northwest provinces the water revenue was in 1830 $3,000 per annum. In 1840 it was $29,300 per annum, and in 1845 it was $48,200 per annum.[2]

LAND AND CROPS.

The following table gives the area and population of the principal provinces of India according to the census of 1881:

Area and population.

Province.	Area.	Population.	Density per square mile.
	Sq. miles.		
Bengal	156,560	66,691,450	426·0
Northwest provinces and Oudh	106,111	44,107,870	415·6
Punjab	106,632	18,850,440	176·8
Central province	84,440	9,840,000	116·5
Madras	139,900	30,868,500	220·6
Bombay	124,122	16,454,400	132·7
Total British territory	868,314	198,790,150	222·9
Total native states	509,730	55,191,742	108·2
Grand total, India	1,378,044	253,982,595	184·3

[1] Report of the Indian Famine Commission, Part 2, London, 1880.

[2] R. Baird Smith, F. G. S., Italian Irrigation, London, 1855, vol. 1, 318–340.

Of British-born inhabitants there were 89,800; of agriculturists 70,000,000, or two-sevenths of the whole population, and of workers or manufacturers 22,000,000. The mortality in India varies from 21 to 28 per thousand. In 1888 the area of British territory had increased to 1,064,720 square miles, the population of British territory was 208,793,350; and the native population numbered 60,684,378, giving a total population in 1888 of 269,477,728.

The following table shows the areas cultivated and irrigated in the various provinces during the year 1888:

Area cultivated and irrigated.

Province.	Acres cultivated.	Acres irrigated.
Madras	25,186,000	6,234,000
Bombay	27,056,000	2,418,000
Northwest provinces	29,764,000	6,208,000
Punjab	22,790,000	6,091,000
Oudh	11,268,000	2,468,000
Central provinces	14,984,000	516,000
Others	Scattering.	Scattering.
Total	144,006,000	24,936,000

The following table gives the areas under cultivation of the principal crops produced during the same year:

Extent of crops.

Crop.	Area under cultivation.	Crop.	Area under cultivation.
	Acres.		*Acres.*
Rice	24,238,600	Oil seeds	7,299,500
Wheat	19,886,600	Tea, indigo, etc	Scattering.
Other food grains	73,992,400		
Sugar cane	1,768,800	Total	144,006,100
Cotton	9,042,300		

It will be observed from the first table that the proportion of area irrigated to the total area under cultivation is very large, one-sixth of the whole being irrigated. Since the introduction of improved irrigation works and the great increase in the area of land brought under the control of these works the quantity of the more valuable food crops, and more especially those which come in direct competition with foreign countries, has greatly and rapidly increased. The production of cotton was largest in 1866, at the close of the American civil war, when the exports amounted to $185,000,000. Since then the exports of this product have decreased considerably, and now its average is on the increase and amounts to about $40,000,000. Cotton is produced chiefly in Guzerat, the Deccan, the Central provinces, Sind, and Bombay. The yield is as high as 100 pounds of cleaned cotton per acre, but the staple is short and the product is not as valuable as that of the United States.

Another crop which is being extensively exported in recent years is

wheat. It is grown generally everywhere, but does not thrive where rice does nor south of the central provinces. The Punjab is the greatest wheat-producing district, then the Northwest provinces, Oudh and Bengal south of the Ganges. In the Central provinces wheat occupies 23 per cent of the cultivated area, in Bombay and Sind 6 to 12 per cent, and all India has as large an area under wheat as has the United States. The output per acre is rather small. In the Punjab it is 13 bushels per acre, in other places a trifle more or less. Wheat is an autumn crop and is irrigated. To the construction of the great canals of the Punjab and Northern provinces is due the quality and prominence which it possesses.

Rice is an extensively cultivated crop, but it is limited to the deltas of the Orissa, Godaveri, and other large rivers and to Bengal; 80 per cent of the crops raised in such regions is rice. Elsewhere little is grown excepting in the lowlands along the coast. In Bengal the average yield per acre is 1,200 pounds of clean rice. Millet is more extensively and generally grown than any other crop excepting in the special rice districts. A variety of sorghum called jowari and a spiked millet called bajra are the most common varieties. They are wet weather or spring crops and are used somewhat by the natives for food, but are chiefly used as fodder. Oil seeds form an important crop. Oil is extensively used in India for lamps and for food. These are usually grown as a second crop after rice and pulses. The largest oil-seed producing provinces are Bengal and the Northwest, but these crops are also extensively grown in Madras and elsewhere.

All kinds of vegetables and fruits are produced everywhere in India, these being the chief food of the natives. Among the more important kinds are potatoes, which are grown especially in the hills, maize, tomatoes, eggplants, mangoes, oranges, lemons, melons, figs, plantains, and cocoanuts. Cocoanut palms are grown most abundantly on the west coast lowlands, and date palms in Bengal. The production of the ordinary spices is rather abundant. They are mostly, however, for home consumption, for use in curries, etc., as tumeric, chile, chickory, coriander and others. Sugar cane is very extensively cultivated throughout India, especially in the Northwest provinces, and in Bombay, but it is an expensive crop to produce both because of the time required to mature it and the amount of water necessary to irrigate it. The varieties of sugar cane produced in India are not equal to those produced in America and in the West Indies, the proportion of saccharine matter being comparatively low.

Jute is a plant almost exclusively produced in India and very extensively exported. It is chiefly grown in northern and eastern Bengal. Indigo is extensively grown in the Northwest provinces, Punjab, and Madras, chiefly by the natives. It is most extensively produced, however, in Behar by English capitalists. The expense of making the dye from the plant is such that the natives are seldom able to cultivate and manu-

facture it, hence the factories are usually under the control of British capital. Poppy for the production of opium is grown extensively in the Ganges Valley near Patna and Benares, and in central India. Its cultivation requires much care and attention and is usually an indication of intelligence and prosperity on the part of the cultivators. Tobacco is generally grown in small quantities everywhere in India. The best is produced in Madras, whence the variety know as Trichinopoly is extensively exported. Coffee is produced in small quantities in southern India only. Tea is extensively cultivated in Assam where it is indigenous, but it is also raised about Darjeeling in the foothills of the Himalayas. It is an expensive crop to prepare for market and is chiefly cultivated by Europeans. Its quality is constantly improving and the amount exported is annually increasing.

The advantage of using manure is apparently well understood, and if not extensively used it is because of the limited means of the cultivators. The rotation of crops is not generally practiced, since, owing to the extensive use of water for irrigation it does not seem to be so necessary. The soil throughout India differs essentially in different localities; it is generally very fertile on the great Gangetan Plain, while the black cotton soil of the Deccan is perhaps the most fertile in the world.

The kharif, or wet weather crop, is matured chiefly by the rains of the summer monsoon. It is sown as soon as the spring rainfall admits of the plowing of the land, and it is reaped in September or October. The rabi, or autumn crop, is the dry weather crop and requires the largest amount of artificial watering for its cultivation. It is sown in October and is reaped in March or April. The principal crops produced during the wet season are rice, cotton, sugar cane, etc. During the autumn season the more hardy grains are produced, especially the food grains such as wheat, barley, etc. The millet and fodder grains are chiefly sown in the higher lands and depend for the most part on natural rainfall, as their requirements in the way of water are usually less than those of other crops.

CHAPTER II.

TOPOGRAPHY, METEOROLOGY, AND FORESTRY.

TOPOGRAPHY AND GEOLOGY.

India includes within its borders the highest mountains in the world and some of the mightiest rivers and greatest plains. Topographically it may be divided into three distinct parts each possessing different topographic features. First, the Himalayas which form a great mountain barrier on the north and shut out the rest of Asia, forming an overruling factor in the climate and physical geography of India; secondly, the plains of the great rivers issuing from the Himalayas, the Indus and Ganges plains; and thirdly, south of these plains a high, steep-sided tableland supported by the Vindhaya Mountains on the north and by the western and eastern Ghauts on either side of the peninsula. This great interior tableland is broken by many peaks and mountain ranges separated by broad and fertile valleys.

The Himalayas take their name from an Indian word which means literally "dwelling place of snow", and consist of a great mountain range 1,500 miles long, the general trend being from northwest to southeast. This mountain range may be likened to the Sierra Nevada, bordering the eastern side of the great California Valley. Approached from the southern or plains side, there is the same general appearance of low, rolling foothills, the higher peaks being so far back from the edge of the valley as to be scarcely discernible. This mountain range or aggregation of mountain ranges is also similar to the Sierras in its composite formation. On top and behind it is a high arid plateau which corresponds to the Nevada desert.

The highest peak in the Himalayas is Mount Everest, 29,002 feet above the sea, while peaks above 20,000 feet elevation abound in all parts of the range. There are numerous well traveled trails leading from India through Kashmeer and Nepal into Thibet and China, and the passes on these are from 16,000 to 19,000 feet high, and for several days the traveler remains above 16,000 feet in altitude. Only one pass is as low as 16,400 feet.

The Indus River rises well north of the first great range of the Himalayas and drains nearly half of their northern slope, and after flowing around the western extremity of the range it turns and flows southwardly, being joined by various tributaries which drain the southern and western slope. Its main drainage area is situated at a great alti-

tude among the glaciers of the Himalayas. Its drainage basin in the Himalayas alone is about 32,550 square miles in area, while with its affluents the whole basin drains 311,600 square miles. This river, with its branches, affords the chief source of water supply and drainage to the provinces of Punjab and Sind.

The northeastern slope of the Himalayas is drained by the Brahmaputra River, which, like the Indus, rises north of the mountains, draining about one-half of their northern slope, and after breaking through the Himalaya Range it flows westwardly through the valley of Assam to its junction with the Ganges River, 100 miles from the sea. The drainage basin of the Brahmaputra north of the Himalayas is about 95,000 square miles in area. Like the Indus, its upper basin is at a great altitude. As yet its waters are but little used for irrigation, as the country through which it flows generally receives a fair rainfall. The average elevation of the Indian watershed between the headwaters of the Brahmaputra and Indus rivers is above 18,000 feet in altitude.

The Ganges River and its tributaries drain the larger portion of the southern slope of the Himalayas. The catchment area above an elevation of 1,000 feet is very small relatively to that of the Indus and Brahmaputra, while the total catchment area is 414,000 square miles. This river flows eastward through the great plains of the northwest provinces and Bengal to its junction with the Brahmaputra, whence it flows southward to the Bay of Bengal. The southwestern slope of the Himalayas, in the province of Punjab (which name means "The Five Waters") is drained by the main five tributaries of the Indus, viz ,the Sutlej, Ravi, Chenab, Jhelam, and Indus rivers, all of which join below Mooltan, whence they flow southward to the Arabian Sea. All these rivers are extensively used in irrigation.

The southern foothill ranges of the Himalayas north of the Punjab and the Northwest provinces are from 3,000 to 4,000 feet high and are called the Sewaliks. Between the Sewalik Hills and the sub-Himalayas is a disconnected line of valleys from 2,000 to 2,500 feet in altitude. These valleys are called the Duns. The sub-Himalayas, which form a higher range or belt of hills north of the duns and between them and the main range, are from 15 to 50 miles in width north and south, and are sometimes separated by several successive dun-like valleys. These latter are artificially drained and cultivated in places and are very fertile. In the sub-Himalayas are the mountain resorts of the various provincial governments of India, at altitudes varying between 7,000 and 8,000 feet. In a portion of the northern or Gangetan plain to the eastward of the Ganges is a broad belt from 10 to 15 miles wide. It is a broad, grassy tract, traversed by sluggish streams, with extensive morasses and marshes and is called the Tarai.

The great northern plain stretches with an unbroken surface along the foot of the Himalayas from the upper Indus in Punjab to the Ganges delta near Calcutta and in a wide valley along the Brahma-

putra called Assam. Its area is about 500,000 square miles, and it is nowhere above 1,000 feet in elevation and appears to be perfectly flat. The northern, central, and eastern portions are well watered by rivers having their sources in the Himalayas or in the Ghauts. Assam has a periodical rainfall, and the whole of this northern plain forms the best cultivated, the richest, the most populous, and the most civilized district of India. This plain receives the water of four great river systems, that of the Indus, of the Brahmaputra and the combined Ganges, Jumna, Sutlej, etc., draining the southern Himalaya slopes, and the Betwa, Chumbul, and Soane, draining the Vindhaya Mountains and northern Ghauts.

The third great topographic division of India is the table-land before alluded to, generally called the Deccan, and includes the Central provinces, Hyderabad, Bombay, Madras, and Mysore. The highest peaks of the northern Deccan are Mount Aboo, 5,650 feet high, on the west and Mount Parasnath, 4,450 feet high, on the east, while the hills generally vary from 1,500 to 4,000 feet in altitude and consist of ridges separated by broad, high plains and masses of forest.

The eastern and western Ghauts are great, irregular ranges of mountains extendingthe whole length of the eastern and western coasts. The eastern Ghauts average 1,500 feet in elevation; the western Ghauts ascend sharply from the sea to an average elevation of 2,000 feet, with peaks varying from 6,000 to 8,700 feet in height. The western slope of this range is extremely rugged, having much the appearance of the mesa edges in the western United States. The eastern Ghauts are a series of broken spurs, not continuous like the western Ghauts, and afford easy access to the interior. The inner plateau between these mountain ranges is from 1,000 to 3,000 feet in elevation, dotted with peaks and ranges over 4,000 feet in elevation, and it is approached through the western Ghauts by only a few difficult passes. The general appearance of this country is very similar to that of northern New Mexico and Arizona and of southern Utah.

The western Ghauts form the watershed of the central plateau. Only short streams flow from them into the Indian Ocean, the main drainage making its way eastward across the central plateau, breaking through the eastern Ghauts and emptying into the Bay of Bengal. The chief rivers, viz, the Godaveri, Cauveri, and Kistna, rise in the western Ghauts; their deltas in Madras form extensive and fertile plains, which their waters irrigate. The chief population of this central region is on the eastern slope, and here irrigation is extensively practiced, not only from great rivers in their lower or coast levels, but also by means of storage in the western portions of Madras, Mysore, and in Bombay. Of the important rivers of this region the drainage basin of the Godaveri is 119,000 square miles; that of the Kistna is 59,500 square miles, and that of the Cauveri 30,300 square miles in area.

The flood discharges of the various great Indian rivers are enormous.

The Indus above Sakkar discharges as high as 380,000 second-feet, which is equivalent to 15 second-feet per square mile of catchment. The Ganges in flood may discharge 1,350,000 second-feet, which is a little less than 5 second-feet per square mile of catchment, and the Godaveri discharges in great floods 1,350,000 second-feet, or 11 second-feet per square mile; the Kistna a little less than 1,200,000 second feet, while so small a stream as the Soane, rising in the Vindhayas, with a catchment area of about 34,000 square miles, discharges 1,700,000 second-feet, equivalent to 50 second-feet per square mile of catchment. One river in southern India, the Gadanamathi, having a cachment of only 29 square miles, discharges in flood 28,000 second-feet, or 972 second-feet per square mile, and other rivers discharge nearly as large relative amounts.

The following table, giving some details of discharges, etc., of various large rivers near their mouths, is taken from Heywood.[1]

Rivers.	Extreme breadth of river bed.	Extreme breadth of channel.	Least breadth of channel.	Fall per mile.	Rise in monsoon.	Greatest depth in dry season.
	Miles.	*Miles.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Ganges	5¼	2¼	1¼	.....	27	30
Kistna	1½	1¼	¾	1·17	35	10
Godaveri	4	2½	1½	1·09	30	10
Cauveri	1	⅜	½	3·5	12	6

Rivers.	Surface current in floods per hour.	Flood section.	Flood discharge per second.	Least discharge in dry season per second.	Longest duration of flood.	Area of delta.
	Miles.	*Sq. feet.*	*Cubic feet.*	*Cubic feet.*	*Days.*	*Sq. miles.*
Ganges	4 to 7	288,000	1,800,000	45,000	40	.....
Kistna	7½	153,000	1,500,000	1,125	10	.....
Godaveri	4¼	216,000	1,500,000	2,250	10	3,000
Cauveri	6	37,800	300,000	None.	10	.....

The geology of India varies with the topography. The great northern plain is an alluvial deposit on the surface of which not a pebble can be found excepting near the foot of the hills. It probably belongs to the post-Tertiary, judging from a few fossil mammals, fishes, and crocodiles which have been found, and is probably the result of delta deposits. The Sewalik Hills also belong to recent geologic times and are composed of micaceous sandstones interspersed with bits of clay and marl, their age being Miocene or Pliocene. The sub-Himalayas belong to the Tertiary epoch and are of marine origin, composed chiefly of sandstones, argillaceous shales, schists, and limestones. The main range of the Himalayas is composed chiefly of schistose rocks, mica schists, and gneiss, and some granite and limestone.

In the Deccan the oldest rocks consist of gneiss, which is found in large portions of Bengal and Madras and is pre-Silurian. The great mass of the central plateau, perhaps 200,000 miles in area, consists of what is known as Deccan trap, which forms the most striking physical feature of the landscape. Most of the great ranges of mountains, with their

[1] Hydraulic Works, Jackson, London, 1885, page 250.

rugged outlines and the square buttes or ghauts and mesas, are the denuded edges of basaltic flows. It is from these jagged or step-like ranges that they receive their name of ghauts, which means "steps." The soil is largely composed of disintegrated laterite, a ferruginous and argillaceous rock occurring over the trap but also found elsewhere. High-level laterite is usually a result of the decomposition of trap, and the soil of much of the central plateau which it forms is very poor in quality. Low-level laterite is more sandy, often containing gravel, and forms most of the better soil fringing the coast.

METEOROLOGY.

The rainfall in India is exclusively from the evaporation of the Indian Ocean and the two bays which surround the peninsula. The distribution of rainfall is extremely variable, ranging from a couple of inches per annum in portions of the Sind to over 600 inches which falls in a limited area in Assam. By far the greater part of the rainfall is brought direct from the ocean between the months of June and October by the regular periodical wind known as the summer monsoon. In Upper India the cessation of the summer rains is followed by a rapid fall of temperature under a perfectly clear and cloudless sky. A cool and dry current sets in from the northwest, down the Ganges Valley toward Bengal and from the north across the northern Deccan, south of which it turns and sets toward the Bombay coast. The plateau of Hyderabad, Madras, and Mysore receives a small amount of rain in October and even later. In lower Bengal and on the coast a few inches of rain are expected in October and are of importance to the late summer crops and in sowing or germinating cold-weather or autumn crops. The latter part of October and November and the earlier portion of winter in northern India is generally rainless. The late winter rains, which are small in amount and are regular only in upper India, rarely set in much before January.

With regard to this periodic distribution the rainfall in different parts of India may be summarized thus: From June to September rain falls more or less heavily throughout the entire area, excepting upon the dry plains of the Sind, where it it extremely rare and sometimes fails altogether. In a portion of the Punjab and in the Carnatic the summer rain is restricted to occasional showers. In October, when the rains have ceased in upper India, Bengal, etc., the heavy rains of Madras set in and continue until the middle or end of December. About this time begin the light rains of upper India, which are experienced in the northwest provinces and fall at intervals to the end of March, after which the dry season continues till the end of June, the beginning of the monsoon. In lower Bengal and in Assam the rains become more frequent from January on, and are chiefly afternoon storms. On the coast of Malabar they are earlier than in Bombay. In Madras occasional showers are expected after February, but the steady rain begins only in October.

In the Ganges delta the mean annual precipitation is from 60 to 70 inches. On the great plain, including the Northwest provinces, it averages 40 inches, and at the summit of the great plain west of Delhi it varies from 25 to 30 inches per annum. At the mountain stations in the sub-Himalayas the annual precipitation ranges from 90 to 120 inches. Farther in the Himalayas, at an elevation of 10,000 feet or above, the rainfall is only 10 or 20 inches, while the snow fall may be 6 to 8 feet or more. There is a difference of from 10 to 15 inches between the precipitation over the southern and northern portions of the Gangetan plain. In the Punjab the highest average precipitation is in the sub-Himalayas, where it is 68 inches per annum. At Mooltan it is but 7 inches per annum, which is a low average, and at Dera Ismail Khan the annual precipitation is 8·2 inches per annum, nearly the average of the Punjab. In central India the annual precipitation in the lower lands varies between 20 inches at Jeypur and 32 inches at Khundwa, while the minimum in the mountains, such as Mount Aboo, is 61 inches.

In the Northwest provinces the general average is 26·5 at Muthra or Agra, while Aligarh has a minimum of 24 inches. In Bengal the maximum average on the coast is 105 inches, and the minimum average on the plains at Patna is 38 inches. In Assam at Chara Punji the maximum average of the world is reached in an annual precipitation of 368 inches, while in the same place in 1861, 30 inches fell in twenty-four hours, and 805 inches fell during that year. In Bombay in the western Ghauts the maximum average is 250 inches, and the minimum average in the lowlands at Duhlia is 17 inches. The general average of Bombay is 67 inches. In the Sind the maximum average of 16 inches is at Negar, and the minimum average, 4·3 inches, at Jacobabad. In Madras the highest annual precipitation is 132 inches at Manalore and Calicut; the lowest at Belary and Tuticorin is from 16 to 18 inches, the average of Madras being 44 inches.

The following average annual temperatures at different points in India indicate the tropical character of the climate and the small percentage of cold weather which prevails. At Trichinopoli and Madras, on the southeast coast, the annual averages are 82·8° and 82·4° respectively. On the southwest coast, at Goa and Cochin, the annual average temperature is nearly 80°. At Calcutta it is 79·2°, and at Bombay 78·8°, the latter city being the coolest of the three presidency towns. At the hill station of Simla at an elevation of 7,100 feet the average annual temperature is 54·4°. The highest monthly temperature occurs at Mooltan in June and is 95°; at Delhi it is 94·3. The lowest monthly temperature is at the high hill stations, being at Simla 39·6° in January.

FORESTRY.

In recent years the British Indian government has paid much attention to the preservation of its forests, and is now reaping the benefit in the large income derived from the sale of timber.

The establishment of the government department of forestry is of recent date, brought about by the destruction of forests for fuel, for charcoal, and other wasteful causes. In 1844 and 1847 the subject was first taken up by the governors of Bombay and Madras. In 1864 Dr. Brandis was appointed inspector-general of forestry, and in 1867 the regular training of forestry officers was commenced at the schools of France and Germany, where it is still continued. At present discriminate timber cutting is allowed, but the burning of hill brush is stopped; the forest areas are surveyed and demarked, plantations laid out and maintained, and forestry conservation otherwise carried on.

Forests are classified as reserved and open. The former are the immediate property of the State and are managed by the forestry department, their development being a source of wealth. Cattle are excluded from them, destructive crops and undergrowth destroyed, and the cutting of timber is strictly regulated. The open forests are less carefully guarded, but certain kinds of timber trees are protected. Large amounts of money are annually spent in the plantations, and wherever needful young trees are planted to replace those removed. In 1878 there were 12,000,000 acres of reserved forests; the revenue was $3,320,000 and the expenditures $2,000,000, showing a fair net profit. Ten years later, in 1888, there were 43,520,000 acres of state forest land, the net revenue after deducting all working expenses being $2,020,000.

The British officials generally hold that the effect of forest denudation on rainfall is doubtful and much disputed. Contrary to what might have been expected, there is no evidence to show whether the actual rainfall has decreased or increased in consequence. They all agree, however, that forest destruction has acted injuriously by letting flood waters run off too rapidly and that these waters are lost. They also do much damage as floods. Three-quarters of a century ago immense tracts of southern India were overspread with jungle and the slopes of the Ghauts were universally timber clad. The most of the level woodland has since been cleared for cultivation and the timber cut down for fuel. But another and scarcely less evil has resulted. Formerly the water was partially protected from evaporation by the sheltering trees. Its flow on the surface was mechanically reduced by the jungle grass and tree trunks; it had time to be absorbed by the vegetable mold and to sink into the earth, thereby insuring the permanence of the natural springs. Not till this was done did the residue find its way to the rivers, and then at a comparatively tardy pace. Now, however, as a rule the rivers are in violent flood for about as many days as they used to be for weeks in moderate flood.[1]

[1] W. T. Thornton, Journal of the Society of Arts, London, 1878, vol. 26, page 279.

CHAPTER III.

HISTORY AND ADMINISTRATION.

HISTORY OF IRRIGATION WORKS.

Among the first mention made of the irrigation works of India are those of Arab historians of the works constructed by the early Mohammedan emperors in the northwest provinces and in the Punjab. Small works, especially tanks, probably existed at much earlier dates in southern India.

It is related that about 1351 A. D. the Emperor Feroze Toghlak built fifty dams across rivers for the promotion of irrigation, and thirty reservoirs for irrigation purposes. The first important canal specifically mentioned was built by the same emperor, and was taken from the Chouting River to Hansi and Hissar. Fifty years later this canal became partly disused after the emperor's death. The next important mention of irrigation work is that the great Emperor Akbar constructed in 1567 a canal from the river Jumna. It is stated that this canal was constructed by the aid of forced labor, but the laborers had privileges thereafter of using the water and the superintendent saw that all parties, rich and poor alike, received their share. This was the first Western Jumna Canal. In 1626 the Shah Jehan had the celebrated architect, Ali Murdam Khan, construct the Delhi Canal, which follows much the same line as does the present Western Jumna. At first this canal was constructed on a high bank following the water courses, but the banks burst and the canal became inoperative. The architect then ran a new line as far as Delhi, following the watershed. On this canal an escape was introduced for the discharge of surplus water. It had one channel 60 feet in depth cut through solid rock. About 1753 these ancient Mogul canals ceased to exist owing to the decline of the Mogul power and to the constant wars, which at that time prevented their being kept up.

The Eastern Jumna Canal was also begun by Ali Murdan Khan and headed at the foot of the sub-Himalayas. This canal reached to Saharanpur and beyond. It was abandoned after the first season, owing to its bad alignment, as it was constructed in the lower drainage lines and bottoms. In 1780 Zabita Khan reopened this canal, but it was carried away during the first season and was then abandoned.

The first of the modern irrigation works of magnitude was commenced under the Marquis of Hastings in 1817, when Lieut. Blaine established

the head of supply of the Western Jumna Canal at a point high up on that river. This work was practically a restoration of the old Mogul Canal, following and using the low lines of drainage to Delhi. No bridges were constructed and only earth embankments were used. The new development of these canals is due to Col. John M. Colvin, who in 1820 extended the above project beyond Delhi, and constructed many bridges and drainage works. Ten years later the earth banks across the drainages of Patrala Sombe were replaced by masonry dams.

The line of the Eastern Jumna Canal was surveyed in 1822 by Lieut. Debude and the canal was opened in 1830. The ancient bed was cleared to a depth of 4 feet below the surface level and in general a new alignment was made which was fairly good, following up the highest divide or watershed. Owing to the steepness of fall given at first the levels retrograded and nearly destroyed the canal. Col. Cautley rectified this by the introduction of falls, and in 1840 he introduced better works for the passage of side drainage.

Up to this time the irrigation works of India had been constructed chiefly by the East India Company. In 1858 the Government granted the Madras Irrigation Company and East India Irrigation Company 5 per cent on the capital invested and these companies commenced the construction of works, the Government retaining considerable command over their operations, inspecting the plans and sanctioning the expenditures. Both of these experiments proved costly failures to the state, and in 1867 the Government purchased the works of the East India Irrigation Company when the latter was practically bankrupt. The Madras Irrigation Company has succeeded only one year in paying working expenses, but still carries on works under Government guaranty.

In 1867 the Government decided to construct its own irrigation works and great activity prevailed at once, the Government irrigation force being largely increased. In 1869 schemes for ten years' work, involving $150,000,000 expenditures, were outlined, and the following sums were expended: In 1867, $1,096,000; in 1868, $2,344,250; in 1869, $10,040,000, and so on. The total expenditures for the first ten years actually amounted to $52,850,000. Since then the Government works have generally proved satisfactory investments, and as they have certainly added to the wealth and prosperity of the country and have mitigated the severity of famines, large sums have been annually appropriated for the maintenance of existing works and the construction of new ones.

ADMINISTRATION AND LEGISLATION.

The administration of the irrigation works of India is conducted by the public works department and the engineers are all civil servants in the employ of the British Government. Their status is fixed by law, their promotions are usually by seniority as in the army or navy, and like the members of those branches of the governmental service they receive

stated salaries according to the grades they occupy. They are entitled to leaves of absence and furloughs, and are retired with pensions after certain periods of service.

By parliamentary act of August 2, 1858, all the territory of India was vested in her majesty the Queen. All tributes and payments are received and disposed of in her name. In the British cabinet the secretary of state for India was vested with the powers previously held by the board of control under the old East India Company régime, and later on by act of January 1, 1877, at Delhi, India, her majesty assumed the title of Empress of India.

The executive authority of India is vested in a governor-general called the viceroy, who is appointed by the Crown and acts under orders of the secretary of state for India. He is empowered in council to make laws for all persons, whether British or native subjects, foreign or otherwise. The governor-general has a council of seven members whom he consults in the formulation of all laws.

Of the larger presidencies the governors of Bombay (including Sind) and of Madras are separately appointed by the Crown, and have each their own council and civil service, and in all orders they directly address the secretary of state. Bengal and the northwest provinces have lieutenant-governors and a legislative council, but these officers are appointed by the governor-general of India. The other minor provinces have lieutenant-governors or commissioner magistrates, but no councils or legislative powers. Each province is divided into districts, at the head of which is a deputy commissioner. Below this officer is a commissioner and joint magistrate, a deputy collector, and minor officers.

India is divided into British territory and the native states. The former is governed as above described, the latter by native princes, with the help and advice of a resident at his court who is called a political agent and whose duties are purely diplomatic. The highest land officer in nonregulation provinces, as the central provinces or the Punjab, is a deputy commissioner. This officer collects revenues and administers civil justice. He is the unit of administration, the sole responsible head of his jurisdiction, and on his energy and character largely rests the efficiency of the Indian government. In India there are 239 districts under deputy commissioners. These districts each average in area 3,778 square miles, and have each a population of 803,000. They are divided into divisions, and these again subdivided into the ultimate unit of subdivision, which is known as a tahsil. The subdivision is in charge of an assistant magistrate or executive officer, and the tahsil in charge of a deputy collector or fiscal officer. Land is the main source of revenue of the Indian government, and hence the levying and collection of the land tax is the main work of the administration of that government.

In Bengal permanent settlements have been largely made. The zam-

indar or headman of a village makes the settlement for the whole village for the government, he taking from each cultivator his portion of revenues and retaining for himself a proportion of the same for paying the revenue. In Madras the cultivator is the rent-paying unit, as the zamindar is in Bengal. In Bombay revenue settlement is proceeded with as elsewhere, only in more detail, by a careful revenue land survey; each field is marked out, measured, and assessed separately. This method is simple, as the government recognizes only the owner of each field. With these owners terms of settlement are made for periods of thirty years. In the Northwest provinces and the Punjab the village is taken as the unit, as is the case in Bengal, and the payment is made to the government by the village. Terms of settlement are also made there for periods of thirty years.

In order to convey a clear understanding of the method of promoting irrigation development in India, it is essential first to give a brief outline of the present attitude of the English rulers toward irrigation. At first the Government permitted private corporations to construct and operate irrigation works; the earliest work planned by British engineers being undertaken by a private corporation on a guarantee of interest by the East India Company. During the last thirty years the Government has been active in the promotion and construction of nearly all good works projected. These projects are studied, examined, and reported on usually several times during a series of years, and when the Government is finally satisfied with them, either as financial investments or as measures for the relief or prevention of famine, the work is sanctioned and the funds for its construction appropriated.

The government of India is as a rule greatly in favor of the extension of irrigation works. It encourages enterprises by granting loan funds for the construction of works whenever it can be proved that profits, increase of interest, and all the maintenance charges will probably be derived. It also constructs works as a means of famine relief in certain places, even when profits can not be obtained. The government further fosters the use of irrigation waters by placing the water rates very low, or by even giving water away in years of scarcity. As shown in the succeeding acts, the government of India has entire control over all sources of water supply and so exercises it as to make it the greatest benefit to the community at large. The powers of control over the waters for irrigation are entirely centralized.

Each province of India has a separate branch of the public works department known as the irrigation branch, at the head of which is a chief engineer, generally also secretary to government of that province, and over all the chiefs of engineers is an inspector-general of irrigation attached to the staff of the governor-general of India. The officers in the upper grades of the irrigation branch are nearly all Europeans, and are recruited from the royal engineers, or from civil engineers educated in well known colleges either in England or India. The civil

engineers from England receive a technical education at Cooper's Hill College, and the majority of those from India are educated at the Thomason Civil Engineering College at Roorkee, or at the colleges in Bombay or Madras. The lower grades of officers are composed of selected noncommissioned officers and soldiers and from natives who have passed an examination after studying for a period at some college.

The chief engineer is the head of the department in the province, and this latter is divided into circles presided over by superintending engineers. Each circle is again divided into divisions, over which executive engineers preside. Each division is again divided into subdivisions, of which there are generally several under the charge of an assistant engineer. This concludes the list of the upper grades. Under the assistant engineers again come the lower grades of subordinates who have charge of the different works.

Besides the engineering establishments proper, there is the revenue establishment which works in conjunction with it, and whose duties are mostly concerned with the administration and the measurement of the fields for assessment. This establishment consists chiefly of natives, and is presided over by a deputy magistrate under whom are zilahdars, ameens, and patrols.

All of the upper grades—that is, from the assistant engineers upward, including the deputy magistrate—have to pass an examination in canal law, and are given magisterial powers which enable them to inflict punishments for breaches of this law. The powers conferred vary with the standing of the officers. The executive engineers may pass on estimates within certain limits connected directly with the construction or maintenance of works in their division. All estimates involving considerable expenditure are sanctioned by the superintending engineer within certain limits, beyond which the sanction of the chief engineer, practically that of the government of the province, is required. All large projects, such as a new canal system or storage reservoir, pass to the inspector-general, and are referred by him to the Government of India and to the secretary of state.

The rules, regulations, etc., by which water is served to cultivators, are detailed in the canal acts, given further on. In irrigating districts water is served to cultivators on certain days, very often on three days in one week, or possibly they are allowed to use it during one week and are deprived of it for another. The period in which they are not allowed water is known as a period of "tatil," an Indian word meaning closed. The breaches of "tatil," or taking water when its use is not allowed, render the individuals committing the act liable to fine or imprisonment. The executive engineer of the division has entire control over the distribution of the water, and complaints regarding scarcity, repairs, misappropriations of water, etc., are all referred to him, and he either decides them himself or empowers the supervisorial officer or deputy magistrate to do so. The assistant engineer is generally a

European, and his right-hand man, as far as irrigation matters are concerned, is the deputy magistrate, who is generally a native of some standing and education. The assistant engineer has magisterial powers, and his time is largely employed in trying cases and settling disputes. Zilahdars, of which there are generally two under the assistant engineer, have under them 5 or 6 ameens, under whom are from 8 to 10 patrols. These latter note the fields as they are irrigated, and when the irrigation is complete their measurement is made by the ameen, the whole being superintended by the zilahdar, who is held responsible for the correctness of the measurement.

The first act bearing with any importance on irrigation legislation was Act VII, by the governor-general of India in council, passed April 12, 1845, and entitled "An act for regulating the levying of water rent, tolls, and dues on certain canals of irrigation constructed by the Government in the northwest provinces and the protection of said canals from injury." From clauses in this act the following extracts are made:

> And it is hereby enacted that the said lieutenant-governor of the Northwestern provinces shall be competent to draw out rules to regulate the levy of water rent and the supply of water for irrigation. * * * The rules thus drawn out shall be published for general information in the Government Gazette.
>
> And it is hereby enacted, that all balances of water rent due for lands irrigated by the canal shall be levied, either by temporary deprivation of the benefits of the canal, or by the same process as is prescribed for the recovery of balances of land revenue.
>
> And it is hereby enacted, that whoever willfully causes any obstruction to any of the said canals, or to any of the water courses drawn and supplied therefrom, or damages the banks of the canal, or the works constructed for its maintenance, or willfully defiles the water in the canal, shall be liable to the penalties hereinafter described.
>
> And it is hereby enacted, that all persons offending against the provisions of this act shall be punishable, on conviction before the magistrate, by imprisonment without labor for a term not exceeding fourteen days, or fine to an amount not exceeding 50 rupees [about $25], or both; and in default of payment of such fine by additional imprisonment for fourteen days.

On May 31, 1845, the lieutenant-governor of the Northwest provinces, under authority of the above act, passed resolutions regarding various canals, from which the following extracts are made:

> In conformity with Section VIII of the aforesaid act, the superintendents of the said canals are invested with the powers of deputy collectors for the levy of rents, and of joint magistrates for the enforcement of penalties under the aforesaid act; and their assistants are declared competent to exercise the same powers under their directions, and on their responsibility. The subordinate establishments of such superintendents have the power of subordinate revenue and police officers for the aforesaid purposes. An appeal lies direct to the commissioner of the division against orders passed by the superintendent or his assistants in the capacity of deputy collector, and to the sessions judge, against orders passed in the capacity of joint magistrate.
>
> When it may be more expedient to give water on contract rather than according to the surface irrigated, the terms of contract may be as follows:

Where the water flows naturally, 2 rupees [$1] per annum for every square inch of opening taken from the summit level of the water, and having a free course.

In the event of any person secretly taking water from the canal in any manner, for which rent is leviable, without coming under engagements to pay the rent, or secretly taking more water than he has engaged to pay for, he shall be chargeable with double rates for all water so taken.

All land brought into cultivation within 20 yards of the canal or any branch stream from it, subsequently to the construction of the channel, shall pay water rent, whether taking water or not; and similarly all land cultivated from wells which have been dug or reopened within 20 yards of the canal boundary, or within 10 yards from any branch stream from it, subsequently to the construction of the canal, shall pay water rent, whether taking water from the canal or not.

When, from the carelessness of cultivators, either in not properly closing the heads of their water courses, or in leaving the water courses in bad order, the water overflows and spreads over waste or fallow land, a fine shall be levied not exceeding the highest rate of water rent leviable on the extent of land flooded.

It shall be in the power of the canal officers to close the whole of the branch water courses from sunset to sunrise for the purpose of forcing the water onto the lower parts of the canal; and also, when necessary, for any period not exceeding three days in a week. At other times the water shall be at the command of the cultivators, provided it be in the power of the canal officer to furnish a supply. Persons taking water once so as to benefit a crop shall be liable to the charge for the whole year, or the whole crop, as the rate may be leviable.

Special agreements between individuals and the superintendent for the use of water for irrigation, for driving machinery, or for other purposes, on other terms than are embodied in these rules, shall be constructed as other ordinary contracts are.

In addition to these, rules are laid down defining the powers of the superintendents and their assistants and other officers on the works, as well as rules giving the charges which villages or individuals are subject to who do not take water for irrigation, but who use it for watering live stock or for domestic purposes. The charges for filling reservoirs or tanks are also specified, as are the tolls for rafts or boats. The right of ownership of water was summarily settled in India in 1873 by the passage of "An act to regulate irrigation, navigation, and drainage in northern India." The preamble tersely states the claims of the Government thus:

Whereas, throughout the territories to which this act extends the Government is entitled to use and to control for public purposes the waters of all rivers and streams flowing in natural channels and of all lakes and of the natural collections of still water, etc.

This statement of rights is perfectly plain and in India the Government has no need to use its power to enforce these claims. This act is known as "Northwest canal provinces act No. VIII of 1873," and lays down all of the fundamental laws governing canal administration in those provinces.

The principal act establishing the laws covering irrigation in the presidency of Bombay is act No. VII of 1879, which was amended in 1880 by Bombay act No. III. The preamble reads as follows:

Whereas, it is necessary to make provision for the construction, maintenance, and regulation of canals for the supply of water therefrom, and for the levy of rates for the water so supplied in the Bombay presidency, it is enacted, etc.

The act then goes on to define what are understood as canals, water courses, and drainage works; defines the various officers appointed by law, with their powers, and makes the following further provisions:

Whenever it appears expedient to the governor in council that the water of any river or stream flowing in a natural channel, or of any lake, or any other natural collection of still water should be applied or used by the Government for the purpose of any existing or projected canal; the governor in council may, by notification in the Bombay Government Gazette, declare that the said water will be so applied or used after a day to be named in the said notification, not being earlier than three months from the date thereof.

At any time after the day so named any canal officer duly empowered in this behalf may enter on any land, remove any obstruction, close any channel, and do any other thing necessary for such application or use of the said water, and for such purpose may take with him, or depute, or employ such subordinates and other persons as he deems fit.

Following this, equally broad powers are given canal officers to enter or examine land in connection with projected works, to inspect and regulate water supply, to enforce repairs, and prevent accidents. Additional regulations are formulated providing for suitable canal crossings, the removal of obstructions to drainage, and the construction of drainage works. Further:

Every owner of a water course shall be be bound to construct all works necessary for the passage across such water course, of canals, water courses, drainage channels, and public roads existing at the time of its construction, and of the drainage intercepted by it, and for affording proper communications across it for the convenience of the occupants of neighboring lands to maintain such water course in a fit state of repair for the conveyance of water.

This act further provides for compensation in cases of damage, the remission of water rates when allowable, compensation on account of the interruption of water supply, and for further causes.

Part 4 of the act lays down the rules for the levying of water rates, and opens by stating that "such rates shall be leviable for canal water supplied for purposes of irrigation, and for any other purpose as shall from time to time be determined by the governor and council." Special rates are laid down to be charged where persons use water unauthorizedly; also when water is permitted to run to waste. Provisions are made for the obtaining of labor on the canals in times of emergency, and penalties are provided for damage done to canals and other works.

Land tenures.—In southern India, including Bombay and Madras, while the landholders do not own land, they possess certain rights in it, such as the right to hold and to till it so long as they make payment of part of the produce to the Government, while the Government possesses the right to a share of the land revenue. In northern India, including the Northwest provinces, Punjab, and Bengal, there is a class of supe-

rior landholders between the cultivator and the Government. The cultivator tills the land and pays the rent to the landlord, and the latter pays a portion of this to the Government. These proprietors are associated together in villages with an elected or hereditary head, who is responsible to the Government for the rent of the entire village. In Bengal there are about 130,000 landlords or heads of estates, who are entitled zemindars, or may even be Rajahs. In the central provinces there are 28,000 separate estates. In the Punjab 1,695 zemindars hold 5 per cent of the total area of that province; 33,020 village communities hold 91 per cent of the total area, and 1,711 other landholders have charge of 4 per cent of the total area. In the Northwest provinces the area is divided in about the same proportions among the various classes of holders. In southern India, where the cultivators or ryatwari hold the land, it is leased to them for fixed periods of thirty years, though they can resign these holdings at the end of each agricultural year. They can sell or mortgage the land, and at the death of the holder his heirs inherit the right to the lease. In Madras there are 2,392,000 ryatwari or individual tenures, on which the average assessment is $5. In Bombay there are 1,367,600 ryatwari.

In these southern presidencies each village is indicated on the revenue map with a defined boundary, and each field is marked out and numbered on the village plan. The different classes of soil are indicated in colors, with a description of the class of tenure, marked in a register accompanying each map, in which are also indicated all particulars of soil, tenants, and amount of assessment. The size of the field is determined by the extent of the particular variety of soil, which can be cultivated with the assistance of a pair of bullocks. Thus in light dry soil a field will constitute 20 acres, in heavy dry soil 12 acres, and in rich garden land 4 acres. Some of the circumstances affecting the classification of land and the value of the fields are the position of the latter with respect to the village, the facilities for agricultural operations, the character of the soil, and the opportunities for irrigation.

CHAPTER IV.

WELLS AND INUNDATION CANALS.

CLASSES OF WORKS.

The irrigation works of India are divided by the engineer into two great classes, (1) gravity irrigation and (2) lift irrigation. The former includes four great heads, namely, perennial canals, intermittent canals periodical canals and inundation canals. The water supply for these may be supplemented by storage works. This will be treated as a third class. Perennial canals are taken from the rivers the discharge of which at all times suffices for the irrigation of the lands without the aid of storage. Intermittent canals are taken from intermittent streams the water of which must be stored in order to furnish a contant supply. Periodical canals are taken from streams having an available supply during the rainy season only, and are used altogether in the cultivation of the summer crop. Inundation canals are taken from rivers having a constant discharge of some magnitude, but are fed by those rivers only when in flood.

Lift irrigation is chiefly illustrated by wells. Of these there is little to say, although the area irrigated by them is considerable. They are used in a country where labor is cheap, and are valuable adjuncts of irrigation, catching the seepage water from the canals and irrigated fields which otherwise would be wasted. Owing to the cost of labor it is doubtful if they will ever be used to any extent in America.

Canals are divided into two great classes, those for irrigation only and those which are also employed for purposes of navigation. The conditions required to develope an irrigation canal are usually, first, that it shall be carried at as high a level as possible, so as to have sufficient fall to irrigate the land to a considerable distance on both sides of it; second, that it shall be fed by some source that will render it a running stream in order that the loss of the water consumed in irrigation may be constantly replaced in the canal. The chief requirement of a navigable canal, on the contrary, is that it shall be as nearly as possible a still-water canal, so that navigation may be equally easy in both directions, and no water is lost except by evaporation or absorption and at the points of transfer from the higher to the lower levels. Hence it is most economically constructed at a relatively low level. In India, among the earlier great perennial canals, it was considered the rule to make them navigable as well as irrigable, but since the introduction of

modern modes of transportation, the development of the railway system, and the construction of excellent metalled roads throughout the country, the authorities have generally come to disapprove of the use of irrigable canals for navigative purposes.

EXTENT OF IRRIGATION.

In the presidency of Bombay there are 34 irrigation works in operation, of which 3 are major protective works, 7 are major productive works, and the remainder are minor protective and productive works. The total capital outlay on these is $7,870,000. The total gross revenue during 1889 was $75,000, and the net revenue was $46,000. The area irrigated during that year was 79,195 acres, of which about three-fifths were autumn or dry weather crops. The gross revenue assessed was $1.73 per acre and the water rate averaged $1.14 per acre irrigated. This water rate ranged, however, from 35 cents to $4 per acre, the maximum price being very unusual and due to the large amount of sugar cane which was irrigated on the canal where that rate was levied. The working expenses per mile varied from $70 to $200 and the working expenses per acre irrigated varied from 30 cents to $2. The latter high figures were in both cases charged on the Mutha Canal, where a large amount of sugar cane was under cultivation.

In the Sind the net area cropped in 1887 was 1,567,470 acres. The area irrigated from canals was 1,330,660 acres, irrigated from other sources 220,550 acres, and the total area irrigated was 1,551,210 acres. The area under wet-weather crops was 1,407,780 acres and under autumn crops about 186,000 acres. The irrigation's share of the net revenue for that year was $1,196,500. The financial statement for the works of the Sind for 1889 was as follows:

Gross revenue	$6, 754, 000
Working expenses	507, 600
Net revenue	616, 000
Net profit, less simple interest on the borrowed capital	517, 300

The average rainfall for all of Sind during the year was 4·98 inches.

In Madras the great irrigation works are constructed in the deltas of the principal rivers. The approximate cost of the works of Madras, without interest, to the year 1878 was $18,305,000, and the approximate area commanded by canals was 2,619,730 acres.[1] The total area of cultivation due to irrigation in Madras in the same year was 5,155,800 acres and the total revenue was $9,682,000.

In Bengal, at the end of 1877, there were in operation 844 miles of main canals, of which 614½ miles were navigable; they commanded an area of 2,698,800 acres, of which 1,768,800 acres were actually irrigated. The total capital outlay on the three major works, viz., Midnapore, Orissa, and Soane canals, was $18,803,000.

In the Punjab the capital outlay in 1889 for major works only was

[1] R. B. Buckley, the irrigation works of India, London, 1880, pp. 12 and 23.

$16,316,000; the total net revenue was $797,000, or 4·5 per cent interest on the capital outlay. On inundation works the capital outlay was $620,000, and the interest on this outlay varied from 10·8 per cent as a minimum to 181·5 per cent as a maximum. In this province there were 3,968 miles of main canals and 6,441 miles of distributaries. The working expenses per acre irrigated were from 25 to 60 cents and the establishment cost from 10 to 25 cents per acre irrigated. The area irrigated during the summer crop was 1,238,000 acres, and during the autumn crop 1,376,200 acres.

The Northwest provinces, including Oudh, have an area of about 55,000 square miles, of which 25,500 square miles may have been said at the end of the year 1887 to be protected by irrigation works. The total outlay on irrigation works in these provinces at the end of 1888 was $26,256,000; the net revenue for that year was $1,000,000, which is 3·8 per cent interest on the capital outlay. The net interest on four principal works, the Upper and Lower Ganges, Agra, and Eastern Jumna canals, was 4·1 per cent. The total working expenses for the same year were $860,000. There were in operation 1,427 miles of main canals and 6,566 miles of distributaries. The total area under irrigation was 1,517,290 acres, of which 612,440 acres were summer crops and 904,850 acres were autumn crops. The value of the principal crops was $10 per acre.

FINANCIAL AND AGRICULTURAL RESULTS.

Of major productive works, the capital for which has been provided from borrowed money, there are 34 in the six principal provinces.[1] The capital expended on these works to the year 1888 was $128,113,375, while the sanctioned estimates for the completed projects were $142,604,470. These 34 major works are designed to irrigate, when fully completed and irrigation has been fully developed, something more than 10,000,000 acres. Of 5,520 miles of main and branch canals no less than 2,250 miles are navigable. The cost of making these canals navigable can not be readily ascertained, but should be eliminated in determining the true cost of each irrigable acre. The Mutha Canal, in Bombay, which is the most expensive of any canal of its kind, derives a considerable income from the supply of water for domestic purposes to the city of Poona. It may be said that the works of this class cost $14 for each acre irrigable. Of the 10 largest of these major works, the most expensive, the Orissa system in Bengal, cost $28 per acre, and the Ganges Canal, which covers the largest area of all, and is at the same time the cheapest, cost a little under $10 per acre.

In addition to the 5,520 miles of main canals constructed in these 34 systems there are 17,135 miles of principal distributaries. Up to the present time only 10 of the 34 major productive works have been worked

[1] A statistical review of the financial and agricultural results obtained from the irrigation work of India, R. B. Buckley, Calcutta, 1889, pp. 1–4 and 13–17.

at a profit of more than 4 per cent, but the profit from these 10 has been more than sufficient to cover the deficiencies of the other 24. The net result is that the works of this class have covered the interest charges, with a gross excess to the Government of nearly $15,000,000.

Among the six provinces in which this class of works lie, Madras and Sind are preeminent as those in which all the works have been in operation for more than ten years and are thoroughly successful. In the Northwest provinces and Punjab there is little doubt that all of the works will finally be successful, while the older ones already pay well. One of the youngest works, the Sidnai Canal, is very remarkable in having paid nearly 14 per cent on its capital during the second year it was in operation. Of the Bengal works little hope can be entertained, as the normal rainfall there is too large and too regular to make irrigation an urgent requirement for agricultural prosperity. These works must be looked on as a protection against occasional drought and famine rather than as a source of profit.

Of major protective works there were in operation in 1888 in the six principal provinces 6 works, the capital expenditure on which was $7,518,550. These works are designed to irrigate 610,466 acres, at an average capital cost of nearly $10 per acre. There are completed in these systems 302 miles of canals and 535 miles of main distributaries.

Of minor works the capital of which has been provided from the general revenues of India 54 were in operation in 1888, distributed throughout nine provinces, including Burmah and Beluchistan. The capital expended on these works was $19,943,415 and the net revenue was $830,495. The percentage of net revenue on the total capital outlay to the end of the year under consideration averaged 4·16 per cent, and varied from naught in the case of some works in Bombay to 18 per cent in some of the works of Burmah. These works comprise altogether 3,416 miles of canals, 2,648 miles of distributaries, and render irrigable an area of about 2,090,000 acres. The works of this class taken collectively are more remunerative than the major productive works which were specially constructed to pay more than 4 per cent. The numerous small works in Bombay are unproductive, and there is but little hope that the returns derived from them will materially improve.

From the agricultural statistics given by Mr. Buckley it appears that in 1888 there were irrigated by major productive works alone over 5,672,000 acres, and these works would, if fully developed, irrigate 10,100,000 acres. The rate of working expenses per acre on all the classes of works varied between 40 cents and $2.60. The gross area irrigated by all classes was more than 12,000,000 acres. The average water rate charged was less than $1.40 per acre. The average value of crops per acre varied from $10 to $35, and the percentage of rate charged on the value of the crop was between $3.30 and $8.25. Gauged by the standard of the percentage of rates charged, theoretically the gauge of the severity of the charge on the cultivator, the Bombay

rates, which are actually the highest, are shown to be the lowest, and this is really the fact because of the very high value of the sugar-cane crop so extensively cultivated in that province. The gross value of the entire area irrigated in 1888 by all the four classes of irrigation works administered by the government reached the sum of $155,000,000.

"At a moderate compensation," says Mr. Buckley, "it may be said that one-half of this sum is the increased value of the outturn from the fields due to irrigation from the canals." This figure shows perhaps more readily than any other the value of the agricultural interests which are bound up with irrigation works of India.

OBJECTIONS TO IRRIGATION.

In 1845, during surveys for the great Ganges Canal project, a committee was appointed, under instructions from the governor-general of India, for the purpose of reporting on the causes of unhealthfulness which existed along the line of the Delhi Canal, and ascertaining whether injurious effects on the health of the people were likely to be produced by the contemplated Ganges Canal. Their report is one of the most complete and exhaustive ever prepared relative to the effects of canal irrigation on the health of the neighborhoods irrigated. The members of the committee were Maj. W. E. Baker, R. E., president; Surgeon T. E. Dempster, and Lieut. H. Yule.[1]

Among the more important conclusions reached were:

(1) That in considerable portions of the district under the influence of existing canals sickness has been largely developed.

(2) That this sickness is not attributable to the results of irrigation but to the canal works or water courses of private individuals having intercepted the natural drainage of the country, and having thus led to the formation of swampy tracts diffusing malarious influence around them.

(3) That where the soil is light and the irrigation carried on by means of main distribution channels, all the advantages of canal irrigation may be gained without the prevalence of any of those evils to be found in localities differently constituted.

(4) That if care is taken to irrigate only that land which has an open soil and which has such slope and low drainage lines as to prevent water-logging, no unhealthy results will follow irrigation.

(5) That irrigation with free surface drainage may be regarded as quite innocuous.

(6) That when malarious influences are developed by irrigation their effects are almost strictly local.

This committee recommended that the Ganges Canal be kept as much as possible within soil, that is that its ordinary surface level should be below that of the country. That earth wanted to complete embankments be never obtained from excavations made outside the canal ex-

[1] Col. Sir Proby T. Cautley, the Ganges Canal, London, 1860, vol. 3, p. 24.

cept from such localities as would readily admit of drainage. That the canal and its branches be taken as much as possible along the watershed of the country so as not to interfere with drainage: and that irrigation be prohibited in localities which appear to possess naturally a malarious character.

On this same subject Capt. Douglass Galton, of the Army Sanitary Commission, wrote an interesting article,[1] in which he gives several instances where localities that have been sandy deserts devoid of vegetation had by means of irrigation been converted into rich grain fields. For many years the irrigation measures have not been attended by any effects prejudicial to health. The subsurface water had been, however, gradually rising nearer to the surface, and at the same time fever had greatly increased. In Madras where during drought little fever prevailed, during the southwest monsoons large districts were flooded and fevers became prevalent. It was observed in the Punjab that the fever appeared not to have been generated so much during heavy rains as from the conditions which follow them, and the remedy required is the rapid removal of water to prevent stagnation. Nearly everywhere that low-lying tracts are found saturated with moisture the people were fever-stricken. Capt. Galton sums up by saying: "The whole evidence shows the high fever death rate to be largely due to the stagnating water in the soil." The objections on the score of health are, generally defective drainage, the stagnation of the water, the deterioration of well water by infiltration or the application of too much water. These are all remediable and within the control of the engineer.

On the line of the Mutha Canals in Bombay where sugar cane is extensively cultivated, it is found that the stagnating waters retained by the roots of the plants are producing fevers, and as a consequence, the Government is endeavoring to reduce the area under sugar cane, hoping thus to reduce the extent of the fever. In the Northwest provinces regular observations are made of the height of the spring level, and these are submitted annually with the revenue reports, thus indicating by the rise of this level the necessity for artificial drainage works to prevent supersaturation of the soil.

Another of the more important ill effects of irrigation is the production of alkali, or the efflorescence of alkaline salts on the surface of lands irrigated. That the effect of irrigation, however, is not altogether bad in this respect may be surmised from the following remarks made before the Famine Commission by Maj. Grey, C. S. I.:[2]

> Canal irrigation has rendered fit for cultivation large tracts in the Bahalpur State which were utterly unculturable because of alkali, and that when heavily irrigated the salts were washed off or driven into the soil.

Mr. E. O'Brien testified to practically the same effect, and stated

[1] Capt. Douglass Galton, Sanitary Progress in India, Journal of the Society of Arts, London, 1876, vol. 24, p. 526.

[2] Report of Famine Commission, London, 1881, Appendix V, p. 4.

that if properly effected, canal irrigation is a cure for efflorescence. Mr. E. C. Corbin found that on lands covered by efflorescent salts canal water has eradicated the evil of alkalinity, and that land before worthless is now highly productive.

In all probability the most valuable report on the effects and causes of alkalinity was that made by the "Reh" (alkali) Commission for the Aligarh district of northern India, of which Mr. H. S. Reid was president, and among the members of which were Mr. Medlicott, the superintendent of the geological survey of India, Mr. Burch, the director of agriculture and commerce, and others. In this report, which was printed in full by Prof. E. W. Hilgard,[1] of the University of California, the following is the substance.

Tracts rendered unculturable by excess of alkali exist more or less throughout the Northwest provinces of India, but it is due to the introduction of extensive irrigation works that no appreciable increase of the area of alkali lands is perceptible. In the earlier of these irrigation works no provision for drainage was made and they were simply built for the purpose of affording an abundance of irrigation water. Gradually, however, it was noted that crops began to languish and the lower lands were rapidly being converted into swamps, while on the higher lands were formed alkali spots which were rapidly enlarging, and that new spots were being formed where none had previously been known. The cause was apparent, and there was no difference of opinion regarding it. Not only near but within even considerable distance from the canals the subsoil water level has been raised from a depth of 50 feet to within a few feet of the surface. This subsurface water has brought up with it by a leaching process all the alkali salts existing within the subsoil thus traversed, and by evaporation these salts were diffused throughout the many feet of substrata, accumulating at the surface to such an extent as to render cultivation unprofitable and even to make the soil absolutely barren, and covering it with a white crust of salt. While the committee agree that the most damage has been brought about by the rise of this subsurface water by the sidewise soakage from the high-lying canals, they state that the trouble has been greatly aggravated by the extravagant use of water by the peasants. The remedies suggested are as follows:

First, a deepening of the two canals so as to lower their water levels and hence that of the soakage subsurface level at least several feet below that of the land to be irrigated. Secondly, they recommend the establishment of a system of drainage. It unfortunately happens that both of these measures frequently offer great engineering difficulties in a region where, from the scantiness of rainfall the surface conformation of the country is not favorably sculptured.

The investigations of the committee all point in one direction, viz, that the introduction of canal irrigation is the principal cause of alkali

[1] College of Agriculture, Appendix 7, Report of 1886, Sacramento, 1886, p. 34.

extension, and that when the removal of soakage water takes place almost exclusively by evaporation, irrigation by canals must end in a destructive crop of alkali where the indigenous resources of the ground in that way were comparatively harmless. *As a remedy the members of the committee almost unanimously proposed deep drainage*, and great importance was attached to keeping the natural drainage of the country open. No dams or cultivation should be allowed in the natural drainage courses, and the more water that can be gotten to flow away from the canal tracts the better, while any alkali that it may carry away in solution is so far a gain. The committee agreed that the lavish use of canal water which the gravity-flow system encouraged caused extensive saturation of the soil. As a résumé of the evil effects of irrigation it becomes apparent that they are almost all produced by a wasteful use of water and careless alignment of canals, advantage not being taken of the natural drainage of the country, together with careless irrigation of those portions of the country which are too low to afford natural drainage. It is apparent that alkalinity, once fairly developed, can never be cured under existing conditions of water level, and the same is doubtless true of malarious fevers. The primary conditions of alkalinity and fever may be expressed as defective water circulation, though mere surface drainage is ineffectual for the removal of alkali.

Relative to double cropping the soil the chief engineer of the Punjab said in his report for 1889:

> The area double cropped on the Bari Doab Canal was 14.1 per cent of the whole area and nearly one-fourth of the autumn crop. It seems to be slowly increasing, which is not satisfactory, as the practice is generally detrimental and exhausting to the soil.

Similar opinions have been expressed by other engineers, and the practice of double cropping is not encouraged unless accompanied by the free use of fertilizers.

Regarding the effect of irrigation on the navigation of rivers and its effect on riparian rights, Col. Baird Smith states:[1]

> At the head of the Jumna Canals the Jumna River carries at low season, during four months, a minimum of 3,500 second-feet. The canals use 3,000 second-feet, leaving the river bed practically dry. At Agra, which is about 303 miles lower down the same river, the Jumna carried at the same period about 3,500 second-feet and is an unfordable stream.

This supply is derived from subsurface drainage and seepage from canals, so that the canals have not in the least affected navigation. The Ganges River at Hardwar carries at least 8,000 second-feet, of which 6,700 second-feet may be abstracted by the canal. Still, at Narora, lower down on the same stream, and the head of the lower Ganges Canal, the stream is large enough to admit of 2,000 second-feet being taken by that canal without affecting navigation.

[1] Irrigation in Italy. London, 1856, vol. 1 page 385.

WELLS.

As before stated in classifying the irrigation works, lift irrigation from wells is extensively practiced throughout India. Wells are economically among the most important irrigation works in India, because they are the most general. They vary in depth from 10 to 60 feet, and may be unlined if shallow, lined with stone dry-packed, or with masonry.

FIG. 230.—Paecottah.

The modes of lifting water from wells are of different kinds, viz, by means of a bucket raised by a well-sweep and called the paecottah, extensively used in Bengal; by means of a mot or churus, whereby a

leathern bag is raised from the well by bullocks walking away with a rope. This method is practiced most extensively in the Northwest provinces, in central India, and Bombay. Lastly, by means of the Persian wheel (Pl. CIX), chiefly employed in the Punjab. As an indication of the extent to which wells are employed in irrigation, we find in the Central provinces 650,000 acres irrigated from tanks, while 120,000 acres are irrigated from wells. In Madras there are 31,000,000 acres under cultivation, of which 5,320,000 acres are irrigated by canals and tanks, and 2,000,000 acres by 400,000 wells. In the Northwest provinces in 1888 the area irrigated by wells was 358,600 acres, or 23·6 per cent of the whole area under cultivation. In Coimbatore there are said to be 100,000 wells sunk, in many cases through hard rock, to a depth of 80 or 90 feet, and capable in ordinary seasons of irrigating from 1 to 4 acres each. As a contrast with the utility of canal or tank irrigation it has been estimated that the Ganges Canal alone replaces the work of 300,000 men and 1,300,000 bullocks, besides increasing the value of crops irrigated by wells by 50 per cent.

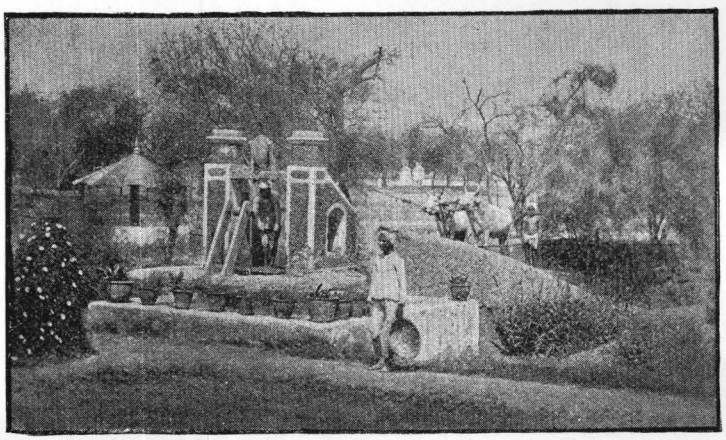
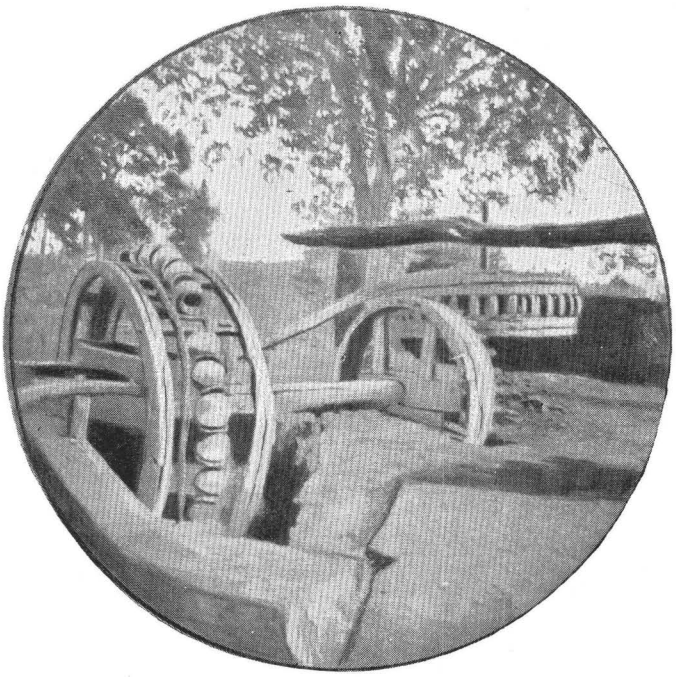


FIG. 231.—Mot.

The paecottah (Fig. 230) is usually worked by two men who labor from six to eight hours daily. Authorities estimate that they will raise from 400 to 2,000 cubic feet per second per day. From moderate depths three men working two paecottahs will water 3 acres a season. The mot (Pl. CX.) is a leathern bucket made of a whole oxhide, and is raised by two bullocks walking down an incline and drawing after them the rope attached to it. When the bucket reaches the surface it is emptied automatically or by an attendant. In Bombay the bullocks usually return by walking backward; elsewhere they are not trained to do this, and they face about to return (Fig. 231). Sometimes two yoke of oxen are used hitched alternately to the rope. From the Calcutta Engineers' Journal it appears that two bullocks working ten hours a day for a season of ninety days will raise with the mot 162,000 cubic feet of water, or about $3\frac{3}{4}$ acre-feet.



PERSIAN WHEEL.

PAECOTTAH.

The Persian wheel (Fig. 232) consists of a large wheel revolving vertically in a shallow well. On its outer periphery are a large number of small buckets. These lift the water and empty it into a trough, whence it runs into the ditches. The wheel is made to revolve by means of a cogged gearing and is turned by two bullocks walking in a circle and hitched to a horizontal sweep. By this method it is estimated that 2,000 cubic feet of water may be raised per day.

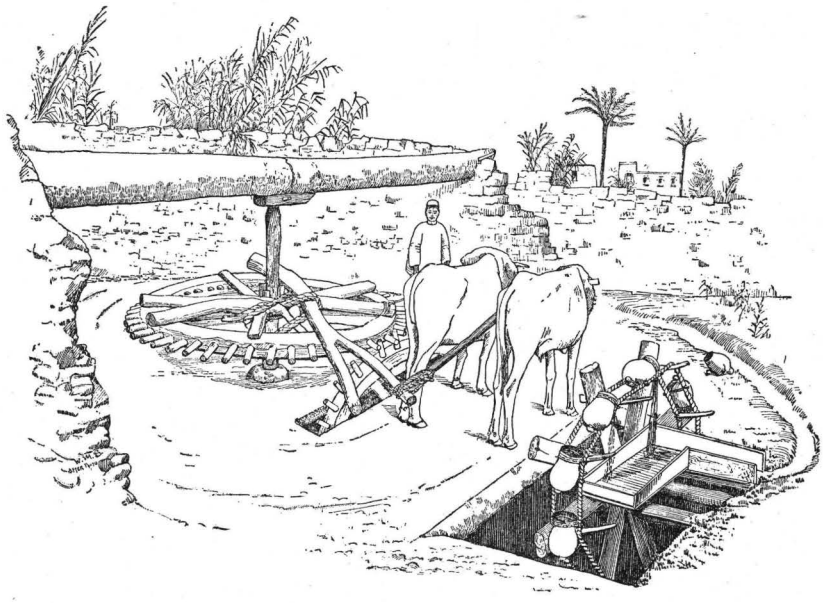


FIG. 232.—Persian wheel.

INUNDATION CANALS.

The inundation canals of India have been constructed and are chiefly used in the valley of the Indus, and as they have no permanent head works they depend for their utility on two conditions generally absent in the United States. Firstly, the stream from which an inundation canal is taken must flow at a high elevation relatively to the surface of the surrounding country; that is, its bed must be practically on the summit of a ridge, as is the case with the lower Sacramento and Mississippi rivers. Secondly, the river must be subject to great annual floods lasting through a long period. Inundation works have been among the most profitable canals operated in India, chiefly because of their simplicity of construction. As a general thing the canals constructed on the borders of the rivers in the Punjab and Sind were used to irrigate the lowlands only. Cuts are made from the river inland for a certain distance, thence the canal line follows the general slope of the country. By these canals the autumn crop is watered when the river is in flood. Large quantities of silt are left in the beds of the canals or heaped up

at their mouths, varying from 1 to 8 feet in depth, and this is cleaned out during the cold season. From the main canal the water is distributed to the fields by branch canals and minor channels in a mode similar to that employed in irrigating from other canals.

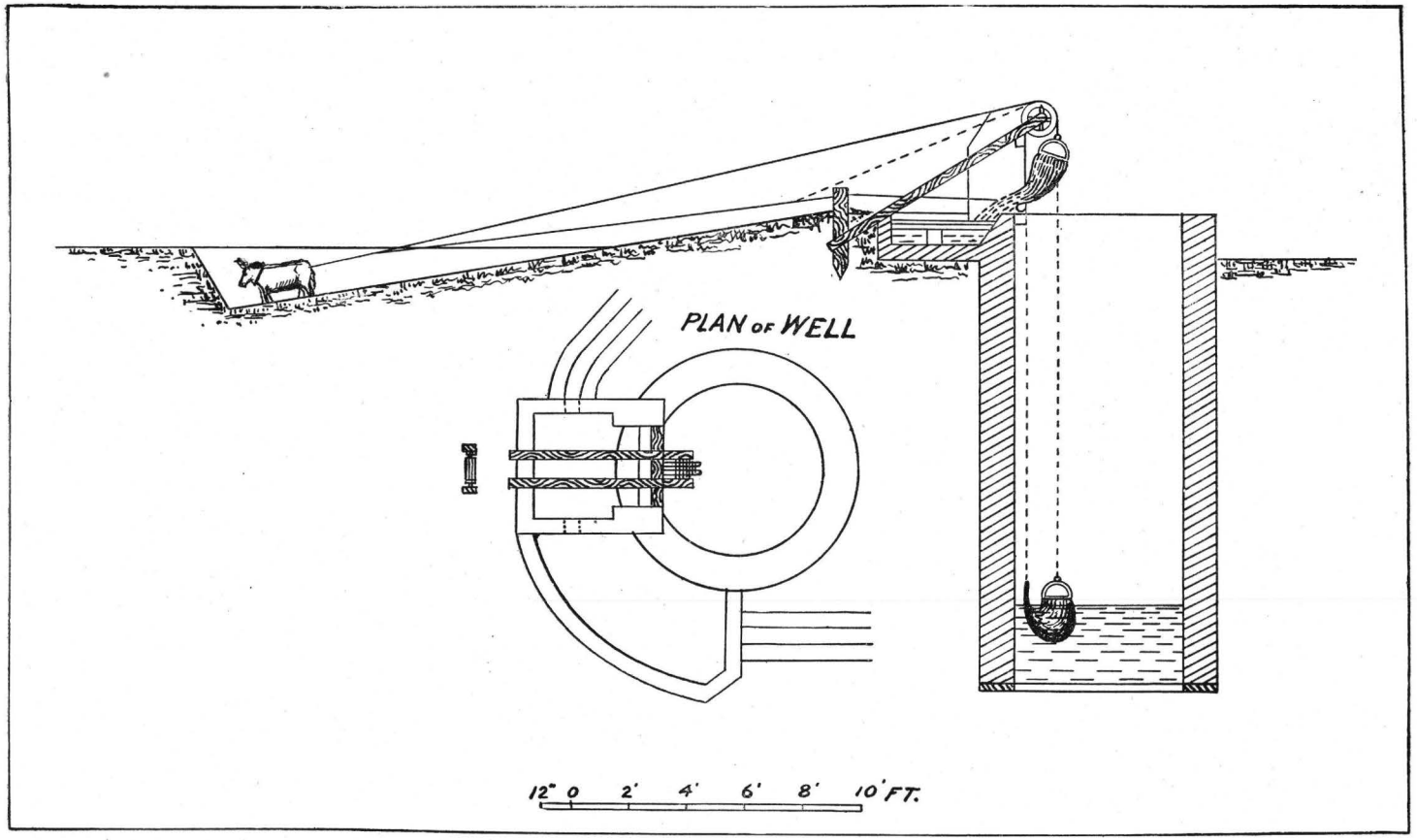
There are no works at the heads of inundation canals to control the supply of water. They are constructed on rivers whose courses are so uncertain that they may at any time desert the head, when the water will have to be brought into the canal by a new mouth excavated the next season. Under any circumstances the deposit of silt at the head is considerable and would naturally be increased by anything in the shape of a dam. The labor in clearing the silt is a heavy annual charge on the benefits received from the water and the numerous deserted channels in various parts of the country show that unless carefully maintained these canals soon become useless.

Channels thus opening direct from the river and unprovided with regulating works are subject to several disadvantages. The current of a river may set on the mouth of the canal or on the bank and wash it away. The supply may become too great in the large floods or may be altogether cut off owing to the destruction of the head or the changing of the course of the river. The violent action on the mouth of the channel may be checked to a certain extent by revetments and groynes and other river-training works, but these also have the effect of diverting the action of the stream from its natural course and may throw it away from the canal head.

The freshets in the Indus commence in March and high flood is most frequent in August. The lower stages commence at the end of October. The velocity of the current in the dry season varies from $2\frac{3}{4}$ to $3\frac{3}{4}$ miles per hour. In the freshets it is from 5 to 7 miles per hour and has sometimes reached a maximum of 8 miles. The width of the water surface of the Indus in low water or the dry season varies from 1,500 to 5,000 feet, the average depth being from 3 to 6 feet. The rise of ordinary floods is from 5 to 7 feet in twenty-four hours and averages 50 feet above low-water level. The highest recorded flood was 92 feet above low-water level.

From the borders of the Punjab the Indus flows for a distance of 450 miles through an arid alluvial plain, almost every portion of which has at some time been swept by the river or its branches. Owing to the deposits of silt the bed and banks of the river are continually rising. It has been estimated that the Indus annually brings down sufficient silt to form an island 42 miles long by 27 miles broad and 40 feet deep. When the river bed attains a certain height the water falls over the bank and the river changes its course. It is this movement which causes the difficulties of irrigation in the Sind and has resulted in the construction of inundation works.

Inundation canals are generally carried away from the river in an oblique direction. They vary from 10 to 300 feet in width and from 4



WELL IRRIGATION—SINGLE MÔT.

to 10 feet in depth, and resemble natural water courses more than canals. The following tables give an idea of the dimensions of some of the larger inundation canals in the Sind, their cost and revenue:

Sind inundation canals.

Canals.	Discharge.	Area irrigated.	Duty, acres irrigated per second-foot.	Rainfall.		Revenue and interest.	
				Irrigation season.	Annual.	Capital outlay to 1887.	Interest at 4 per cent.
	Second-feet	*Acres.*					
Begari	3,186	177,377	55·62	1·94	2·81	$550,000	$21,500
Desert	1,311	70,510	53·78	1·65	2·26	386,000	14,700
Ghar	4,282	168,017	39·24	0·55	1·20	147,000	5,500
Fuleli	5,875	203,817	34·69	4·21	5·03	321,000	12,400
All Sind						3,776,000	144,000

In the Punjab the capital outlay on the five principal inundation works to the end of 1889 was $478,000. The working expenses were $333,000 and the net revenue $145,000. The per cent of net revenue on capital expended on the upper Sutlej Canal was 10·8, while on the lower Sutlej and Chenab Canals an interest of 181·5 per cent was realized. It is stated, however, of the last figures, that this interest is fictitious as the capital outlay does not represent the first cost of the canals, most of which were in existence at the time of annexation by the British. Of the inundation canals of the Punjab there are 2,760 miles of main canals and 870 miles of distributaries. The cost per mile irrigated by these canals varies between 35 and 50 cents, which figures correspond very nearly with the cost of working the perennial canals in the same province. The total area irrigated in the Punjab by inundation canals was 1,220,000 acres, about two-fifths of which were autumn crops.

CHAPTER V.

DELTAIC AND PERENNIAL CANALS.

SOURCE OF SUPPLY.

Perhaps the first consideration in designing any irrigation work is the source of supply. In the case of perennial canals this may be from perennial streams or from storage reservoirs. In either case the Indian engineer deems it necessary first to make a thorough examination of the hydrography of this source to ascertain the quantity of water available and the point of the river's course at which the canal can be taken off. The headworks are almost invariably located high up on the river to command a sufficient level, and if possible to tap the stream where the water is clear and not laden with silt. By thus locating the headworks it is usually possible, owing to the greater slope of the country, to reach the high lands or watersheds of the area to be irrigated with the shortest possible diversion line, or that portion of the canal's course which is necessary to bring the line to the neighborhood of the irrigable lands. This is usually unprofitable, as it does not directly irrigate any land. The disadvantages of locating the canal head works high up on the streams are serious. The country having an excessive fall requires rough hillside cuttings, perhaps in rock, and the line is, moreover, intersected by hillside drainage, the passage of which entails serious difficulties.

WATER DUTY AND EVAPORATION.

In discussing the source of supply the engineer has to determine the quantity of water required and the area of irrigable land. It is then necessary to determine the "duty of water" for the crops to be irrigated, the quality of the soil, and the loss to be anticipated from evaporation and absorption.

The "duty of water" is an expression which is used in India, as in the United States, to indicate the area of land which a fixed unit of water will irrigate, and, as in America, the unit adopted is 1 cubic foot per second of flow, or, as commonly called, one "second-foot." In referring to the contents of reservoirs the Indian engineers usually quote them as holding so many cubic feet of water, but owing to the difficulty in dealing with the billions of cubic feet which a large reservoir will store the author prefers to use the American unit "acre-foot," by which is meant a quantity of water necessary to cover an acre 1 foot in depth

or 43,560 cubic feet. In designing canals in India the expenditure is frequently reckoned per linear mile of canal, and this has been found to be generally from 6 to 8 cubic feet per mile. Such a method of computation is possible only when the main and branch lines of canals have been previously determined, as it enables the engineer to regulate the cross sections of the canal along its entire length, diminishing it as the water is expended.

The duty of water differs greatly with different soils and crops, and has usually to be determined by the engineer for each locality. The following results indicate the variability of duty as discovered in India. On the Mutha canals, near Poona in Bombay, the duty of water in 1888 during the autumn season of four months was as follows: Wheat required 2·18 acre-feet per acre irrigated, or the water performed a duty of 170 acres per second-foot. Sugar cane, however, required 19 acre-feet per acre irrigated, the water performing a duty of 43 acres per second-foot.

Sir P. T. Cautley, from results obtained experimentally on the Delhi and the Doab canals in 1845, discovered that for that region 800 second-feet constant discharge was a fair irrigation supply for 100 miles in length of canal, assuming that a district having an area on each side of the canal from 4 to 5 miles wide would be irrigated. On each 100 miles he discovered that the canal would irrigate 237·4 square miles, and allowing that only one-third of the area controlled was irrigated, the above supply would suffice for 820 square miles.

Before proceeding to a further consideration of the duty of water, it will perhaps be well to examine some of the theories regarding its determination. The following remarks are liberally quoted from an extremely interesting investigation of this subject made by Mr. J. S. Beresford,[1] executive engineer in the irrigation branch of the Indian public works department, northwest provinces.

Theoretically 1 cubic foot of water running for a month will cover an area of 60 acres to a depth of 1 foot. It is generally held that 5 inches is a safe allowance for one watering. Mr. Beresford is of the opinion, however, that more than 2 or 3 inches is rarely given. In order to determine the depth of moistened soil, the following experiment was made on July 25, when a fall of 5·5 inches of rain was gauged at the Mankri station. About five hours after the cessation of this rainfall the field examined was covered with a film of water averaging 1·5 inches in depth. Several holes were dug, and the depth of moistened soil was found to be from 16 to 18 inches. In other fields near by, free from surface water, the depth was from 12 to 18 inches—that is, 5·5 minus 1·5 or 4 inches of water will moisten ordinary loam to a depth of from 16 to 18 inches. A few days previously holes had been dug in irrigated fields of the same soil that had been recently watered, and the depth of moistened earth

[1] Memorandum on the Irrigation Duty of Water, Roorkee Professional Papers, No. 212, 1875.

was found to be from 11 to 12 inches. On the 30th the 1·5 inches of standing water had disappeared, and more holes were dug; one in a low place, the other where the ground seemed a few inches higher. The depth of water in the former was 34 inches; in the latter, 18 inches. The conclusion reached was that the ground absorbed the rain uniformly everywhere up to a fall of 4 inches in ten hours, the duration of the storm referred to. What fell in excess accumulated in low places and soaked those to a much greater depth.

Not a drop of rain had fallen before the 25th of July, excepting a fraction of an inch on the 5th and 9th, which softened the ground sufficiently for plowing. Allowing 4 inches as the depth required for one watering, and that in the hottest weather this is given only once a month—for if watered oftener a proportionately less quantity will suffice—the theoretical duty of one second-foot of water is 180 acres in the summer months. In the autumn, however, crops are rarely given more than two waterings, many only one, and the theoretical duty during the autumn season, allowing the watering to be lighter than in the summer and probably about as frequent, ought to be 320 acres, or the theoretical duty in the locality examined should, for the year, be 500 acres.

The actual duty obtained on the best divisions of the Ganges Canal in the neighborhood under examination is not over 160 to 180 acres per second-foot, or about one-third of the assumed theoretical duty. There are sufficient statistics to show what the actual duty is. The next important thing is to make the theoretical and actual duty approach as closely as practicable. Considering the Ganges Canal as a great machine, its principal parts are the main canal, the distributaries, the village water courses, and the cultivator who applies the water. Each cubic foot entering the head is expended principally as follows:

(1) In waste by absorption and evaporation in the main canal. (2) In waste from the same causes in the distributaries and in the village water courses. (3) In waste through carelessness of the cultivators not distributing the water evenly, or in allowing the ground to get saturated to an unnecessary depth. (4) In useful irrigation of the land. The object is plainly to increase the last by reduction of waste through all the rest.

From a consideration of the actual duty obtained by various experiments as compared with the theoretical duty Mr. Berseford shows that the efficiency of the canal under consideration is sometimes as low as 25 per cent. The next point established by him is the nature of the waste called absorption and evaporation, and what proportion is due to each. This discussion is extremely interesting. The loss by evaporation is the first considered. Taking a distributary 30 miles long with a water surface averaging 10 feet wide, the loss by evaporation per second in this length of water course would be 0·8 of a cubic foot by computation, and assuming that the area of water surface in the village channels equals twice the surface in a mile of the distributary, the loss

by evaporation in all the village channels would be 1·6 cubic feet, or the whole loss by evaporation on the distributary 30 miles long with its minor water courses would be over 2·5 second-feet or about 5 per cent of the probable discharge. From this we see that evaporation is not of so much consequence as far as the different channels are concerned even in the hottest weather, and may be neglected in the autumn season. The chief loss must, therefore, be due to percolation and absorption. The former may be said to be due to cultivation, the latter to capillary attraction.

With the aid of the accompanying illustrations (Fig. 233) the following discussion will be readily appreciated. Absorption is a more complicated process than percolation. The latter takes place in bowlders or coarse gravel in a manner similar to that by which water issues through pipes or strainers in the bottom of a vessel, and the quantity discharged

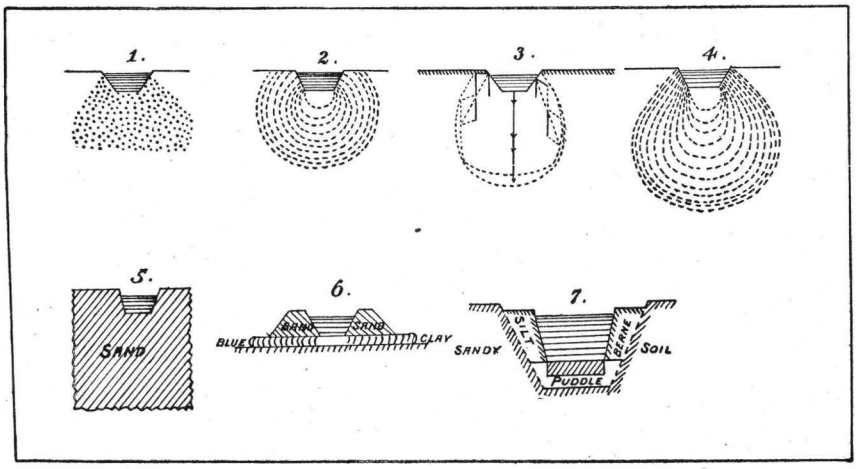


FIG. 233.—Percolation and evaporation.

per second will depend on the size of the interstices of the stones, their number, the head of the water, etc. The thicker the bank through which the water is escaping, the longer and more broken the channels of escape will be and the greater the friction; but the question of discharge depends on the same principles as does the discharge through pipes. If the gravel is considered to be broken into very fine sand and the embankment formed of this material, the principles of discharge are quite changed. The interstices are now very small and act in the same manner as do capillary tubes. If empty, the water rushes in and fills the cavities, and if the particles are sufficiently fine, are rammed close together, and the embankment is of a certain width, the water is retained in the cavities with greater force than that due to the hydrostatic head pressing it through. The force that thus retains the water is termed capillarity, and, although it may in reality be the same thing as gravitation, it may in this discussion be considered as quite a separate force.

Fig. 233, No. 1, represents a channel in a gravel soil or one composed of coarse sand, and the dots indicate the manner in which the water would trickle through the ground. No. 2 represents what would probably take place if the action of gravity were suspended and only absorption brought to play in a homogeneous soil. But gravity, which is always in play, modifies this capillary action, and the water has actually to follow the resultant of two forces. No. 3 explains this action, where the straight lines and their resultants indicate the distance to which capillarity and gravity alone and combined will carry the particles of water, and the result would be as shown in No. 4.

That absorption does not make itself more visible in high embankments is due to two reasons, the first being that the soil in low places is much more clayey than elsewhere, and there only are high embankments constructed, and the second that absorption ceases when the absorbing medium is limited. In an embanked channel the absorbing medium immediately stops at the outer slope, and only what has evaporated is made good by absorption. If we dig a hole in a bank of sandy soil, as represented in No. 5, and the hole be filled with water, this will dry up in a few moments, but if a layer of clay is spread on the ground, as in No. 6, and an inclosure made with the same sandy soil rammed as a natural bank and filled with water, the latter will not decrease beyond what the banks at first absorb. In the first instance the absorbing medium is unlimited; in the second it is limited to the soil in the embankment. It is for this reason alone that sandy embankments can dam up water at all. A very interesting experiment suggested by Mr. Beresford well illustrates this action. Take a bottle and close the mouth tightly with a small piece of sponge. If the bottle is then turned upside down the sponge will become saturated, but unless pressed by the finger will give out no water. If another large dry sponge is placed in contact with it the water at once begins to flow through the sponge in the neck of the bottle, and this continues until the second sponge can absorb no more.

We may fairly conclude that it is the layer next the wetted perimeter that limits the quantity absorbed; that the greater its area the more it will pass through to the still greater area of the next layer. Everything being equal we may say that absorption varies as the wetted perimeter. Hence for sections of canals of small length we may take the loss as being so much per mile, but in general the discharge and wetted perimeter decrease with the length, but the latter not nearly in the same proportion as the former. Thus the loss up to any point may be found when the loss between two other points is found. The total loss up to any point is the loss in the first mile multiplied by some function of the length. This in some cases has been found equal to five-sixths.

Mr. Beresford next enters into an interesting computation in which the efficiencies of the various causes of waste are considered as algebraic factors with the numerical values determined as above, while the efficiency of the cultivator, which varies within wide limits, is taken as

being between 0·5 and 0·9 where unity represents his efficiency at the theoretical limit. He finds the loss from percolation to be 1·25 cubic feet in the first mile, and in long lengths of canal about a quarter of a cubic foot per mile. The final result obtained indicates that for each cubic foot entering the distributary only 0·68 is available for fields beyond the tenth mile.

The remedies heretofore applied to lessen these defects have been few. The distributary of to-day is the same as that of 20 years ago so far as construction of channel is concerned. The minor water courses are rarely constructed or attended by an engineer and as a rule are badly aligned and constructed, and not maintained. The cultivator is the only part of the machine which has been improved. Mr. Beresford is of the opinion that the widest field for improvement is in the minor water courses. The same applies to the private irrigating channels of the farmer of our own West. These minor channels are certainly on an average 25 per cent longer than need be. They even run a long distance through sandy ground which absorbs a great proportion of water. The size of discharge of the module or regulator is frequently not suited to the length or conditions of the water course and two different water courses sometimes run side by side, thus increasing the wetted perimeter and the consequent loss. The first recommendation made by Mr. Beresford is in all cases the construction of a good map. This is desired by all canal engineers, but it is rarely made because it is thought to mean an endless amount of surveying. The saving from the construction of such a map would be more than paid for in the saving of water. It is recommended that all small water courses be puddled when running through sandy soil. A layer 3 inches thick, Fig. 233, No. 1, would suffice. If the cost of this was as much as $100 per mile it would not be exorbitant, for in the length of a mile, if the discharge at the head is 1 second-foot and the loss 25 per cent, the saving effected would increase the duty by from 20 to 40 acres.

The losses in distributaries, although proportionately less than in the minor channels, are often large, especially in new channels. The particles of sand or silt carried in suspension are usually dropped in the upper reach, but particles of clay or very fine sand are carried to the very tail and are often deposited on the sides and bed to a considerable thickness, forming a more or less impervious lining or silt berm. The deposit on the bed, even a long way down, is more charged with sand than is the berm. The sand being heavier, drops to the ground, and as it is rolled along picks up the lighter particles of clay. It is not recommended that the sides of the distributaries be puddled unless in the first few miles, but the bed in sandy soil might be advantageously puddled everywhere to a thickness of several inches. A temporary measure suggested by Mr. Beresford is to collect clay and, breaking it into fine particles, throw it in near the canal head or at the falls, when the action of the water will thoroughly break up the clay and carry it

into the berms and water courses miles below, thus rendering them impervious.

In 1867 Mr. E. C. Palmer, executive engineer of the irrigation works, northwest provinces, made some interesting experiments in the same direction on the Bari Doab Canal.[1] Among other experiments conducted one was made to determine the time required to saturate thoroughly an acre of ground. In these experiments the discharge orifices were 15 feet in length, each of the same dimensions and working under the same heads. The experiments were repeated on different varieties of land. It was found that an average depth of 3 inches of water on the whole surface represents a thorough watering on average soil. In sandy soil it was as much as 4 inches. This gives 10,454 cubic feet or about one-fourth acre-foot as the volume required to water one acre. In ordinary soil the average is actually a little over 0·2 of a foot, or 9,150 cubic feet. In these experiments the quantity of water varied, according to the soil and other circumstances, between 9,000 and 14,500 cubic feet per acre for one watering, and the time required to water an acre varied from two to twelve hours. In the dry season wheat required four waterings and 10,500 cubic feet of water. For the first watering, in order to prepare the ground for plowing and sowing, 8,000 cubic feet were required, and the same amount for each of the remaining four waterings on the standing crop. An acre of wheat, therefore, required 42,500 cubic feet to mature the crop, or nearly an acre-foot of water per acre. At the prices then current the cost to the State was 75 cents per acre and the water rate derived was $1.60 per acre. The time required to cover an acre of land was 0·445 day, or 2·2 acres per day. For standing crops the rate is about 4·4 acres per day, as they ordinarily require not more than half as much water as is necessary for plowing.

The losses by evaporation and absorption and the duty of water are now well known in India on the various lines of canal and for the numerous reservoirs that have been in operation for many years. In the Northwest provinces the duty of water for the year 1888 varied for different crops between 120 and 194 acres per second-foot, and the money value was from $143 to $286 per second-foot. From experiments conducted on the Betwa Canal in the same province it appears that mixed sugar-cane and indigo crops (which need much water) required a total volume in eighty days of 310,000 cubic feet per acre for wet-weather crops; while the autumn crops required 150,000 cubic feet, or about $3\frac{1}{3}$ acre-feet per acre. In some experiments made on the Nira Canal to ascertain the amount of wheat which could be irrigated in a given period of time, it was found that with a second-foot of flow 8 acres of wheat could be irrigated in twenty-four hours.

In estimating the supply of water necessary to irrigate a given area of land, it has been found from actual experiment that a large propor-

[1] E. C. Palmer, Irrigation Experiments, Roorkee Professional Papers, No. 35.

tion of the land covered by any given irrigation system is always unirrigated, and that water need only be provided for a certain small percentage of the total area of irrigable land. This land is not irrigated, for several reasons. It may be occupied with buildings or roads, or be in use as pasturage. A certain proportion receives water by seepage from adjacent irrigated fields and another portion is occupied by towns and villages. In drawing up the projects of the great canals in the northwest it was found by data derived from experience on the Jumna canals that each second-foot of discharge was capable of irrigating 218 acres and it was reckoned that for each acre irrigated there would be 2 other acres unwatered. Hence each second-foot represented a duty of 654 acres or, approximately, 1 square mile. In drawing up the project for the Soane canals in Bengal, Col. Dickens reckoned three-quarters of a second-foot to every square mile of gross area. To date, the Soane canals have been in operation fifteen years, and yet there is a demand now for not over 100 acres in 640, and the system of distributaries as designed for these canals has proved to be unnecessarily elaborate. In the Punjab it is customary to design works to irrigate only from 20 to 30 per cent of the area covered and where water for more is demanded it is usually not given, as it is bad for the land, producing water-logging and its consequent evils. The experiments made on the eastern Jumna Canal in 1845 showed that on the Saharanpur division one-fifth only of the total area cultivated was actually watered, and on the two other principal divisions the percentages were one-fourth and one-third, respectively. A similar experiment conducted the same year on the western Jumna Canal showed that of the total area cultivated from one-half to one-third only was actually watered.

In gauging the velocity of discharge of rivers in India floats are usually employed. In some of the great rivers where there are weirs constructed the depth of water passing over these weirs gives a measure of the volume of discharge; in a few cases only are current meters used. In the canals the discharge is almost invariably obtained by means of wooden floats, sometimes floating on the surface and sometimes submerged. These are timed for given distances, usually marked out in an aqueduct or other portions of the channel where permanent gauge rods are established. On the minor distributaries V-shaped weirs are in general use for the measurement of discharge.

DELTAIC CANALS.

Before entering into a discussion of the perennial canals of the higher lands of India a general description will be given of the great works constructed near the mouths of the larger deltaic rivers, as many of the weirs and mechanical modes of controlling water in use on them will be of interest. These canals have been constructed in an almost level country, having low slopes, and are universally intended for navigation

as well as for irrigation. Aside from the mechanical details referred to these canals are of little interest to the American engineer, as the conditions do not favor similar works in our country.

In the presidency of Madras the most notable canals of this character are those at the deltas of the Godaveri and Kistna rivers.[1] On the Godaveri system there were completed, at the end of 1878, 442 miles of main canals, which commanded 1,000,000 acres and actually irrigated 542,000 acres. The weir at the head of this canal was constructed in 1844. The river drains an area of 115,570 square miles above the weir, and the crest of this latter is 38 feet above mean sea level and 33 miles from the coast. The maximum discharge of the river at this delta head was 1,210,000 second-feet, with a depth of 15½ feet over the weir crest. The head works at Douleshwaram consist of a weir across the river 18,000 feet in length and of three sets of scouring sluices and regulators from which the three main canals irrigating the eastern, central, and western deltaic regions are supplied. The river is broken by islands to a length of 4,500 feet, on which earth embankments connect the various portions of the masonry weir. There are also flanking embankments, making the earthwork in all 7,000 feet long, and there are 2,500 feet in length of wing walls. The total length of the masonry weir is 11,946 feet. It is founded on walls 6 feet in diameter sunk 6 feet in the river bed, and is 19 feet thick, consisting of a core of sandstone faced by a curtain wall 7 feet high and 4 feet thick at the base, having a masonry fall of 28 feet broad and 4 feet thick. Below the weir is a massive stone apron 80 feet broad. On both banks are masonry wing walls and revetments. The three sets of regulating sluices have the following dimensions: The eastern consists of 13 gates 6 by 8 feet; the central of 15 gates 6 by 8½ feet, and the western of 15 gates 7½ feet high, and varying from 5½ to 6 feet in width. The mean supply to the eastern delta during the summer season is 2,826 second-feet, which is the carrying capacity of that canal. The area irrigated is 170,000 acres. The carrying capacity of the main central canal is 1,745 second-feet and it irrigates 122,400 acres. The supply of the western canal is 3,950 second-feet and it covers 319,580 acres. The canals vary in bottom width from 114 feet on the central canal to 225 feet on the western canal, with varying depths of from 7 feet on one to 10 feet on the other.

The Kistna deltaic works head at Bezewada, 60 miles from the river's mouth, where the maximum flood discharge is 736,000 second-feet. The head works consist of a weir 3,198 feet in length, and the greatest flood rose 19½ feet above its crest. The eastern main canal has a bottom width of 200 feet and a depth of 8¼ feet; the western canal has a bottom width of 230 feet and a depth of 8 feet. The total length of main canals in 1878 was 267 miles. The total area of irrigation is estimated at 470,000 acres. The crest of the weir at the headworks is

[1] R. B. Buckley, Irrigation Works of India, London, 1880, pp. 12–15; L. D'A. Jackson, Hydraulic Works, London, 1885, pp. 400–411.

6 feet in width and 15⅕ feet above the top of the foundation. The total width of apron below the crest is 257 feet. The foundation consists of a double row of wells, and at each end of the weir is a set of scouring sluices of 30 gates, each 6 feet wide. The regulating gates are of the same dimensions. The crest of the weir being too low for the required supply, a temporary dry stone wall 4 feet high is annually built on it, and after the stone has been washed off by floods it is used in the repair of the apron. Shutters have recently been substituted for this temporary device.

The principal remaining deltaic canals in India are the Midnapore and Orissa canals in Bengal. According to the revenue report of Bengal for the year 1888 it appears that the total capital outlay to date on the Orissa canals was $7,810,000, and on the Midnapore canals, $2,316,000. The Orissa canals were originally constructed by the East India Irrigation and Canal Company and the source of supply is derived from three principal rivers, the Mahanadi, the Brahmini, and the Byturni. The minimum discharge of all these rivers during the cold weather or autumn crop is 4,100 second-feet, and the maximum discharge of the canal is 2,070 second-feet. The gross area commanded is 412,000 acres, of which at present 227,000 are irrigated. The works consist of 284 miles of main and branch canals and 2,150 miles of distributaries. There are three distinct weirs at the head of this canal. One at the point where the river bifurcates is 3,600 feet in length and 12 feet above the river bed. The second weir is across the Mahanadi River itself, and is 1¼ miles long and 12 feet high. The third, across the Biropa River, is 1,980 feet in length and 9 feet above the river. The system of canals is capable of great extension. The canals actually constructed command an area of 577,500 acres and the head works of all have been finished. There is always an ample supply of water in the rivers.[1]

The Midnapore Canal was also constructed by the East India Irrigation Company. Its supply is derived from the river Cossye, the catchment basin of which is so small that the supply of water in the canal varies with the rainfall on the district covered by the canal itself. The works were commenced by a company in ignorance of the real supply available, and the distributaries have actually been constructed to command an area of 140,000 acres; but in extremely dry years the quantity of water would be sufficient to irrigate only from 40,000 to 50,000 acres.[2]

The canal is divided into four lengths, the first of which is taken off above the weir at Midnapore. In the twenty-fifth mile this tails into the river where the second weir is built across it. The canal crosses the river at this point and the second length is diverted on the opposite bank. A large portion of the remaining length of the canal is con-

[1] R. B. Buckley, Irrigation Works of India, p. 72, London, 1880. [2] Ibid., p. 74.

structed principally for navigation. The automatic sluice gates constructed in the weir at Midnapore are of peculiar interest and will be fully described in another place.

PERENNIAL CANALS.

Perennial canals are taken chiefly from the great perennial rivers which issue from the Himalayas, from whose melting snows they receive an abundant and constant supply of water. The smaller perennial canals in portions of Madras and Bombay are chiefly fed by storage water collected in reservoirs and tanks in the hills. The great rivers of the Punjab and the Northwest provinces rarely discharge less than 4,000 second-feet, and some discharge many times this volume, while in times of flood their discharge increases to as high as 1,200,000 second-feet and more.

In the arid region of the United States no such streams as these exist, though a few of our great rivers, as the Missouri, Columbia, Rio Grande, Sacramento, and their principal branches carry large volumes of water, much of which it is to be hoped will at some future time be utilized for irrigation. Because of the similarity existing between these and the great Indian rivers, the country which they traverse, and its climate during the cultivation of the autumn crop, the use of the waters of these great streams will be of immediate interest to us and may furnish useful lessons and examples when we commence the construction of similar works. The topography of the Punjab and northwest provinces at the foot of the Himalayas has been described in detail in another place. It is very similar in many respects to that of the great California Valley on the western slopes of the Sierras and that of the Colorado and Wyoming plains at the foot of the Rockies. The rivers issue from the sub-Himalayas and Sewaliks through foothills similar in appearance and with corresponding surface slopes to those of the Feather, American, Stanislaus, and other rivers flowing from the Sierras in California, or to the Arkansas and Platte rivers issuing from the Rockies.

In designing these great perennial canals the Indian engineer first makes a careful topographic survey of the entire region to be irrigated, and numerous trial lines are run before the final location of the main and distributary canals is decided upon, and the position of the head works definitely fixed. In the case of the rivers having a constant regimen training works are unnecessary, as the head works are generally located in narrow portions of the river where the banks are firm and the channel stable. In some of the larger canals heading in the plains, notably the Agra and the Lower Ganges, expensive river regulating works are required to control the movements of their channels.

The machinery of a great canal consists usually of the following parts: The head works at the point where the canal is diverted from the river, the main canal, the distributaries and the minors. Each of these

units of the system has its own set of regulating works and escapes to control the supply of water in the canal. Between different canals these differ but slightly, the point of greatest difference usually being at the head works and in the first few miles of diversion line. Here various devices have been resorted to for the passage of hillside drainage.

GANGES CANAL.

It is probable that the first attempt to construct a canal on the interfluve between the Ganges and Jumna rivers occupied by the present line of the Ganges Canal was made by Mohammed Aboo Kahn at some time early in the eighteenth century. This canal consisted of a shallow ditch 12½ miles long taken from the west Kali Nadi and was filled by means of a temporary weir thrown across that stream. No masonry works were constructed and much damage was done by the flooding of lands above the weir. The second attempt here made was in 1827 when Capt. Debude tried to restore the above by putting in permanent head works across the Kali Nadi. This plan contemplated the extension of the canal through Meerut to Aligarh, and it was also intended that a dam should be thrown across the Hindun River and the water of both streams utilized. This was merely an attempt to improve on old and bad methods. The third and present project was purely a British one. In 1836 Col. John Colvin, C. B., proposed to build a canal from the Ganges River heading at Hardwar.

The famine of 1837 and 1838 caused an increased desire for the construction of this canal, and in 1839 Lord Auckland, the governor-general, sanctioned the surveys. In 1840 Sir P. T. Cautley made the first surveys and reported on the project, and from then to 1845 about $50,000 per annum was expended, chiefly on surveys. In his report[1] Col. Cautley said:

"To deny the value of irrigation to agriculture in an arid country is like denying the value of manure to an European farmer." On the strength of the report made in 1840 the board of directors decided on the construction of the Ganges Canal as an irrigation work, the canal as sanctioned being designed to carry 6,750 second-feet. When Lord Ellenborough was governor-general, between 1842 and 1843, he did everything to discourage the project and so modified the sanction that only a small navigation canal could be constructed. During Lord Ellenborough's governorship to 1847, Col. Cautley was in England attempting to further the project and the works were carried on by Maj. Baker. In 1848 Lord Harbinge became governor-general and sanctioned the work as originally devised, urging its immediate construction, which was at once prosecuted by Col. Cautley.

In 1845 Col. Cautley submitted detailed estimates for three separate projects, in each of which the discharge at full supply was to be 6,750

[1] The Ganges Canal, 3 vols., London, 1860.

second-feet, of which it was assumed that 1,000 second-feet would be lost by evaporation, absorption and navigation. The last of these projects was estimated to cost about $4,670,000 and render irrigable an area of 1,470,000 acres. When in 1847 the government directed that these works should be constructed, among other instructions they said that the primary object of the canal was to be irrigation, navigation being carried only as far as not inconsistent with irrigation, thus reversing the instructions of Lord Ellenborough's government.

Water was first admitted into the canal in 1854 and irrigation commenced the following year. During the next few years defects in the works gradually came to light and in 1864 an investigation was ordered by the government. At the close of that year detailed estimates were submitted for rectifying the principal of these defects. Previous to this Sir Arthur Cotton reported on the works considered by him necessary for the improvement of the canal. In his report he stated that the head of the canal was too high up on the river; that the whole canal had been so cut as to carry the water below the level of the surface, entailing a vast unnecessary excavation; that the whole of the water was admitted at the head, so that it was conveyed in places 350 miles to the land to be irrigated, and that there was no permanent dam across the river at the canal head so as to secure the supply of water. In addition to this, Sir Arthur Cotton enumerated fourteen minor defects in the canal. In 1868 the attention of the government was drawn to the question again by a note from Col. Strachey, in which he pointed out that though the existing Ganges Canal was able to supply the upper portion of the interfluve, there would be tracts lower down to which the available water in the river could hardly be distributed by the construction of a lower canal, as suggested by Sir A. Cotton. This led to the projection of the system of works known as the Lower Ganges Canal and to material alterations in the measures for rectifying and completing the old Ganges Canal.

This canal is the largest in existence. As at present constructed its head works are situated near the city of Hardwar, about 20 miles above the railway town of Roorkee. At this point the Ganges issues suddenly from betweeen the foothills of the Himalayas on to the broad level plains. In the first 20 miles of its course (Fig. 234) the canal encounters a considerable amount of sub-Himalaya drainage and the works for the passage of this drainage and for the reduction of the slope of the canal by means of falls are important. The slope of the river bed in this section is from 8 to 10 feet per mile.

A short distance above Hardwar a branch of the Ganges about 300 feet in width separates from the main river and hugging the Hardwar shore rejoins the stream a half mile below Hardwar. The discharge of the main river at this point in the dry season is about 8,000 second-feet, a majority of which is diverted by training works and temporary bowlder dams into the Hardwar channel. This has been deepened and given a

uniform slope of $8\frac{1}{2}$ feet per mile to the canal head. At Myapur the canal is taken from the Hardwar channel the water being diverted into it by means of a weir and sluices across the channel and a masonry regulator at the head of the canal. To the sixth mile the canal crosses

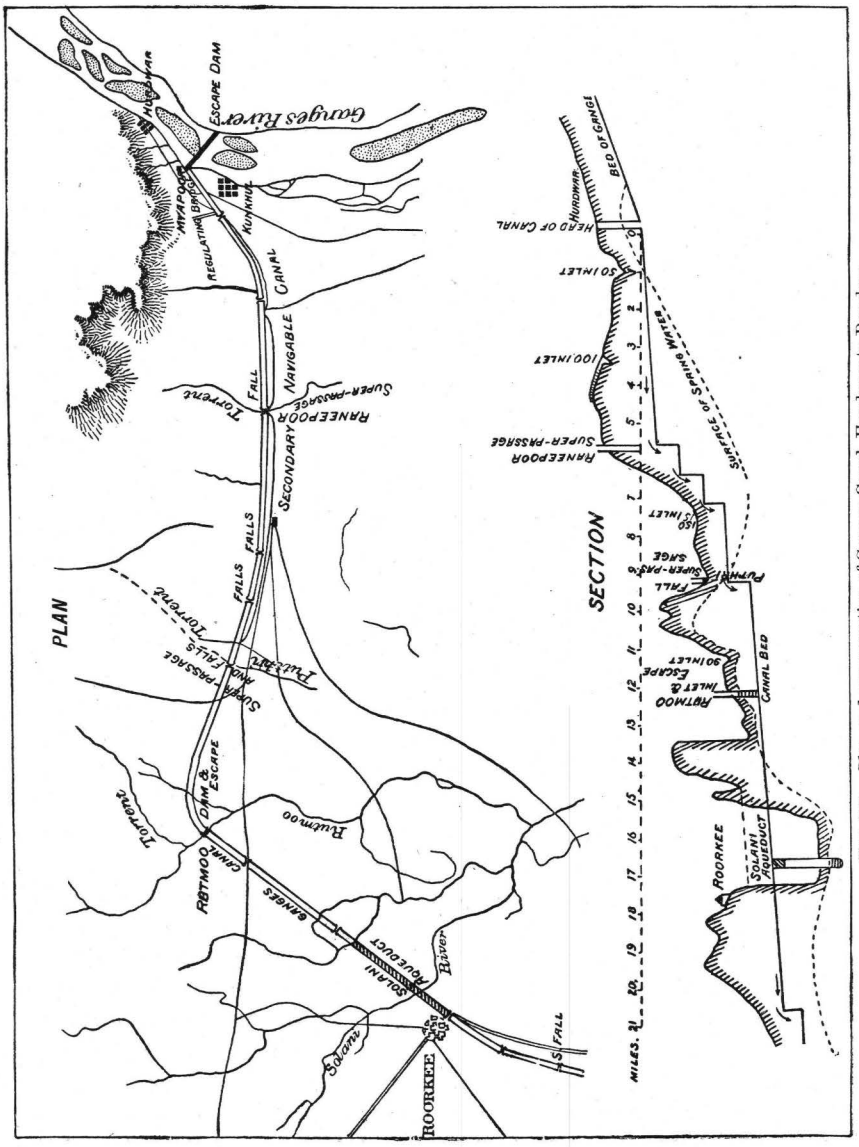


FIG. 234.—Plan and cross-section of Ganges Canal, Hurdwar to Roorkee.

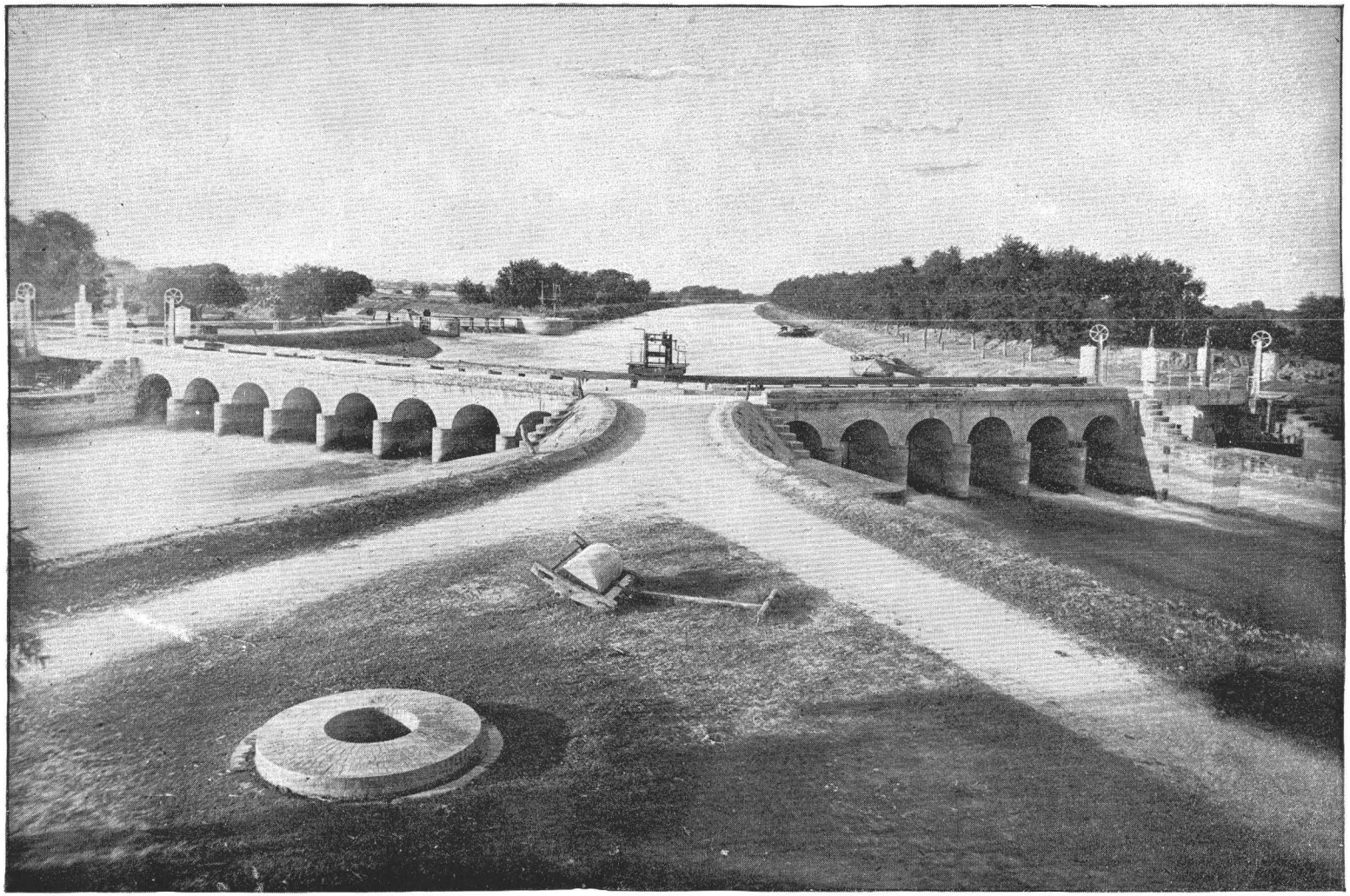
several minor drainages which are admitted by means of little inlets. At the sixth mile it is crossed by the Ranipur torrent passed over it by means of a masonry superpassage about 195 feet in breadth. In the tenth mile the Puthri torrent having a catchment basin of about 80

square miles or twice that of the Ranipur, is carried across the canal by a similar superpassage 296 feet in breadth. The sudden flood discharges in these torrents are of great violence, the Puthri torrent discharging as much as 15,000 second-feet and having a velocity of about 15 feet per second.

In the thirteenth mile the canal encounters the Rutmoo torrent with a slope of 8 feet per mile and a catchment basin half as large again as that of the Puthri. This torrent is admitted into the canal at its own level. In the side of the canal opposite to the inlet is an open masonry outlet dam or set of escape sluices. In the canal just below this level crossing is a regulating bridge by which the discharge of the canal can be readily controlled; thus in time of flood, by opening the sluices in the outlet dam and adjusting those in the regulator so as to admit into the canal the volume of water required, the remainder is discharged through the scouring sluices whence it continues in its course down the Ranipur torrent.

In the nineteenth mile, near Roorkee, the canal crosses the Solani River and Valley on an enormous masonry aqueduct. The Solani River in times of highest flood has a discharge of 35,000 second-feet and the fall of its bed is about 5 feet per mile. The total length of the aqueduct is 920 feet. The banks of the canal on the upstream side are revetted by means of masonry steps for a distance of 10,713 feet, and on the downstream side for a distance of 2,722 feet. For $1\frac{3}{4}$ miles the bed of the canal is raised on a high embankment previously to its reaching the aqueduct and for a distance of half a mile below it is on a similar embankment. The greatest height of the canal bed above the country is 24 feet. The aqueduct proper consists of fifteen arches of 50 feet span each. In addition to these great works there are in the first 20 miles of the canal five masonry works for damming minor streams and a number of masonry falls.

Beyond Roorkee the main canal follows the high divide between the Ganges and the west Kali Nadi and continues in general to follow the divide between the Ganges and the Jumna to Gopalpur, a short distance below Aligarh where the main canal bifurcates (Pl. CXI), forming the Cawnpur and Etawah branches. The former branch tails into the Ganges at Cawnpur and is 170 miles in length. The Etawah branch is also 170 miles long and tails into the river Jumna near Humerpur. The Vanupshahr branch leaves the main line at the fiftieth mile and flows past the towns of Vanupshahr and Shahjahanpur. It formerly terminated at mile $82\frac{1}{2}$, emptying into the Ganges River, but it is now continued to a point near Kesganj where it tails into the Lower Ganges Canal. The first main distributaries are taken from both sides of the canal a short distance below Roorkee. The nature of the country offers abundant facilities for escapes from the canals. Five are constructed on the main line, four on the Cawnpur branch, and three on the Etawah branch, besides numerous small escapes to the distributaries. These



GOPALPUR BIFURCATION, GANGES CANAL.

escapes will be described in another place. They are essential for the proper regulation of the canal in the discharge of local drainage.

The minimum discharge of the canal is 6,780 feet. The average annual rainfall over the area irrigated is 33 inches. The entire area commanded is 2,800,000 acres. The culturable area is 1,820,000 acres, and the area irrigated is 1,600,000 acres. The maximum area irrigated within any one year, including both spring and autumn irrigation was 2,800,000 acres in 1883; the total mileage of main canals is 456 miles. There are 2,560 miles of distributaries and 859 miles of drainage cuts and escapes, or a total of 3,972 miles.

Of the total area irrigated in 1888, 79,300 acres, or 13 per cent of the whole, were double cropped and the duty performed by the canal for the autumn crop was 135 acres per second-foot on the discharge at the head, or 155 acres per second-foot on the discharge utilized. The total capital outlay on these works to the end of the year 1888 was $9,413,000 and the working expenses for that year were $640,000. The working expenses per second-foot of discharge at the head was $103, or 52 cents per acre irrigated. The total water rate derived was $1.30 per acre irrigated or $253 per second-foot of discharge at the head. Among the principal crops cultivated were 106,000 acres of sugar cane, valued at $2,332,000; 228,300 acres of wheat, valued at $3,275,000; 31,400 acres of rice; 80,000 acres of indigo, and a grand total, including all other crops, of 601,900 acres, valued at $7,600,000. The net profits in 1888 were 5·4 per cent on the capital invested.

The number of days in the year when water was supplied for irrigation and the canal was in active operation was, in 1888, 275. In this year a comparatively small supply of water was used, the mean supply being only 2,400 second-feet.

LOWER GANGES CANAL.

As described in relating the history of the Ganges Canal, the Lower Ganges Canal was undertaken at the suggestion of Sir Arthur Cotton, in 1863, after an investigation by Col. R. Strachey in 1865, as a means of relief or improvement of the Ganges Canal. It irrigates a part of the Ganges-Jumna interfluve that was originally intended should be commanded by the Ganges Canal proper. The work comprises a masonry diversion weir at Narora, about 3 miles below the railway crossing at Rajghat. It relieves the Ganges Canal of 128 miles of the Cawnpur branch and 130 miles of the Etawah branch, and as originally projected was intended to carry 6,500 second-feet in the spring season and 3,270 second-feet in the autumn season. In 1871 the works were commenced, but were delayed awaiting a revised estimate submitted in 1876, when the work was finally commenced. It is now considered as a work separate from the Ganges Canal.

The weir is a substantial one, resting on masonry wells, usually 20 feet deep; the front and rear curtain walls rest on smaller wells. The

weir is 3,800 feet long and is 10 by 10 feet in cross section, having a vertical overfall to a paved floor. It is constructed chiefly of brick. The weir scouring sluices opposite the canal head are 42, each 7¼ feet wide. The regulator at the canal head is constructed of masonry and has thirty openings each 7 feet wide. The weir crest is 7½ feet above the sill of the canal and this can be raised to 10 feet by means of shutters. For the first 26 miles of main canal the bed is 216 feet wide; the full supply depth is 10 feet and the slope one-tenth of a foot in 1,000.

In the first portion of its line the canal is compelled to follow the low river bottom for some distance before its grade enables it to surmount the banks and reach the summit of the interfluve. In this low reach the canal is threatened constantly by the encroachments of the river and extensive river-training works are necessary to preserve its integrity. These extend for a distance of 4 miles above the canal head and 15 miles below, and consist chiefly of long earthen groynes or embankments, sometimes 2½ miles in length, projecting into the stream at right angles to its course and protected at the end by loose rock noses. The general slope of the Ganges River and of the country at this point is about 1½ feet per mile and the greatest flood the river has discharged is 350,000 second-feet. Its minimum discharge has been as low as 1,200 second-feet. The velocity in the canal is very low, being but 2 feet per second, and as a result much silt is deposited and the growth of weeds is excessive. The maximum discharge of the canal as now constructed is 5,100 feet. The average annual rainfall on irrigable land is 31·1 inches; the gross area commanded is 4,387,000 acres, and the culturable area 2,435,000 acres, and 1,187,000 acres will be irrigated when the project is completed, though at present but 538,000 acres are irrigable. The total length of the main canals is 564 miles. There are 2,021 miles of distributaries and the total length, including escapes and drainage cuts, amounts to 2,992 miles.

The capital outlay to the end of 1888 was $10,500,000. The total receipts in that year amounted to $114,000, a little less than 2 per cent net profit on the capital invested. The area irrigated in 1888 during the autumn crop was 327,000 acres, of which 184,000 acres were irrigated by wells. Twenty-three per cent of the whole was double-cropped, and in the autumn season 1,765 second-feet of water were utilized, the duty on which was 185 acres per second-foot. The cost of maintenance of the distributaries was $13 per mile. There were 222 acres irrigated per mile of distributaries at a cost of a little less than $6 a hundred acres, and the average depth of water used in these was 3·1 feet. The most notable works on this canal will be described in their proper place. They are the training works, the weir and other head works, and the great aqueduct at Nadrai, by which the canal is carried over the Kali Nadi torrent.

AGRA CANAL.

The Agra was the third of the great perennial canals of the Northwest provinces visited by the author. This canal was contemplated when the question of the remodeling of the Ganges Canal was being agitated in 1864. It was then pointed out that water might be drawn from the river Jumna below Delhi to supplement the irrigation of the Ganges-Jumna bench lands. The idea was further discussed in 1866. In 1867 projects were submitted and in 1868 the works were sanctioned for the purpose of famine relief. The works as eventually sanctioned in 1872 correspond closely to the present completed Agra canal project. It was formally opened in March, 1874. In 1875 it was found that the original weir was insufficient. The great flood of that year had seriously injured the scouring sluices and the works were then reconstructed. The head works of the canal are situated at Okhla on the River Jumna, 10 miles below Delhi, and consist of a weir about 2,573 feet in length at a point where the river is 4,400 feet wide. The left wing of the weir rests on an island, whence it is continued as an earth embankment 20 feet wide on top. This weir rests on wells sunk in the deep sands of the river bed. On the upstream side it has a slope of about 1 in 4, the downstream slope being very long, as flat perhaps as 1 in 20. As originally constructed in 1870 this weir was not more than 130 feet in width from toe to heel, but after being injured by successive floods it was carried out and added to until its width is now over 240 feet. The scouring sluices are 139 feet long at the end of the weir and are composed of sixteen gateways of 16 feet each. The regulating sluices consist of twelve openings, each 6 feet wide and 10 feet high, to the springing of the arches, and are so located as to avoid the deposit of silt at the canal head. The water of the river is deflected toward the right bank against the regulators by a series of groynes and river-training works. There are about 8 miles of enbankment along the river margin to protect the low land from inundation and to prevent the flank wall of the weir from being turned.

From Okhla the canal follows the high land between the Khari Nadi and the Jumna, and its course throughout is fairly parallel to that of the Jumna about 3 to 12 miles from its right bank. It finally tails into the Ootunghun River about 20 miles below Agra. The main branches connect the canal with Muttra and Agra.

The source of supply is from the Jumna River. The highest recorded flood was of long duration and rose 50 feet above low-water level, the velocity then being 12 feet per second and the discharge about 1,300,000 second-feet. The supply of the Jumna having fallen occasionally below 800 second-feet it is supplemented by a cut from the Hindun River, which discharges into the Jumna just above the diversion weir, and is capable of supplying 300 additional second-feet. The grade of the canal from the head to the thirty-second mile is 6 inches per mile. There is

a fall of 5·75 feet, beyond which the gradient is increased to 1 foot per mile to the end. In the first portion of the canal the bed width is 70 feet per mile and the depth from 6 to 10 feet, while the velocity is from 2 to 2½ feet per second. Below the first fall the bed width is decreased to 60 feet and the maximum depth to 7 feet. Beyond the one-hundredth mile the velocity is from 1½ to 2½ per second, the bed width 20 feet, depth 5 feet, and the discharge about 200 second-feet.

The Hindun cut is 9 miles in length and 24 feet wide at the bottom, with a mean depth of 5½ feet. The works of especial interest on this canal beyond those of the weir and head works proper are an interesting superpassage made of boiler iron situated at about the eighth mile, and some drainage settling basins constructed as reservoirs for the collection and concentration of numerous small drainage channels. The total length of main canal as completed is 134 miles and there are 558 miles of distributaries. Its total maximum discharge is 1,500 second-feet. The average rainfall on its irrigated lands is 27 inches; the gross area commanded 768,000 acres, nearly all of which is culturable, while the area irrigated is 240,000 acres. The total capital outlay to the end of 1888 was $3,010,000, and the net revenue varies between 3 and 4½ per cent per annum.

Of the total area irrigated in 1888, 11 per cent was by means of wells. The water rate charged was $233 per second-foot of water utilized or $1,120 per mile of canal; the cost of maintenance was $11.50 per mile, and 74 acres were irrigated per linear mile at a cost of $5.15 per 100 acres. The average depth of water used in the autumn season was 1·2 feet. The principal crops cultivated were much the same as those cited for the Ganges Canal, the cultivation of indigo heading the list with an acreage of 28,500 acres, cotton being second with 22,000 acres, and peas next. The area of wheat cultivated was 14,500 acres, and the total value of all crops $1,090,000.

The canals of the Duns are usually small and have been constructed in a mountainous country at a rate of expenditure that would be considered quite unwarranted and prohibitive in the United States. There are five principal canals in the Duns, raging from 11 to 19 miles in length and aggregating 67 miles. They have annually returned over 6 per cent interest. These canals command 5,000 acres, more or less, each. The works are simple in character, but owing to the great rainfall expensive masonry aqueducts crossing high valleys and broad torrents are numerous, and in many cases the canal channels are constructed wholly of masonry for long distances. The total maximum discharge of these canals is 240 second-feet, and the precipitation on the irrigated lands averages 100 inches. They irrigate a gross area of 25,000 acres. The capital outlay on their construction was $1,070,000, and while the average interest received is over 6½ per cent, on some of them it exceeds 12 per cent. The crops cultivated are similar to those produced elsewhere in the Northwest provinces, but wheat and rice far

exceed in amount all other crops together. In 1888 there were 15,400 acres of food crops grown, nearly four-fifths of which consisted of wheat and rice.

SIRHIND CANAL.

Of the important perennial canals in the Punjab the Sirhind far exceeds all others in matters of engineering interest, as it is the most recent and modern in construction, besides being one of the greatest. Of the other important canals of the Punjab, the principal are the Bari Doab and the Western Jumna, two of the most profitable canals in northern India. The Sidhnai Canal, which has only recently been opened, was as originally constructed an inundation canal and is still partially operated as such. Though the author saw little of the Sirhind or Sidhnai canals, a brief description of each will be given, as they represent some of the latest developments of irrigation as practiced in India.

In the time of the Emperor Feroze attempts were made to utilize the waters of the Sutlej River for irrigation. These attempts were, however, of little moment. Maj. W. E. Baker first showed the practicability of a canal from the Sutlej to irrigate what was known as the "Hard Desert" in the districts of Hissar and Bhuttiana. The few wells there were so deep that irrigation from them was impossible, while the water was impure and brackish. The population was scanty and lawless, their chief occupation being cattle-raising. The question was not how to improve agriculture, but how to create it.

Maj. Baker proposed heading the canal above Rupar, utilizing the line of the old canal of Mohammed Shah, but Col. Baird Smith, who examined this project, reported that "the occupation and repair of old canals was the most fruitful source of evil in the existence of canals," and he suggested a new alignment.[1] Maj. Baker's investigations were carried out in 1840, and the project then submitted was very similar to that of the now completed Sirhind Canal. In 1860, at the request of the Maharajah of Pattiala, who offered to defray the expenses, the whole question was investigated by the British officers. A project was submitted in 1862, and in 1865 the British Government decided that any canal constructed here should be devised irrespective of boundaries of British or native States. In 1868 the project was vigorously pushed, the size of the main channel was increased, and the head works were moved 15 miles down the river to a point very near Rupar, and in 1869 the works were actively commenced.

This project (Pl. CXII) comprises a main canal from the Sutlej supplied by a masonry diversion weir. The length of this main channel is 41 miles. Of the branches, the eastern ones irrigate native State lands and are called the Pattiala branches; the remaining or western branches are known as the British branches. The heaviest portion of the work

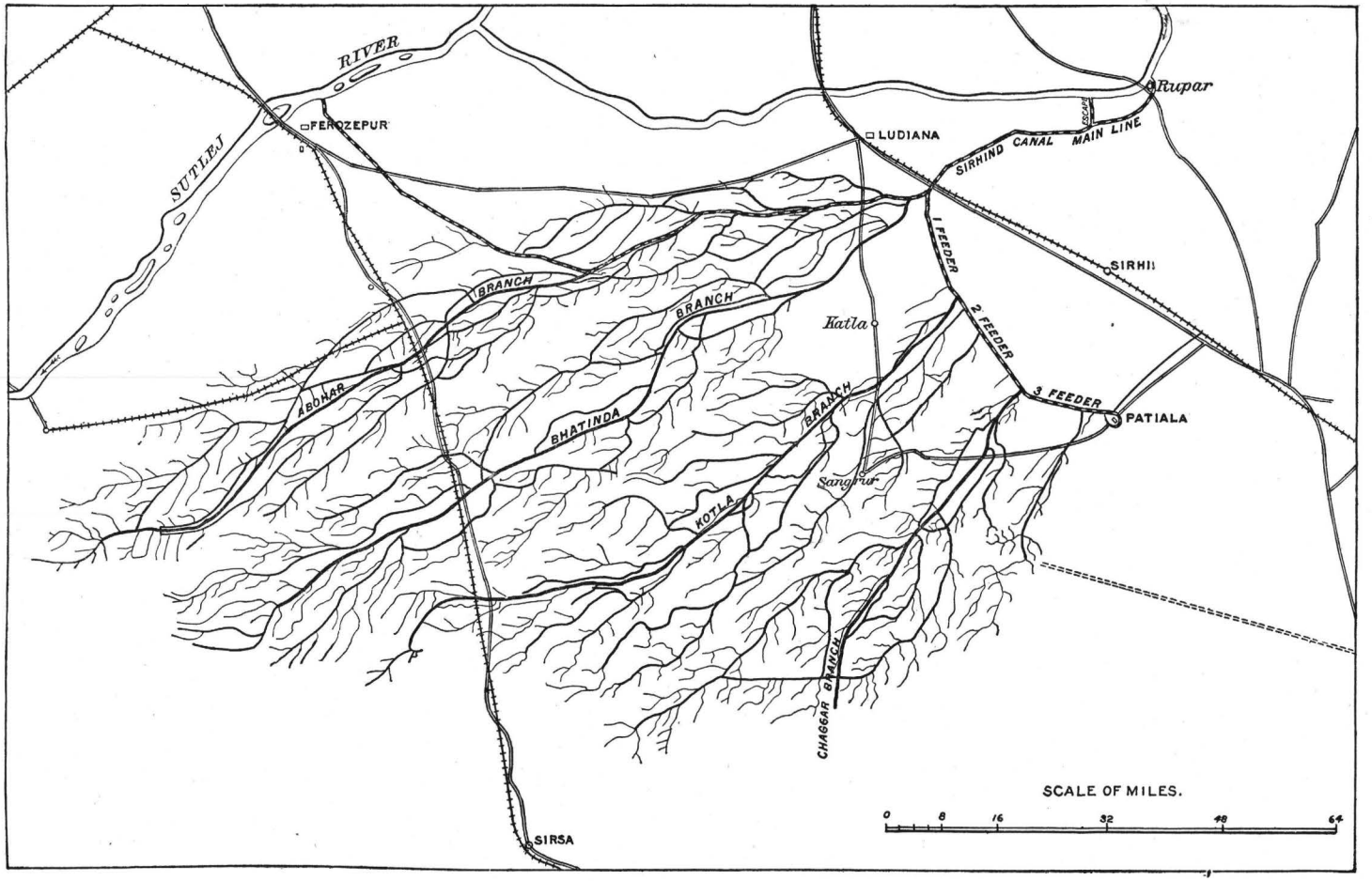
[1] Col. Baird Smith, Irrigation in Italy, London, 1856, vol. 1, p. 256.

is in the first 10 miles, where the line crosses many hill torrents draining into the Sutlej. The head works are, like those of the Ganges and Jumna rivers, situated at the point where the river emerges from the hills through a rocky bowlder channel, and where the general fall of the country is over 8 feet per mile. The maximum depth of the cutting through the spur at the head near the town of Rupar is 45 feet, and the average depth of cutting in the first 7 miles is 28 feet. The drainage in places is passed over the canal by masonry superpassages, while one torrent is diverted into the river by a cut terminating above the head works. At the forty-first mile the main canal ends and the two branches diverge. Three miles below the bifurcation the British branch is again divided into the Bhatinda branch, 100 miles long, and the Ubohar branch, 125 miles long. On the Pattiala side the main feeder is divided into three sections by the diversion of the Kotla, Gagger, and Choa branches, respectively 90, 56, and 25 miles in length. The end of the feeder is the junction of the Choa and Pattiala branches, the latter being 6 miles long and terminating at Pattiala.

The principal works of interest on the line of the Sirhind Canal are the headworks at Rupar, the superpassage crossing the Siswan torrent, which in time of flood discharges 20,000 second feet, and the superpassage across the Budki torrent, which in time of flood discharges 30,000 second-feet. The siphon for a drainage crossing at Hurron torrent, though small, is likewise deserving of particular mention in its place.

The water supply of the Sirhind Canal is less than was anticipated. The least discharge of the river ever recorded was 2,800 second-feet, while the average minimum discharge is 3,600 second-feet. The maximum discharge of the canal as designed is 6,000 second-feet, while the average discharge available is 5,100 second feet, though the maximum flood discharge has been as great as 100,000 second-feet. The rainfall over the irrigable area varies between 10 and 35 inches per annum, and during the autumn crop is from 1 to 6 inches. The gross area commanded by the canal is 4,521,000 acres, of which 800,000 acres are irrigable. During the autumn crop of 1889 only 338,000 acres were irrigated, of which 38,000 acres were double cropped.

The total length of main canals is 41 miles and the total length of main branches 503 miles, while there are 4,407 miles of principal distributaries. The total outlay on this canal to the end of 1889 was $7,831,000, and since the canals were opened the net annual revenue has constantly increased, until in 1889 it amounted to 2½ per cent. In the year under consideration the duty per second-foot in the autumn season on the supply entering the canal head was 119 acres or $113, and on the supply utilized it was 127 acres or $121. The average water rate per acre irrigated was 95 cents, the working expenses being 40 cents per acre, and the cost of establishment was 15 cents. The precentages of the principal crops irrigated were as follows:



SIRHIND CANAL SYSTEM, PUNJAB.

	Per cent.
Barley	3·66
Maize	6·32
Wheat	43·63
Cotton	3·36
Sugar cane	0·33
Millet and small grains	16·10
All other crops	26·60

It will be interesting to examine the items of cost, interest, and revenue of such a canal as this, and to make comparisons between these costs and returns and what might be derived from a similar work if made in the United States. In making this comparison the amounts reported in the revenue returns for such expenditures as pensions, furloughs, and navigation works must be deducted from the total outlay and due allowance made for the difference in cost for each class of construction in the two countries and for the water rate to be charged. To the end of 1889 the total expenditure was $15,350,000, of which $3,100,000 was interest while the work was under construction, and of the whole $500,000 was leave and pension allowance to employés.

Though such a work would have been constructed in a much shorter time in the United States owing to the substitution of mechanical means for hand labor, the rates paid in our country for interest would probably equalize this charge. The total original cost of the works was $12,000,000, of which, exclusive of the cost of land and maintenance, $400,000 was for head works, $6,500,000 for the main canal and branches, exclusive of $1,100,000 for right of way and navigation works. The office establishment in India is an expensive one and, less pensions, costs $2,200,000, while the tools and plant cost an additional $1,100,000. In the main canal and main branches the earthwork alone cost $2,600,000, and on the distributaries this item cost $800,000, making $3,400,000 for earthworks.

For the total 800,000 acres of irrigable land controlled the cost for earthwork was $4.25 per acre. Our contract prices in the West being, say, 10 cents per cubic yard against their 4 cents, this earthwork would have cost us $10.62 per acre. The masonry works—as falls, weirs, regulators, and bridges—cost in all $2,400,000, or $3 per acre irrigated. In India rubble masonry costs about $3 per cubic yard. In our West it averages, say, $6. Hence these works would have cost us $6 per acre. In our works, however, we would avoid the expense of the numerous masonry bridges constructed in India; again, we would do comparatively little masonry work, but would use iron and wood, which are relatively far cheaper. The cost for these items would accordingly be proportionately less. Perhaps one-third can be deducted for the cheaper material, and it would cost us, therefore, $4 per acre irrigated. The drainage works and escapes cost about 73 cents per acre more, or such a work as the Sirhind Canal would have cost $15.35 per acre irrigated against $8 in India.

Owing to the recent completion of the Sirhind Canal it irrigates at present only 467,000 acres. This, however, pays a profit on the capital of from 2 to 4 per cent per annum. It may be expected to yield 6 per cent when worked to its full capacity. The water rates charged average 90 cents per acre irrigated. We could charge at least $2 and in some localities more. As the cost of construction in America would be twice that of India, while the receipts per acre would be nearly three times as great, it is not improbable that under similar circumstances such a work when fully utilized would yield from 5 to 12 per cent, and when doing its maximum duty would realize as a minimum 10 per cent on the capital invested.

In addition to the amount realized from such a work as compared directly with that obtained in India, there is one source of revenue in our country which does not exist in India. That is the annual increase in value of the land served by the canal. There is no such increment available to private enterprise in India, because the government is the owner of the land. In America, however, where land can be purchased at from $1.25 to $2.50 per acre and when supplied with water right will sell for from $40 to $100 per acre or bring an equivalent revenue, the increased return from such an investment is obvious.

BARI DOAB AND WESTERN JUMNA CANALS.

As before stated, these two canals are among the oldest and best paying of their kind in India. In 1351 Feroze Shah constructed the first channel where the Western Jumna Canal now exists, and at different periods up to 1817 the works were reconstructed and utilized. In 1817 Capt. Blaine prepared to restore them. The supply of the Western Jumna is derived from the Jumna River at a point where it leaves the Sewalik Hills, where the fall is great and the bed composed of shingle and bowlders. On the opposite bank the Eastern Jumna heads at nearly the same place. In 1870 permanent head works, distributive and drainage works, were constructed to replace the old ones, and a little later the main canal was almost entirely realigned. At the end of 1878 the total receipts since the works were taken in hand by the government had exceeded the working expenses, and interest on the capital by $12,500,000, or about four times the first cost of the work. The total length of the main canal and branches is 280 miles, and there are 906 miles of distributaries. The area irrigated is 550,000 acres and the maximum discharge of the canal is 3,000 second feet.

The Bari Doab Canal derives its source of supply from the Ravi River and commands 15,000 acres of land between the Ravi and Bias rivers. In 1633 the Shah Jehan constructed the first canal in this neighborhood. The project for the new canal under British rule was first reported on in 1850, when the works were commenced. In 1856 they were revised, and water was admitted to some portions of the canals in 1859. In 1874 the works were decided upon as now constructed, and

were estimated to produce a profit of 8·8 per cent. Recently a considerable amount has been expended in the construction and improvement of falls and rapids. The total outlay to the end of 1889 was $5,443,000 and the interest in that year was 7⅛ per cent. The maximum discharge of the canal is 4,000 second-feet, and the area irrigated 525,000 acres. There are 362 miles of main canals and branches and 1,058 miles of distributaries.

SIDHNAI CANAL.

Estimates for a permanent inundation canal from the reach of the Ravi River were submitted in 1875 by Mr. E. C. Palmer. In this project the head of the canal was located at the top of the straight reach called the Sidhnai. Owing to bad alignment (as Mr. Palmer's project followed a low depression for many miles), the position of the headworks was abandoned, and a new site selected at Tatyraj, where the section of the river is 770 feet across and the banks of stiff brown clay.

The maximum discharge of the river is 18,000 second-feet and is not likely to be exceeded. Gauge records show that all idea of the construction of a perennial canal from this part of the river must be abandoned, as twice since 1875 the Ravi has been absolutely without flow during the cold season. As constructed, the only masonry works on the canal besides the head works are the bridges and the heads of distributary channels. The area commanded is about 192,000 acres. Of this the present project provides for the irrigation of 48,000 acres. The duty was assumed to be 60 acres per second-foot and the discharge of the canal was placed at 800 second-feet. The rainfall on the irrigated area has averaged 5·9 inches per annum. When the canal project was reported on in 1883 most of the country was covered with jungle to within about 3 miles of the river. This jungle consisted of coarse grass, brush, and tamerisk. The crops now grown on this land during the summer season are sugar cane, indigo, rice, cotton, and millet, and during the autumn season are wheat, barley, turnips, and lentils.

On the line of the canal no drainage or protective works are required except one or two very insignificant ones. At first the canal was only excavated to half width, but all the masonry works were constructed of full width. As finally aligned the canal leaves the Ravi River at right angles and runs straight for 2,000 feet, where a long curve commences, ending at 3½ miles. It then keeps along the divide to Chauparata, whence it runs mainly in the bed of the old river Ravi. There are four main distributaries and six minor ones.

The head works consist of a regulator with 8 sluice openings of 10 feet each. The curtain walls of the regulator and river banks are founded on wells 10 feet below the present river bed. Wells were adopted in preference to concrete, though they are more expensive, and it was not certain that the latter could be put in 10 feet below the bed. The weir

consists of a wall 750 feet long, founded on concrete in the center and on wells for 20 feet from each bank.

The discharge from the canal is 800 second-feet, the bed width of the main canal is 80 feet, the depth of water 5 feet, and the velocity of flow 1·85 per second. The discharge of the river varies between nothing at extreme low water and 18,000 second-feet at maximum flood.

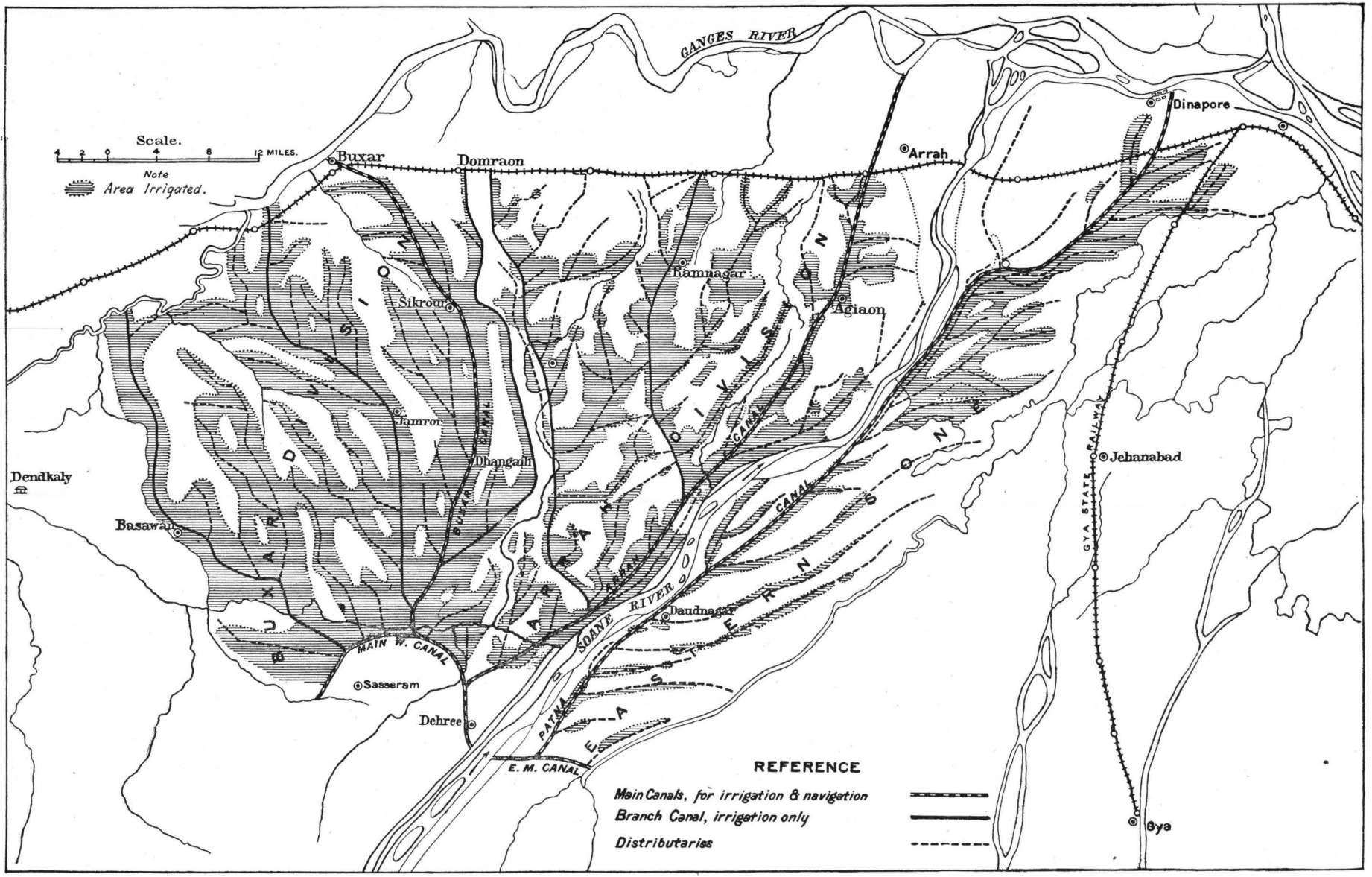
The total cost of this work to the end of 1889 was $277,000. The net receipts for the same year amounted to $33,000 or 12·6 per cent on the capital invested. The water rate charged per acre irrigated during the autumn crop was 62 cents and the duty during the same season was 85 acres or $57.

THE SOANE CANALS.

Like the Sirhind Canal in the Punjab, the Soane system in Bengal may be taken as an example of the most recent practice in the construction of a perennial canal system. The Soane canals are included in one system heading at a common point and having a common diversion weir. They consist of two main lines, one flowing from each bank of the Soane River. The Soane River is a tributary of the Ganges, rising in the central plateau of India and having a course of about 350 miles through the high country. Near Rhota it breaks through the hills, which at this point are 2,100 feet above the sea, whence it flows northeasterly for 75 miles through the Gangetan plain to its junction with the Ganges near Arrah. In the plain it flows through the districts of Shahabad on the left or west bank and Patna and Gaya on the east bank. These are among the most fertile and highly cultivated districts in Bengal, densely populated and studded with ancient cities. The successful operation of the Soane canals is largely due to the acreage which is cultivated during the autumn season.

The works of the Soane Canal were first undertaken by the East India Irrigation Company, but given over to the Government when scarcely any work had been done. The scheme was originally proposed in 1853 by Lieut. C. H. Dickens. A plan to utilize the larger portion of the volume of the Soane was, however, amplified by the same officer in 1861. In 1862 the secretary of state approved of the project, and after discussion by Sir A. Cotton and Col. Rundall it was forwarded for the approval of the Government in 1864. In addition to the features now existing it was proposed in the original project to construct reservoirs in the hills south of Rajmahal to supplement the available discharge of the river. This part of the scheme was considered too expensive, however, and the plans were changed. In 1869 the work was undertaken by the Government. It was estimated to give a net profit of 12½ per cent on the outlay. In 1871 it was decided to reconstruct the slope of the canal, as the supply of water was not as great as had been anticipated.

The catchment basin of the Soane above Dehree, where the headworks are situated, is about 22,000 square miles in area, and in flood the river



SKETCH MAP OF SOANE SYSTEM, BENGAL.

discharges 750,000 second-feet, though the maximum flood provided for is 1,250,000. For about 40 miles below the diversion weir the floods seldom overtop the river banks, but below that point to its junction with the Ganges it is almost deltaic in character, considerable overflow taking place. To about this point the canal follows the bank of the river rather closely, after which it diverges and follows the high ridge between the Soane and Ganges.

The diversion weir across the Soane is at Dehree, a point 25 miles below where the river leaves the Kymore hills, and is the longest weir in one unbroken length of masonry that has ever been constructed, being $2\frac{1}{3}$ miles long and 8 feet high. In high flood the river rises $8\frac{1}{2}$ feet above the crest of the weir. The main western canal (Pl. CXIII) takes off from

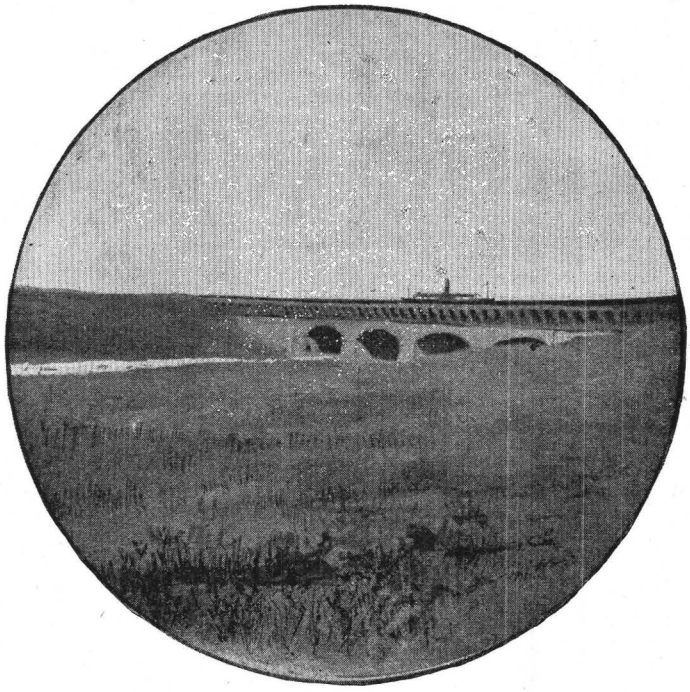


FIG. 235.—Thora Nulla aqueduct, Soane Canal.

the weir on the west bank where it encounters a rather deep cut. It crosses the Kao torrent by a large siphon aqueduct in the ninth mile and similar drainage channels in the seventeenth and twenty-first miles. The Arrah canal leaves the main western at the fifth mile and follows the bank of the Soane to the thirty-third mile, where it leaves it and passes close to the town from which it takes its name, tailing into the Ganges. On this line are thirteen locks with an aggregate fall of 161 feet. The Buxar canal leaves the main western at the twelfth mile and is almost straight from that point to the Ganges at Buxar. The total fall in this line is 153·75 feet, and in the twenty-ninth mile the canal crosses the Thora torrent (Fig. 235) on an aqueduct with 4 arches,

each of 30-foot span. The other main canal of this system, the main eastern, takes off from the Soane weir on the eastern bank opposite to Dehree and is 7 miles long, its termination being at Poon Poon torrent. The Patna canal leaves the main eastern at the fourth mile, and after following the river bank for 60 miles, is diverted to the ridge and tails into the Ganges near Patna. It was estimated by F. T. Haig, R. E., when chief engineer, that these canals would pay both interest and working expenses on the outlay until 1887, when it was expected that they would return a net profit of 4½ per cent.

The important feature of the head works is the mode of construction of the weir, the automatic action of the scouring sluices, and the arrangement of regulating gates. These will be elsewhere described in detail with the drainage works across the Kao and Thora torrents. The weir and principal works were designed by H. C. Levinge, chief engineer of the East India Irrigation Company. The afflux was estimated at first for flood of 6½ feet over the weir crest as being 15 inches, the formula used being $D = 3.5 \times ld \sqrt{d + .035\ w^2} + 8.02 \times ld_2 \sqrt{d + .0153\ w^2}$. The minimum discharge of the Soane River at Dehree is 5,260 second-feet in summer and 1,870 second-feet in autumn. The maximum discharge is 5,950 second-feet, of which the main eastern canals discharge 1,613 and the main western series 4,340 second-feet. The average rainfall upon the area irrigated is 41 inches. The gross area commanded by the entire system is 1,730,000 acres, of which 1,016,000 acres are irrigated. There are 367 miles of main canals and 1,170 miles of distributaries. The average discharge utilized in the autumn of 1888 was 1,180 second-feet, and the duty performed during the autumn was 68 acres per second-foot of the supply utilized. The water rate per acre was 85 cents. The total length of village channels or minor canals is 1,525 miles; the total number of outlets for distribution of water is 6,000, the area irrigated per outlet being 93 acres.

In the Arrah division, Mr. W. A. Inglis, the executive engineer, calculated the supply of water spread over the country was equal to an effective rainfall of 5·7 inches. On the assumption that one watering of 6 inches in depth is given every fifteen days, 1 second-foot of discharge should irrigate 60 acres if the outlet were constantly open, or 40 acres if the discharge outlet were open for only ten out of fifteen days. The cost of repairs to the headworks is about $16,000 per annum and the cost of maintenance exclusive of head works about $81,000. The charges for silt clearances amount to $30,000 per annum, the total amount of clearances being 10,850.000 cubic feet, and the rate about $3 per thousand cubic feet. The silt clearances were made by means of large steam dredges. The total cost for weed clearance was $1,600 in 1888 and the mileage rate or cost of repairs varied from $30 per mile on distributaries to $65 per mile on smaller branches, $211 on larger branches, and $2,800 on the main western canal.

The following is a statement of traffic on these canals for the year 1888.

There were 218 miles of canal open for navigation. The tollage receipts from private boats amounted to $12,000; on government boats $1,400 and on rafts $3,500. These with minor items make the total receipts from tollage $18,600. The maintenance charges, including navigation establishment, were $11,800 and the net revenue from navigation was $6,800. The total number of cargo boats was 4,547; of passenger boats 530. The total tonnage of these boats for cargo traffic was 71,243 long tons and for passenger traffic 12,437 long tons, and the total ton-mileage was 4,635,000 miles. The estimated value of the cargoes was $1,785,000 and the passengers carried numbered 46,170. There were estimated to be 3,089,000 cubic feet of rafts valued at $107,000. The tollage receipts per ton-mile on boats was 3 mills, and tollage on rafts per hundred cubic feet was 11 cents.

The total outlay on the Soane system to the end of 1888 was $8,680,000 and the revenue that year was $175,000. The total receipts were $200,000. There was a net deficit after deducting all working expenses of $38,000. For the previous four years there had been, however, a net profit of from $100,000 to $150,000. The decrease in this year was due to the cost of repairs and to the falling off in water rates on account of the unusual rainfall.

CROSS-SECTION, SLOPE, AND ALIGNMENT.

In designing a canal system the Indian engineer, having decided on the location of the head works, and ascertained the source of supply, the area, and location of irrigable lands to be served, next considers the proportion of width to depth of his channel, the cross-sectional area being fixed by the supply of water to be discharged at any point. On the western Jumna Canal the proportion of depth to width is that which the Jumna River has in the course of years formed for itself, found by trial to be about 1 on 13. On the Bari Doab the proportion fixed in construction was 1 on 15, and on the Sirhind, 1 on 14. In the case of the Nira Canal, which is nonnavigable and of a smaller capacity than those just described, the proportion is much less, the depth being 7½ feet and the bottom width 23 feet. On the Soane the main western line has a depth of 10 feet and a bottom width of 100 feet, or a proportion of 1 on 11. The Betwa, which, like the Nira, is nonnavigable, is relatively deeper than the larger canals, being 5 feet deep to a 15-foot bed width on some branches, and on others 6 feet deep to a 30-foot bed width. The proportion first given is such as will apply only to canals so great as to correspond in their general characteristics to large rivers.

The side slopes of the canal (Fig. 236) are generally arranged according to the facilities for excavation, and are such that the ground will stand at a natural angle. In the soils in which the canals are generally excavated in Bombay the side slopes are usually 1 on 1½ on the inside and 1 on 2 on the outside. The matter of fixing the cross section has been a difficult one to solve on account of the conflicting conditions of

the supply of water required and velocity permissible. This is fixed by the liability to growth of weeds, the deposit of silt, or the destruction of the banks by erosion.

Having determined the quantity of water, fixed the proportion of width to depth and ascertained a maximum for both, the slope of the bed becomes one of the most important remaining problems in the design of the canal. If the slope be too great the bed of the canal and its sides will be eroded and the integrity of the masonry and other structures endangered. If it be too small a larger section of channel will be required to discharge a given quantity of water and additional works, as falls, may be necessary to overcome the excess of surface slope in the country. The growth of weeds and aquatic plants, and the deposition of silt will become a troublesome evil. As it is difficult to avoid both extremes a compromise has generally to be made. It is per-

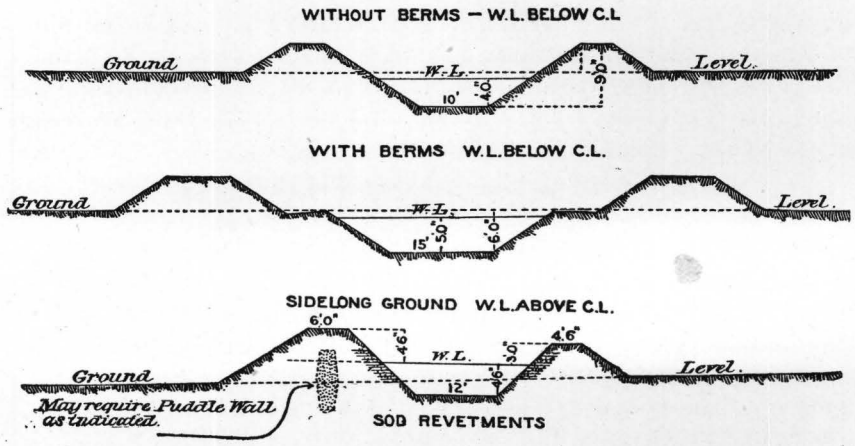


FIG. 236.—Canal cross-sections.

haps well to err on the safe side and give to the bed the greatest slope apparently desirable. If this slope should prove to be too great or the fall of the country too rapid the difficulty may be remedied by introducing falls and rapids in the channel to diminish its general slope and concentrate the loss of grade in a few places. In different soils and in different canals the velocity given for the prevention of the growth of weeds and the deposit of silt differs largely, but it has been found generally that the minimum velocity is about $1\frac{1}{2}$ feet per second. According to American experience this is too low, as we usually consider that $2\frac{1}{2}$ or $3\frac{1}{2}$ feet per second is the minimum. In India the maximum for ordinary soils rarely exceeds 4 feet per second. In America it is often much higher.

One of the greatest difficulties encountered in India in determining the velocity, slope, and cross section to be given to a canal has been the introduction of navigative works. These are generally antagonistic to the requirements for irrigation purposes only. The velocity of the

current in navigable canals must be low in order to permit traffic in both directions. In the Ganges Canal with a bottom width of 170 feet and a 7-foot supply, a slope of 14 inches per mile has been given in the sandy soil of the upper reaches, and the resultant velocity is such that the current has just ceased to cut the banks and to deposit silt. In the first portion of the canal where the bed is in gravel and bowlders the fall is 24 inches per mile. From there on the slope of from 15 to 17 inches has been found to be too great, the water having done much damage to the banks. The larger portion of the reach of 20 miles from Hardwar to Roorkee is extensively riprapped now and the engineers are continually adding a lining of bowlders to the bed and sides of the canal.

The velocity of 3 feet per second, which was originally given to the Soane Canal, caused much damage by erosion and had to be remedied. Col. Anderson, R. E., made some interesting remarks on this subject in the Roorkee Manual, among which were the following: Where the fall of the country is tolerably uniform the slope of the bed of the main channel must be less than that of the branches. This, again, must be less than that of the distributaries and minors, the object being to secure as far as possible a uniform velocity, so that the matter carried in suspension may be carried on from the head and deposited over the irrigated lands. At the head of a canal it is sometimes desirable to reduce the width, in order that with an increased depth the velocity may be the same as that in the channel lower down. He says that the accumulation of silt in the main channels is a serious impediment to obtaining a supply of water until the crops are mature, and their clearances are enormously expensive. If the silt can not be carried to the fields it is a step in advance to prevent its accumulation in the main channel. It is easier to clear out the minor branches without cutting off the supply from the main river. Escapes are introduced at intervals in all canals for the control of the discharge of water and to facilitate silt clearances and as a prevention of its deposit.

The following interesting observations were made by Maj. Crofton in his report on the Ganges Canal relative to velocities of current: Where the current seemed to be perfectly adjusted to a light sandy soil the velocity of the surface was found to be from 2·4 to 2·3 feet per second and the mean velocities, using 0·80 as a coefficient, were found to be 1·93 to 1·85 feet per second. In one place, where silt was being constantly deposited, the mean velocities were from 2 to 2·3 feet per second. On the same canal in very sandy soil, with nearly a full supply of water, the maximum surface velocity was found to be 3·08 and the mean velocity 2·49 feet per second. In one of the distributaries, where the soil is sandy with a fair proportion of clay, the mean velocity was 1·93. Here silt was deposited but no weeds grew. On the Western Jumna Canal Col. Dyer, R. E., found that silt was deposited with mean velocities of from 2 to 2¼ feet, and in sandy soil 2·7 feet per second was the highest

mean velocity for noncutting. Jackson's and Neville's formulæ are those most usually employed in the determination of velocities and corresponding cross sections. In designing the proportion of excavation to embankment and the width of berm, several interesting but involved formulæ are employed by the Indian engineers, of little service, however, as guides to the American designers of canals.

Great care and judgment must be exercised in the alignment of an irrigation canal. Any change of direction causes a loss of velocity, and the slope should be changed if it is essential to introduce a curve. The water drawn into branches and distributaries loses velocity in passing through the head sluices unless they possess the full water way of the channel, and due allowance should be made for this by adding to the slopes at the heads of branches. The Indian engineers have always deemed it essential in designing their canal systems to make a thorough and detailed survey of the country to be irrigated, so the most perfect alignment and command of the lands can be obtained. Trial level lines and careful transit surveys are run, after a rough survey has been made, and the whole is shown on a large scale contour map. A complete delineation of the drainage of the country is one of the primary objects, as is also the direction of the drainage outlets and the interfluves. The nearer the line of the canal approximates to the summit of the watershed the better will be the alignment, as the interference with the surface drainage of the country will then be the least possible. In encountering cross drainage provision must be found for its safe passage, and unless the streams are very small they should never be permitted to enter the channel. The canal should always be made to tail into some drainage line or river, so that the surplus may not be lost, and in order to insure a sufficient scour it is deemed advisable to increase the velocity at the end. When practicable all embankments are formed by ramming the soil in thin layers. Where the channel runs through sandy soil the beds and banks should be covered by an impervious puddle.

Great care has been used to fix the permanency of all transit points and bench marks, etc., on the surveyed lines of canals in India. On the outer edge of the berm are placed masonry mileposts, with smaller masonry pillars every one-fourth mile, while on the inside whitewashed stones are laid into the ground every 100 feet. At frequent intervals large substantial masonry benches are established.

HEADWORKS.

The headworks of canals are usually located at the points where the rivers emerge from the hills, in order to obtain a sufficient command of land and allow the canals to reach the summits of the interfluves with the shortest possible length of diversion line. In India, owing to the great volume of flood water required to be passed over the diversion weir, it is necessary to have an extremely wide water way, and it

is usual to locate the weir in a relatively wide portion of the channel. If the only consideration in the location and construction of a weir was the raising of the water of the river to the level of the canal bed, in order to obtain the shortest possible diversion line, the most favorable location would be in the lower courses of the river, where the fall is gradual and the banks shallow. Such an obstruction of the bed in these localities would, however, raise the surface of the water in freshets, rendering necessary the construction of artificial embankments and other protective works, and would be extremely objectionable. A rock bed, though a great advantage and always to be preferred, is not considered an indispensable requisite in constructing weirs.

Several great Indian weirs have been thrown across rivers whose beds consist entirely of pure sand, reaching far below the foundations. In such constructions the chief requirement is a strong apron beneath the weir to break the fall of the water and prevent the foundations from being undermined. Prof. George Davidson says:

> In order to reduce the first cost of construction it has become a custom in America to build bridges and dams across streams at the narrowest points available, or to contract the streams for that purpose. This frequently involves great difficulty to the engineer in laying the piers and abutments, and also brings in an additional danger by adding to the scouring effect of the water on a contracted channel; it also produces the evil effects by the formation of shoals below the scouring-out channel. The proper location for such works, especially across rivers with unstable banks, is in the broad reaches of the stream, where the depth of the water is less and where a bar has been already formed across the river by natural causes.[1]

A dam across a river is analagous to a bar, and should be located and treated as such. If this is placed at the broadest part of the stream the cost of construction may be increased, but not necessarily. Instances of the location of weirs in the broadest reaches of rivers may be cited in the case of nearly every weir constructed in India. The weir at the head of the Ganges Canal occupies the full width of the channel; those of the Bari Doab and of the Soane are thrown across at points where the width of the river is an average. The weir at Okhla, at the head of the Agra Canal, is also constructed in a broad reach.

The headworks of Indian canals consist essentially of the weir across the river by which the level of the water is raised and its flow checked; of a set of scouring sluices placed in the weir at the end adjacent to the canal head, the object being to create a constant flow past this head, thus preventing and carrying off any excessive deposit of silt, keeping as they do the course of the main channel of the river close to the canal head; and, lastly, of a regulator across the head of the canal channel by which the proper quantity of water is admitted to it. In a few cases, as those of the Ganges and Jumna canals, where the canal is taken from a branch of the river, a permanent dam is thrown across this channel only, the water being diverted to it by means of the river-training works.

[1] Prof. Geo. Davidson, Irrigation Works of India, U. S. Senate Doc. No. 94, Forty-fourth Congress, Washington, D. C., 1875.

WEIRS.

The weirs employed are of various kinds, but are always constructed substantially of masonry and are well founded. They may rest on solid rock foundations and be nearly vertical with an overfall on to a rock bed, or flat and low, founded on wells in sand, with a vertical overfall on to an apron of masonry; or they may be similar to the latter with the exception that instead of the vertical overfall the downstream slope may be constructed of loose-packed rock on a long slope of, say 1 on 15 to 1 on 20; only rarely are temporary weirs constructed simply of loose bowlders. The two great classes of weirs are solid weirs, such as those above indicated, or open weirs, in which the obstruction is temporary, as needles or removable sluice gates.

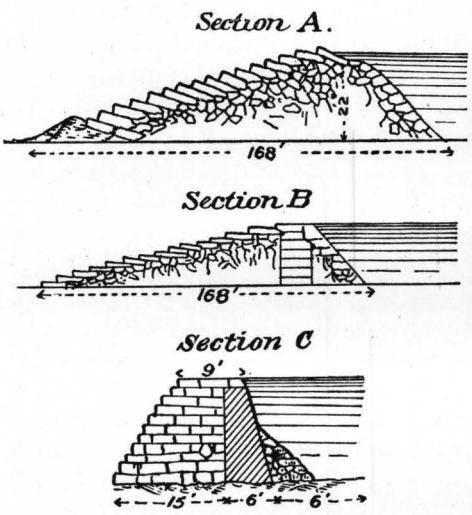


FIG. 237.—Three ancient weirs.

The antiquity of weirs is very remote. The first great weir, that at Tulkad, on the river Cauveri, is said to have been constructed by one Madwa Rou, A.D. 894. Many others are said to belong to the sixteenth century, while others are of intermediate dates. The new works of the Indian natives are of minor importance, with the exception of the Poorniah channel, constructed in the early part of this century to lead the sacred waters of the Cauveri River to Misau. Rough stone weirs exist at the heads of most of the channels in Misau. These raise the water level to the required height, the lowest being 7 feet and the highest 25 feet. The canals are for the most part supplied with regulating sluices at their heads and with escapes for getting rid of flood waters.

The accompanying illustration (Fig. 237) shows the section of a native weir constructed early in the present century, the breadth of which, parallel to the course of the stream, was 168 feet. This weir consisted of a mass of rubble and large stone, the front face formed of stones $1\frac{1}{2}$ by 1 foot, while the apron was composed of rough stone blocks 9 by $3\frac{1}{2}$ by 2 feet, laid in uneven courses. All the interstices were filled with large rubble. Repairs were first made in 1842, and thereafter were carried out on a slightly different plan, the general section being retained. The repaired dam appeared as here indicated. These illustrations give a fair idea of the attention given by the natives to this class of work and indicate the fallacy of trusting to size and position of the material

instead of to the homogeneity of the work. Notwithstanding the employment of large blocks of stone and skillful application of material the dam was breached five times between 1842 and 1863.

A later development is indicated in the cut given of the Muddur weir. Gen. Greene retained the native section of this weir, but corrected its chief failing by building an impervious brick and mortar face against its upper side. The natives, with the object of decreasing the depth of water flowing over the weir in flood times, carried the work in a curved line, its general direction tending upstream. The length of the weir, therefore, was nearly double the actual breadth of the river, and its crest was frequently at different levels; the part next the head sluice being invariably lower than the rest relieved the head of water pressure against it during flood. All these features, shown by experience to be desirable with the native works, are so many defects with the solid masonry work now adopted. The regulators in the old works at the heads of canals were mostly constructed of rough stone posts, the openings between which were stopped with rough timber and fulfilled their objects in an imperfect manner.[1]

In regard to the two main designs adopted by modern practice for weirs, namely, the open and the closed or solid weir, the advantage of the latter is that it is self-acting and if well made requires no repairs or maintenance. Its first cost, however, is greater than that of an open weir and it interferes with the regimen of the river, causing deposits of silt above it and perhaps making the river seek another channel. The open or scouring sluice weir interferes but little with the normal action of the river. The scour produced by opening the gates prevents the deposit of silt and its first cost is less than that of the closed weir. Another form of weir, the best examples of which are to be found in the barrages of France, consists of a weir open the whole width of the channel, the object being to prevent in time of flood the water being backed up, thus submerging valuable property above the weir. The obstruction in the river channel may be entirely removed by opening the gates the full width of the weir.

The ordinary weir consists of a masonry floor acting as an apron, properly founded and carried across the entire width of the river flush with the level of the bed and protected from erosive action by curtain walls up and down stream. On a portion of this is constructed the upper work, which may consist of a solid wall and part masonry piers, the interstices between the latter being closed by some temporary arrangement, thus creating the scouring sluices. Weirs proper are in no instance to be looked upon in the light of storage works. They may for a trifling period during the dry season answer that purpose, but the irrigation from them depends in all cases on the continual flow of a small quantity of water or upon an auxiliary supply from storage waters

[1] Maj. R. H. Sankey, R. E., Roorkee Professional Papers, No. 141, Roorkee, India.

situated higher up. In speaking of the mode of constructing low diversion weirs with long slopes, Col. Baird Smith says:

> In rivers with beds of pure sand and having slopes of 3½ feet per mile such weirs may be constructed and maintained at a very moderate expense, and the elevation of the beds of the rivers on the upper sides of these weirs to the full height of the crowns is an inevitable consequence of their construction and no arrangement of under sluices has yet been effective to prevent this result.

In regard to founding these structures on wells, he further says:

> In pure sands acted on by currents due to a fall in the river bed of 3½ feet per mile, and exposed to the action of floods from 12 to 15 feet deep, well foundations in front and rear of 6 feet in depth have been proved by experience to be safe.[1]

As a general rule the masonry apron should have a thickness equal to one-half and a breadth between 3 and 4 times the vertical height of the weir forming the obstructive part of the dam. The efficiency of the dam depends upon the construction and careful maintenance of the apron. In time of freshets the water backed against the toe of the weir has a protecting effect on the apron by producing a water cushion, and as the flood rises the height of fall from the weir crest gradually diminishes, and in a flood of 16 feet over an ordinary weir it wholly disappears, leaving scarcely a ripple on the surface to indicate the existence of the masonry mass below.

In the construction of weirs in rivers with sandy beds, wells may be considered as the feature of Indian engineering. These are essentially open blocks or cylinders of brick usually sunk in the bed of the river at low stage and are protected by temporary sheet piling placed between their outer edges, while the intermediate spaces are being filled in with concrete, thus forming a solid wall floating in sand, upon which is built the superstructure of the weir, scouring sluices, apron, and retaining walls. Whatever the form of foundation, be it gravel or hardpan, solid rock or wells, the first portion of the weir constructed is the scouring sluices, which are carried on at the same time with the regulators at the head of the canal. This order is pursued, because after the construction of the scouring sluices the water in the river may be diverted through them while the work upon the remainder of the weir is progressing, and especially so that it may be passed through them when the closing of the weir is effected. The heaviest flood of water takes place through these scouring sluices, and in their construction the very best workmanship and material are required. The weir may, if desirable, progress at the same time with these preliminary works. The cross-section of the weir is neither as long nor as flat as that of the foundation and sluiceways. When the closing of the weir is effected the low water in the channel is diverted through the sluiceways, sand or other material available is carried across the last opening, foundations are built up as rapidly as possible, and the superstructure closed.

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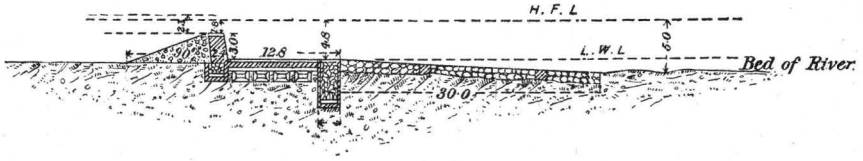
[1] Col. Baird Smith, R. E., Italian Irrigation, London, 1856.

SECTIONS OF INDIAN WEIRS ACROSS GREAT RIVERS.

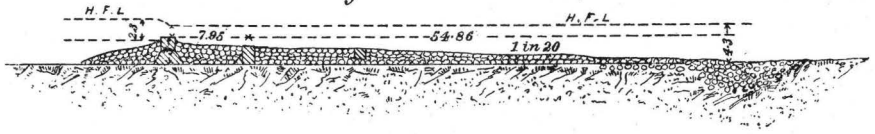
NARORA WEIR – LOWER GANGES CANAL

Length 1260 metres



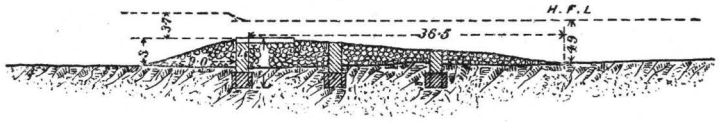
OKHLA WEIR – AGRA CANAL.

Length 743 metres



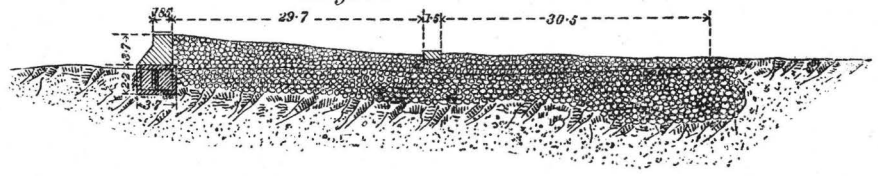
DEHREE WEIR – SOANE CANAL

Length 3825 metres



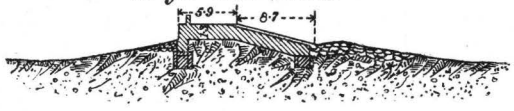
BEZWARA WEIR – KISTNA CANAL.

Length 1150 metres.



GODIVERY WEIR.

Length 6274 metres.



Note: Dimensions in Metres.

Where a good rock foundation is obtainable in the bed of the stream close to the surface the weir is given an entirely different cross-section from that of weirs constructed of other material, and is built throughout of the most substantial masonry laid in cement. In the case of some weirs, the overfall height of which is not great, the cross-section is made nearly vertical upstream, and a slight slope, perhaps 4 on 1 is given on the downstream face, which is usually so curved as to carry away the flood water with the least shock to the dam. In the case of higher weirs of this character, or those over which great floods may be discharged, it is usual to make the downstream face nearly vertical, giving a sufficient top width and slope to the upper face to insure the stability of the structure and bring the resultant line of pressures within the middle third. The object of the vertical slope on the downstream face is to give a clear overfall for the flood water. This drops on the water cushion formed by the construction of a subsidiary weir placed some little distance below the main weir, and backs the water up against its base. In all forms of overfall weirs liable to the severe shock of large floods it is customary to construct these subsidiary weirs, some examples of which will be given in their proper places. In the location of such weirs, a broad reach of the stream is chosen for the site of the main weir in order to reduce the height of water passing over its crest; while the subsidiary weir is, if possible, located in a narrower place so as to produce the greatest depth of water on the toe of the upper weir. Scouring sluices of limited cross sectional area are introduced in such weirs as these, their object being to keep a clear channel immediately in front of the canal regulators.

Of weirs founded on wells in sandy rivers, that at the head of the Lower Ganges Canal at Narora presents a peculiar type, being substantially built of masonry and with a profile similar to that of the masonry weirs just described. This weir is constructed entirely of brick, chiefly because of the cheapness of the material at Narora, and consists of a wall 8 feet wide at bottom, and 7 feet at top, the crest of which is $9\frac{1}{2}$ feet above the river bed. The upstream slope is vertical, while the downstream slope is nearly so. It is protected on the upper side by a quantity of loose rocks or bowlders thrown into the river bed nearly flush with the crest. On the downstream side is an apron nearly 150 feet wide to receive the impact of the falling water. The first 40 feet of this apron is composed of masonry resting on four rows of shallow wells, abutting at its lower end against a row of wells. Below this is a considerable depth of loose hand-packed bowlders carried out to the extreme toe of the apron.

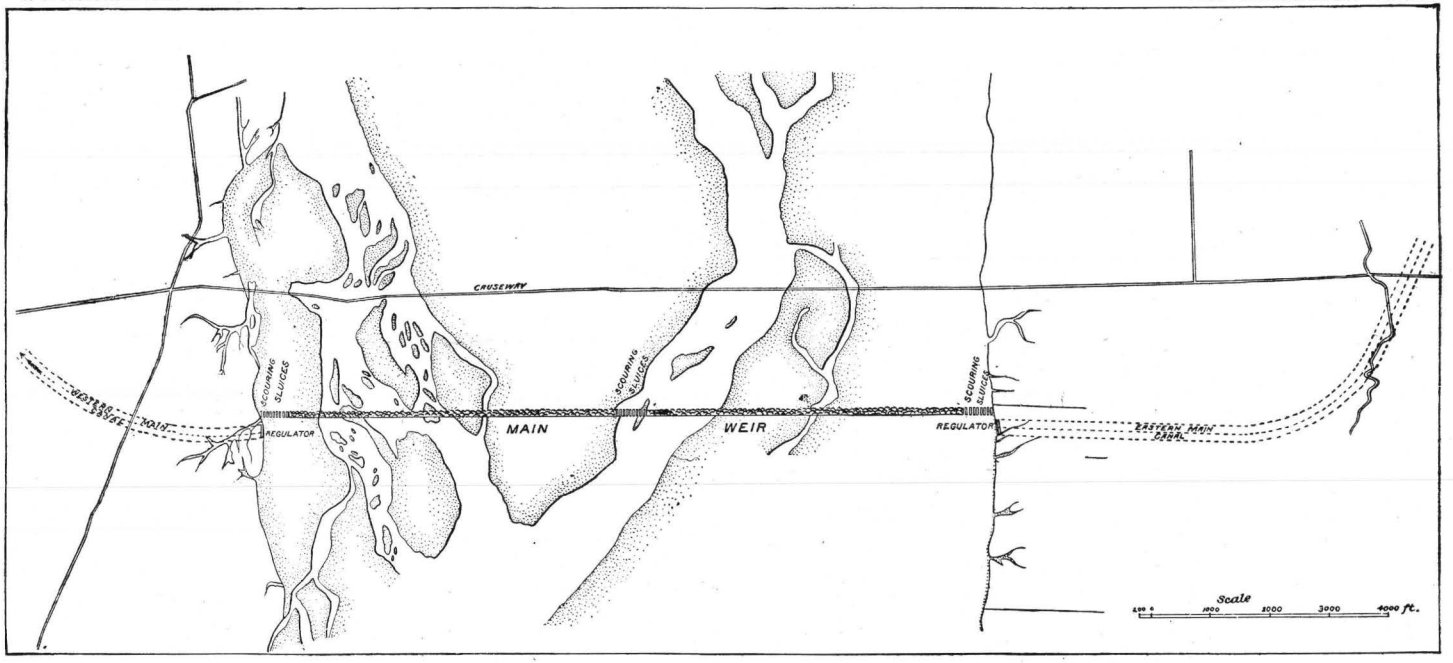
The total length of the masonry portion of this weir is 4,125 feet, including the scouring sluices at the head of the regulator, which are 427 feet long. The left end of the weir rests on an earth embankment a little outside of or beyond the river channel. This embankment is 1,000 feet long with an angle at the shoal end, and is carried up the stream

for some distance, thus protecting the low river bottom on that side from flooding. Detailed drawings of this weir showing its cross section, the plan of its foundations, and the arrangements of the embankment and canal head are presented. (Pls. CXVIII, CXIX, and CXX.)

Another and quite usual type of weir founded on wells is that represented by the weirs at the heads of the Agra and Soane canals. (Pl. CXIV.) The weir at the head of the Agra Canal as first constructed had too bold a cross-section, and during several successive years the lower end or toe was carried away in time of flood. It has remained intact ever since its reconstruction in 1875. This weir is without foundations of any sort, resting on the river bed. It consists of a wall of masonry 4 feet wide on top and a little wider at base forming the main crest line of the weir, the height of which is 10 feet above the river bed. From this crest the slope upstream is carried to a distance of 40 feet, and consists of large stones hand-packed and laid dry. The downstream slope is very flat, averaging about 1 on 20, and is carried a distance of 26 feet to a point at which is constructed another masonry well similar to the first and resting on the river bed, its line being parallel to the axis of the weir for its entire length. Some distance below this is a smaller well similar to the two previously mentioned. The entire remaining portions of the weir consist of large stone blocks dry-packed, the walls acting as bars to prevent their sliding.

This weir is 2,573 feet long from the right bank at the canal head, the left wing resting on an island in the middle of the Jumna River. An embankment 20 feet wide on top was carried thence to and across the east channel and thence up the left bank of the river for some miles. The scouring sluices are 139 feet wide, and are substantially founded on four lines of wells. In order to prevent the destruction of this weir by the action of flood waters groynes of a peculiar shape, called alligator groynes, are constructed on both the up and down stream sides at intervals across the channel of the river and parallel to the course of the stream. The object of these is to deflect as much water as possible toward the right bank with a twofold object, first, the destruction of an island which obstructs the channel just above the canal head, and second, to aid the under sluices in sucking or drawing water toward them at low water, thus affording a sufficient discharge in front of the canal head.

The Soane weir (Pl. CXV) is similar to the Agra weir in general construction, but resembles that at the head of the Midnapore canals more than any other. It consists of three parallel lines of masonry running its entire length and varying from $2\frac{1}{2}$ to 5 feet in width. The main wall, which is in the central axis of the weir, is 5 feet wide and 8 feet high, and all three lines of walls are founded on wells sunk from 6 to 8 feet in the sandy bed of the river. Between these walls is a simple dry stone packing. The upstream slope is 1 on 3, the downstream slope 1 on 12, and the total length of the lower slope is 94 feet. The total



PLAN OF HEADWORKS, SOANE CANALS.

length of the weir is 12,470 feet, and it is 19·3 feet in height, including its foundations. On top, hinged to the lower edge of the crest wall, is a row of iron shutters (Fig. 238), each 18 feet long and 22 inches high, which are supported by struts so that when the river is low they increase the diverting height of the dam by 22 inches, and in time of flood they fall automatically, thus giving the flood a solid masonry crest over which to flow. These shutters are held in place by an iron rod hinged to their centers on the upstream side at about one-third of the height from the base.

The weir across the river Ravi (Fig. 239) at the head of the Sidhnai Canal represents a new and different type of construction. At the point where the weir is built (Pl. CXVI) the river bed for 250 feet on the left bank and 200 feet on the right bank gives a good clay foundation for a reasonable depth below the top of the weir, but the central portion, 390 feet long, is of sand too deep to permit of carrying the foundation to the underlying clay. A trench was dug through this central sandy

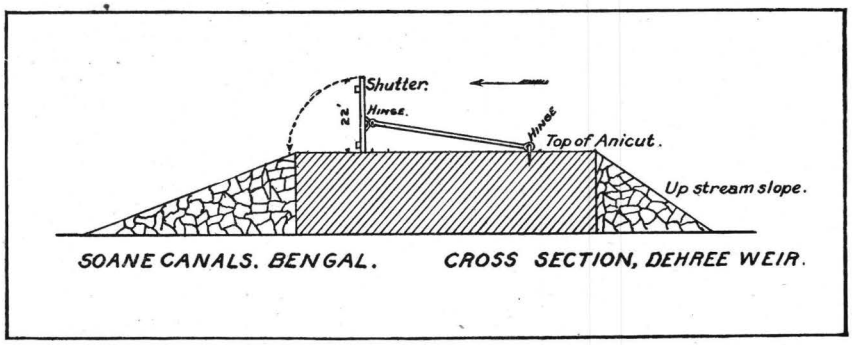


FIG. 238.—Shutter on Soane weir.

portion to a depth of 13½ feet below the crest of the weir, and for a distance of 400 feet, and sheet piles 10 feet long were driven into the sand as a protection for the foundation, and to prevent excessive percolation below the level of the weir. The highest recorded flood would pass 10 feet over the weir crest. The crest of the weir supports a row of wooden needles which are readily removable and are 7·5 feet long. They are placed between masonry pillars about 16 feet apart, thus increasing the effective diversion height of the weir by their length. This mode of construction is indicated in Fig. 241, and the action of the needles is more fully described elsewhere.

Of temporary weirs, the most unique example is that at the head of the Ganges Canal above Hardwar (Pl. CXVII). At this point the bed of the river is composed of bowlders of various sizes to a considerable depth. The headworks of the canal consist of a number of separate structures extending up the river above the head of the canal proper a distance of several miles. The bed of the river is divided into several channels, the principal one being the Hardwar Channel, from which

the canal is diverted and into which the majority of the water in the stream is trained by means of various works. The general plan of these works is given in the accompanying sketch. At the upper end of the bifurcation of these channels is a masonry wall or bar constructed across the left-hand channel, the object being to force the water toward the Hardwar or right bank. The Hardwar Channel from this point on

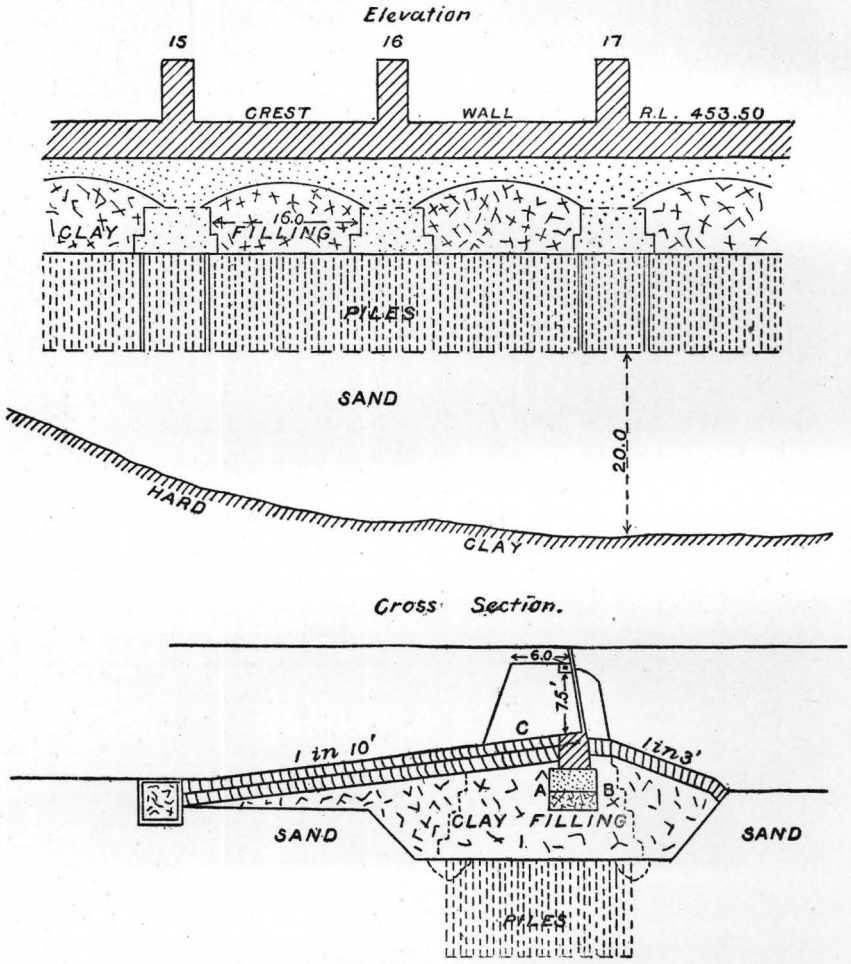
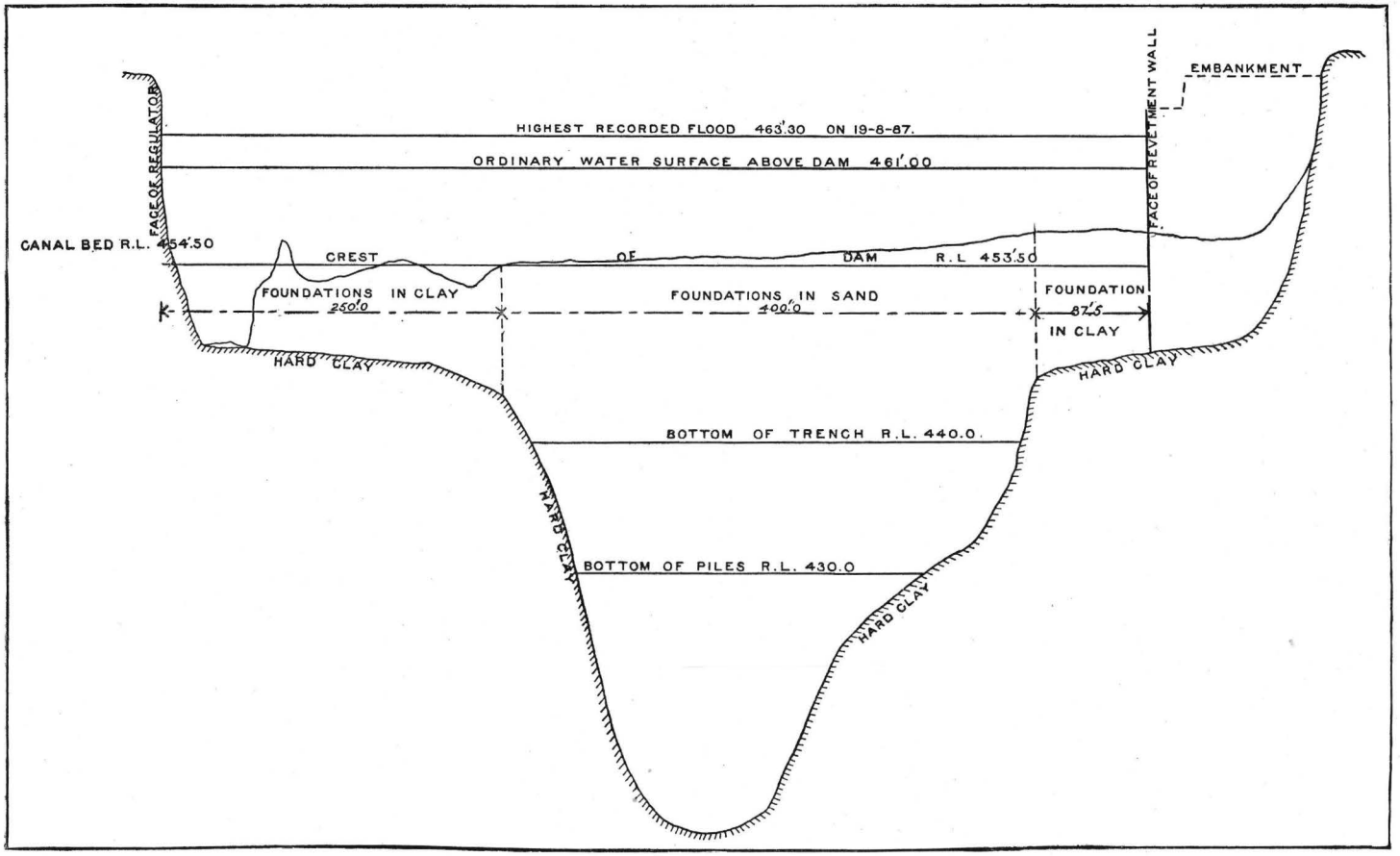


FIG. 239.—Sidhnai weir.

is protected and trained by means of a series of permanent bowlder embankments terminating on their ends in masonry noses. On a minor channel a little lower down a permanent weir is constructed, close to the right bank, to prevent the Ganges from cutting too far in that direction; and a trifle below this, crossing a channel leading to the left bank, are the diverting weirs proper, consisting of a series of three bowlder dams, built across the channel one behind the other in such a manner that the leakage through the first will be caught by the second



SIDHNAI CANAL. SECTION OF RIVER IN LINE OF CANAL.

and turned back into the Hardwar Channel, and that from the second will be caught by the third and diverted again to the Hardwar Channel. These dams are destroyed each year by the floods and it has been found necessary entirely to rebuild them annually, new bowlders being brought down for the purpose, as the old ones are carried too far away to be economically collected. Experience has shown that this mode of construction of temporary weirs is less expensive than would be that of a permanent one at this place.

Large pyramidal-shaped cribs of timber are formed in the roughest manner and when placed in position are filled with bowlders. Bowlders are then thrown on top of these to strengthen and raise them higher and the channel face is covered with small branches and smaller bowlders and sometimes with earth to prevent excessive leakage. The velocity is about 10 feet per second in the major portion of the Hardwar Channel, and its abrading effect is excessive, in consequence of which lines of temporary and of permanent bowlder banks and some masonary dams are carried from this point the entire distance along the sides of the channel to the main regulating weir below Hardwar. Just beneath and below the bowlder weirs above referred to masonry bars are sunk in the bed of the side channel to prevent retrogression of levels, and a few hundred yards below and about opposite the city of Hardwar is a third channel leading from the Hardwar into the left channel. This is stopped by a permanent half open masonry dam laid on a solid bed of masonry. In times of floods the sluices gates may be removed, while at low water their insertion closes the channel.

The regulating gates are at Myapur, at the head of the canal. Here are also the weir and scouring sluices proper. The latter works consist of a weir of solid masonry founded on the bowlder bed with 15 scouring sluices, each 10 feet wide. The weir proper is only 525 feet in length of which 200 feet are occupied by the scouring sluices and their piers. The sluiceways are quite deep and are closed by double sets of gates, some of which are raised and lowered by means of a traveling winch, the remainder being closed by simple planks or flashboards laid in the grooves.

SCOURING SLUICES.

The scouring sluices placed in open weirs consist of the foundation, the floorway, and the superstructure. The floor must be deep and well constructed, and carried for a little distance above the weir and for a considerable distance below it. Above this are built up masonry piers at regular intervals, placed from 6 to 12 feet apart, and grooved for the reception of planks or needles, or closed with automatic gates or some other device which can be rapidly removed or replaced. By this means the water is kept under control and when low can be raised to the level of the crest of the weir by closing the gates, while in time of flood they are opened to secure a scouring of the river channel in

front of the canal regulators. The masonry flooring is carried the entire width of the sluiceway, flush with the river bed and abuts well into the bank of the river. This is protected by a curtain wall of masonry up and down the stream.

The sluices in the weir at the head of the Lower Ganges Canal at Narora are 38 in number, each 7 feet 10 inches in the clear. They have a total length of 427 feet, and the masonry piers separating them are but 2½ feet wide. The total length of these piers parallel to the course of the stream and at right angles to the line of the weir is 36 feet 4 inches, and they are practically two stories high, the upper deck or gallery having been constructed to have sufficient headroom to raise the gates (Pl. CXX). These gates are lifted by traveling winches running on

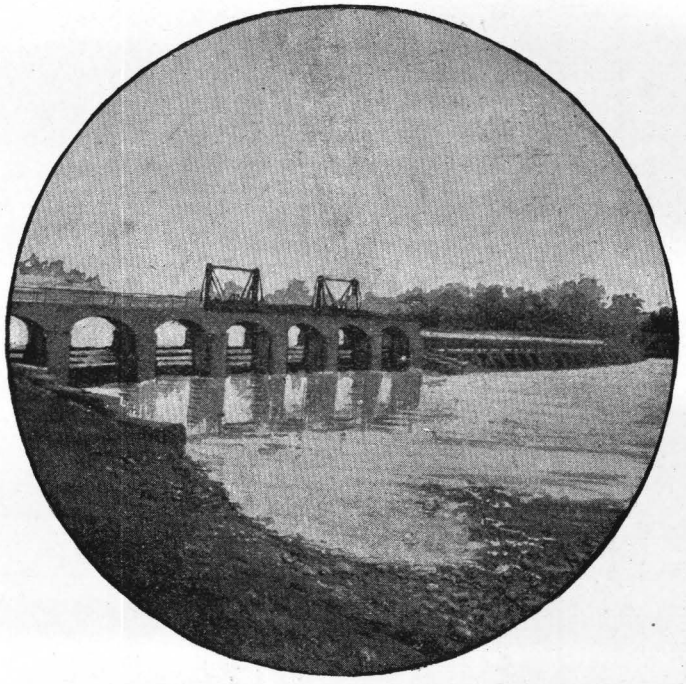
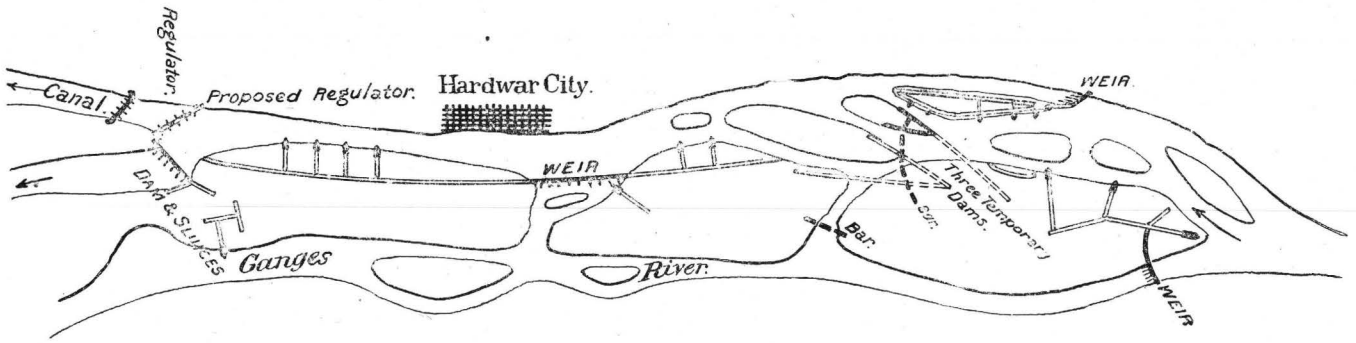


FIG. 240.—Myapur Dam, Ganges Canal.

rails on the upper deck. The sluiceways, like the main weir, are founded on a series of wells sunk in the sands and connected by brick masonry arches between which is a solid filling of brick (Pls. CXVIII and CXIX). The total breadth of loose stones on the upstream approach to the sluiceways is 30 feet, and the total breadth of the bed of the sluiceways is 150 feet. Beyond this masonry flooring is carried and flooring of broken stone well packed for a distance of 100 feet farther. The depth of the floor is 3 feet. The arrangement of sluiceway relative to the remainder of the weir and head works is shown in Pl. CXXII. The sluice gates are substantially constructed of wood and iron, and are two in



HEADWORKS AND RIVER TRAINING WORKS, GANGES CANAL.
HARDWAR.

Legend

Masonry Wall
Permanent Wall
Temporary DAm
Submerged Bars.

number in each opening, the upper row when lowered abutting against the top of the lower row. In time of great floods both sets of gates may be entirely raised clear of the flood line.

The gates in the weir at Myapur, at the head of the Ganges Canal, are similar to those described, and are represented in the accompanying illustration, Fig. 240. The sluices in the weir at Okhla, at the head of the Agra Canal, are similar in design to all others of this class, and contain 16 openings having a sluiceway of 138 feet. The openings 6 feet wide by 10 high, are built into a masonry structure 19 feet high, and the gates slide between piers 2½ feet thick; they are raised by a traveling winch from above. The floor is founded on four lines of wells, and is 11 feet below the crest of the weir. The pavement of this floor is 8 feet wide upstream, 41 feet downstream, and 12 feet in the center of the weir. This is practically a single structure resting on the sand of the river bed, and is subject to considerable leakage. It is required not only to carry the weirs and their superstructure, but also to withstand the force of a torrent of water 16 feet deep.

Among the earliest and for that reason most interesting series of automatic sluiceways constructed are those in the Mahanuddy weir, in lower Bengal, at the head of the Orissa canals. The sluiceway consists of ten bays each 50 feet wide and separated by masonry piers. Each bay is closed by a double row of timber shutters fastened by wrought-iron bolts and hinges to a heavy beam of timber imbedded in the masonry floor of the sluice.[1] There are 7 upstream and 7 downstream or rear shutters, the latter 9 feet high above the floor, and the former 7½ feet high.[2] During floods the upper row of shutters, which fall forward, are fastened down by clutches in an almost horizontal position, while the rear set, which fall backward or downstream, are kept in a horizontal position by the rush of water over them. In the dry season the rear shutters do duty by damming the water up, and for this purpose are provided with strong wrought-iron struts attached to their lower sides. In order to lift these the upstream set are first raised. This operation being aided by the press of water beneath, they are permitted to rise to a vertical position by means of a chain guyed to the floor above them. Relieved of the water pressure by this upper set of shutters it then becomes possible to raise the lower set, after which the upper set are lowered again into their original position, and the weir is in position to withstand a flood, as the lower set can be instantly dropped by merely removing the bolts which support them. The redamming of the water is accomplished in less than a minute. By reversing a lever each upper shutter is released, when they rise more or less rapidly, but with a comparatively slow motion until near the water surface, when they are brought home with a jerk, which does not seem, however, to cause a great strain.

[1] Roorkee Professional Papers, vol. 7, p. 75, 1870.

[2] Lieut. Col. J. G. Medley, Manual Thomason, Civil Engineering College; Irrigation Works, Roorkee, India, 1873, vol. 9, p. 118.

Probably the best example of automatic or self-acting sluice gates are those constructed in the weir at Dehree, at the head of the Soane canals.[1] The sluiceways in this weir consist of 3 separate sets, one of which is placed close to the head of the main western canals, and are 537 feet 4 inches in length, containing 20 openings separated by masonry piers. In the middle of the weir is another set of 16 openings 419 feet in length, and at the extreme eastern end of the weir, below the head of the main eastern canal, is another set of sluiceways 537 feet 4 inches, with 20 openings. In addition to these sluiceways there are, as in all Indian weirs, one or more fish ladders. In the Soane weir there are 4 separate fish ladders, one at the end of each of the shore sluiceways and one on each side of the central sluice.

The crest of the weir is 9½ feet above the river bed. The gates by which the sluiceways are closed are each 20 feet long and 9½ feet high. They are separated by masonry piers each 6½ feet wide and 32 feet long. As at first constructed these piers were much smaller, but it was found they would not withstand the jar produced by the manipulation of the gates and their thickness has since been increased. It is estimated that the velocity of the current through these scouring sluices is about 17½ feet per second. The floor of the sluices is 90 feet wide, parallel to the river channel. As at first designed this flooring consisted of a substratum 4 feet thick of rubble paved with good stone 6 inches thick, but the difficulty of this construction was such that it was abandoned, and the foundations were finally set on blocks. These blocks are 10 by 6 feet, with two well openings each, and were built 3 feet high upon bamboo curbing laid on the surface of the sand, and when the brickwork had set they were sunk until their tops were a foot below water. Concrete was then thrown into the wellholes and around them, and when set in left a solid foundation for the masonry. The ashlar pavement on this solid floor is 15 inches thick in the bottom of the scouring sluices and 9 inches thick over the apron. Twenty-five feet upstream from the sluice flooring is a line of wells sunk 10 feet as a curtain wall to the apron, and the wellholes and interspaces are filled with concrete, as in the foundation of the flooring. The space between the curtain wall and the sluice flooring is packed with large bowlders, and covered with pavement 9 inches thick. Twenty-five feet downstream from the flooring of the sluices a line of wells has been sunk 10 feet, and formed into a solid wall; the spaces between this wall and the flooring has been tiled and packed with bowlders and stone, and downstream from this point a talus, composed of large bowlders and blocks of stone, stretches 50 feet farther. The whole length of the sluice flooring parallel to the river channel is 200 feet. Notwithstanding the good workmanship of this foundation, the floods of 1874 proved very de-

[1] R. B. Buckley: Fixed and movable weirs; Proc. Inst. C. E. London, 1879-'80, vol. 60, p. 64. Lieut. Col. J. G. Medley, Manual Thomason, College Civil Engineering, Irrigation Works, Roorkee, India, 1873, vol. 9, p. 118.

NARORA WEIR

LOWER GANGES CANAL

PLAN OF WELL FOUNDATION.

SCALE.

feet 10 5 0 10 20 30 40 50 60

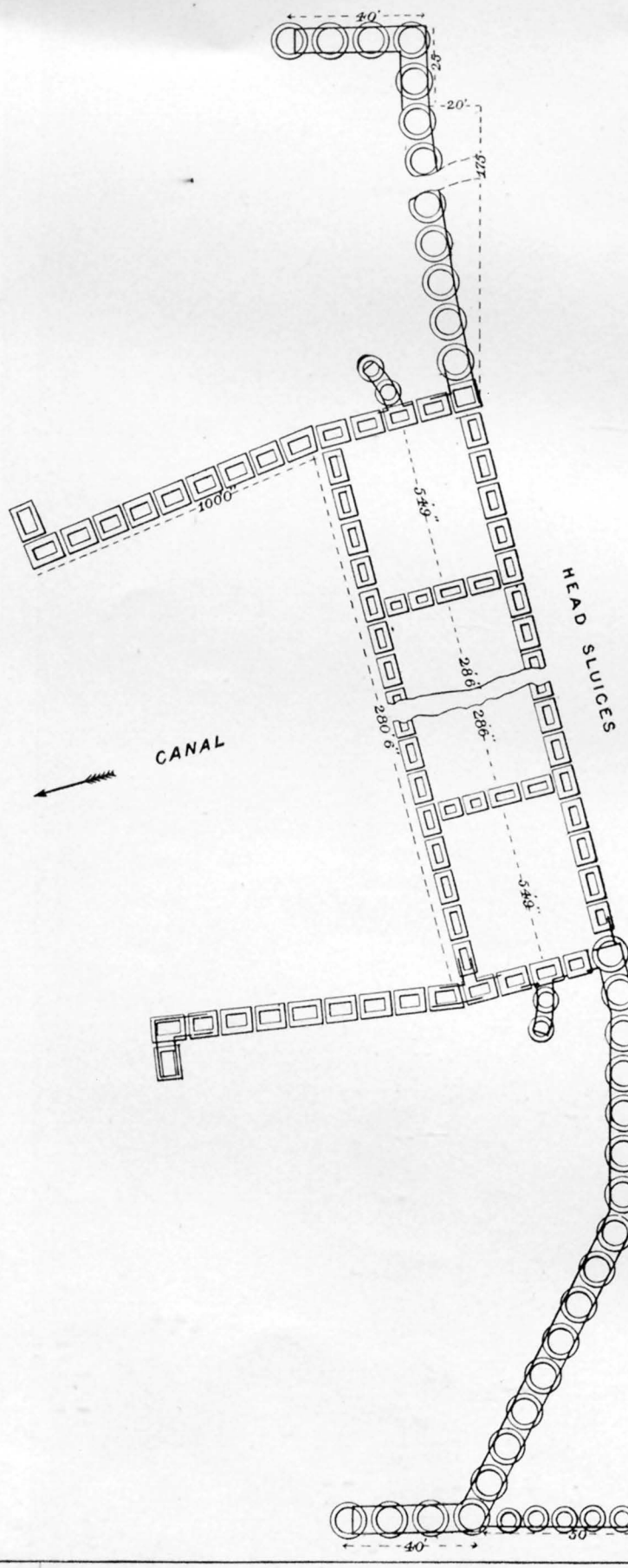
GANGES RIVER.

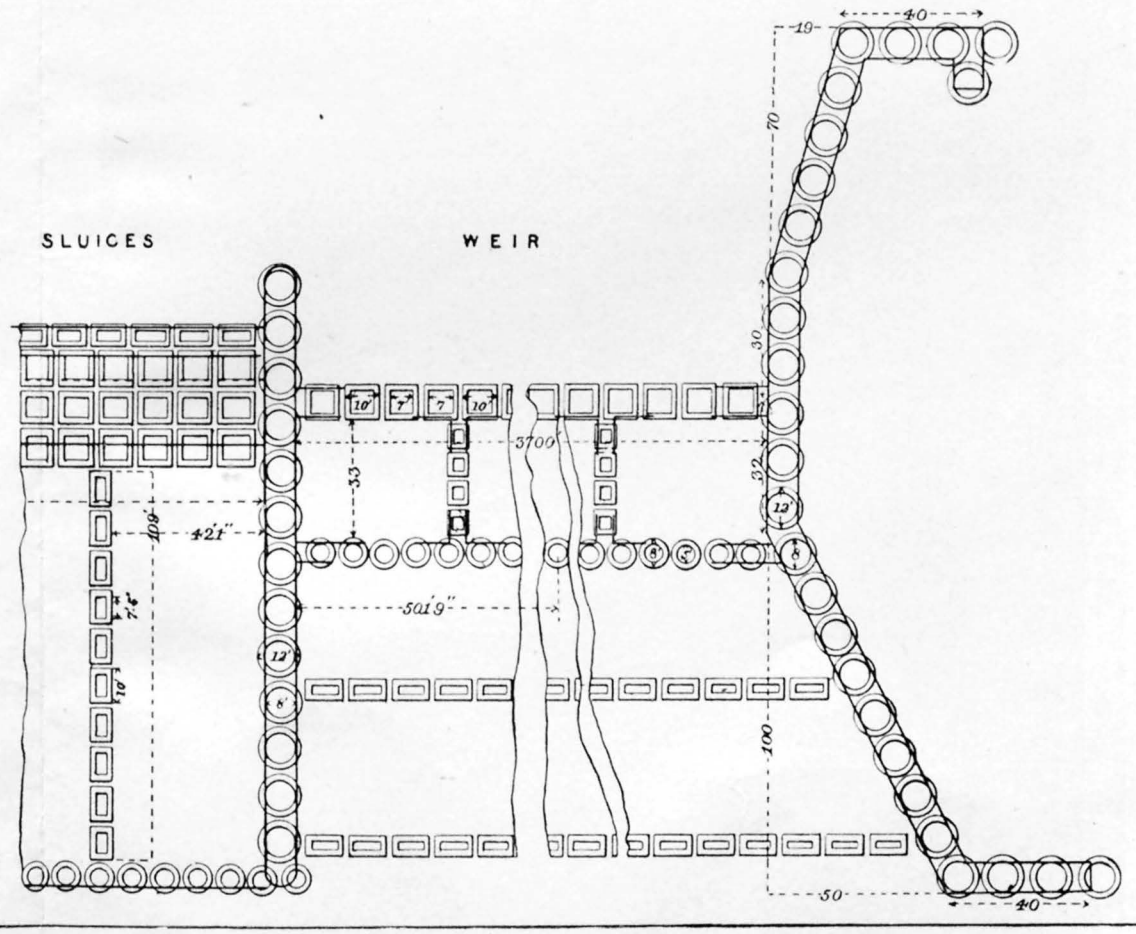
CANAL

HEAD SLUICES

UNDER SLUICES

WEIR





structive, and tore away much of the river bed to a depth of 38 feet below the toe of the talus.

The mode of construction and operation of the sluice gates themselves is as follows: These gates (Pl. CXXI) are constructed of wood, well braced, and there are two for each opening. For each alternate pair of piers on the downstream flooring a low masonry wall 1 foot high is built out, which holds 1 foot in depth of water, thus forming a water cushion on which the lower gate falls and relieving the piers of a portion of the shock. The upper gate falls upstream, being hinged to the floor at its bottom, and abuts against a series of six struts, hollow iron cylinders with small vent holes in which pistons work, so that when

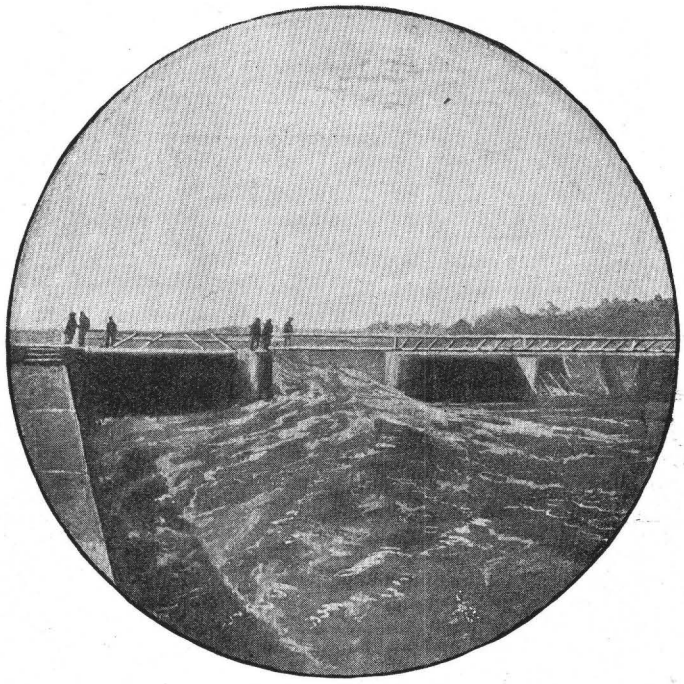


Fig. 241.—Dropping the Soane automatic sluices.

the gate is raised by the water under it the impact against the struts is relieved by the pistons plunging in the water in the cylinders. The downstream gates fall downstream (Fig. 241), and are supported by four iron rods hinged to their upper face below the center of gravity, and when in position are held upright by chains attached to the piers. If both gates are open and it is desired to close the lower one, so as to cause it to dam the water up, the operation is performed in this manner: The lower gate is first relieved by pushing aside the catch which attaches it to the floor, and is raised a little by means of a hand lever, whereupon the force of the water on the under surface brings it up slowly for a short distance, when it comes up with a jar against its cylinder struts.

The pressure is now relieved from the lower gate, which is then raised by hand levers and chained in an upright position to the piers. The upper gate is again lowered, now falling chiefly by its own weight through the water, and is fastened down. The lower gate, now acting as a dam, is prepared to be released at a moment's notice.

The needles used on the Sidhnai weir (Fig. 242) are an improvement on a very ordinary form of gate found in most of the simpler and older structures. At the heads of many old canals, and in some sluiceways, gates are found closed by two classes of needles, the simpler consisting of planks or flashboards let horizontally into grooves in the piers and raised or lowered, one at a time, until a sufficient number have been re-

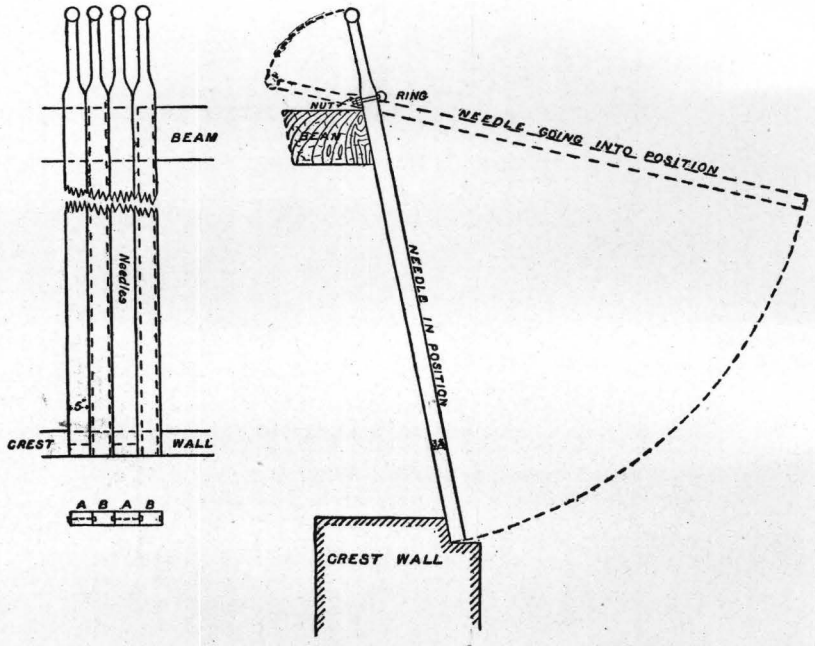


FIG. 242.—Details of Sidhnai weir.

moved or introduced to regulate the discharge of water. The needle is formed by inserting these planks vertically between timber guides or abutments laid horizontally between the piers, the water being regulated by the removal of as many as may be desired. The needles employed on the Sidhnai weir are made of hard wood, of such weight as to be manipulated by a strong man, each needle weighing not over 40 pounds. They are 7½ feet by 5 inches by 3½ inches in size, with a stout handle 1½ feet long ending in a knob.[1]

The most difficult problem when these needles are in position is to make the dam water-tight. Several methods were at first proposed.

[1] Sidhnai Canal Project, Selections of records of the Government of India, No. 248, Calcutta, 1888.

NARORA WEIR

LOWER GANGES CANAL.

PLAN OF SUPERSTRUCTURE.

feet 10 5 0 10 20 30 40 50 60

GANGES RIVER.

CANAL

HEAD SLUICES
30 Vents of 17 feet.

PLAN OVER ALL

UNDER SLUICES

PLAN OVER ALL.

WEIR PROPER

PLAN OVER ALL. PLAN AT ASHLAR FLOOR PLAN OVER ALL

Grooved needles were found to be unnecessary; ordinary needles, if the interstices between them were filled with wood shavings and chopped straw, were found to be readily made water-tight. After the needles are placed in position they are forced together by being driven horizontally with a crowbar, and a basket filled with shavings, etc., is slipped down in front of the leak to be closed, the calking material being drawn by the current into the openings.

CANAL REGULATORS.

A set of regulating gates is always constructed at the head of a canal. They must afford sufficient way to admit all the water the canal is estimated to carry, and by them the amount admitted can be controlled. Like the scouring sluices, these regulators consist of a set of grooved piers resting on a foundation carried across the canal bed.

The water may be controlled by a set of planks or needles worked by hand in grooves, or, as is more usual, by drop gates raised and lowered by a winch from above. When not under too great a head, each opening is closed by a single gate raised by a hand windlass or winch. In some cases, under considerable pressure, a double series of gates, one above the other, is used, or else valve gates are employed, which are worked by hand levers and screws from above. It is customary to connect the piers of the regulator by arches, so as to form a bridge across the canal, at the same time affording a convenient platform from which to operate the gates. The bed and banks of the canal at the head are defended by masonry, so as to be safe from erosion when the gates are opened.

In locating the position of the regulating sluices, the principal object is to bring the water in the river through the scouring sluices in such a way that it shall pass directly in front of the regulator, preventing the deposit of silt at its head. This must be so established that the canal will receive the desired volume of water with the least liability to receiving the heavy silt through the regulators or to damage from matter carried by floods. Where this relation between scouring sluices and regulators is such that the least eddy or quiet water exists between the two, there is certain to be a deposit of silt, which is an element of danger and must be removed. At the head of the Ganges Canal the location of the regulating gates is such that heavy deposits of silt are formed. At the head of the Soane Canal the face of the regulator is set back 30 feet from the abutment of the scouring sluices, and here also is a heavy deposit of silt. At the Bari Doab head works the regulating sluices are close to the scouring sluices and the current is so strong that small bowlders and gravel are carried through into the canal. The head works of the Agra Canal are excellently located, and the river channel and canal line are so nearly at right angles to each other that apparently no silting takes place. At the headworks

of the lower Ganges Canal little or no silting occurs, owing to the excellent relative location of the various sluiceways.

At Myapur, the head of the Ganges Canal, the regulating bridge has 10 bays or openings, each 20 feet wide and 16 feet high, fitted with gates and apparatus for opening and closing. The breadth of the base or platform on which the piers rest is 48 feet, exclusive of the cutwaters, which project upstream 4 feet. The roadway on top of the bridge is 37 feet 9 inches wide between the rear parapet and the row of windlasses on the upstream front. The shutter for closing the regulators, while an improvement on that used on the Jumna Canal is, however, rather crude compared with the modern and improved methods employed on later constructions. The accompanying sketches (Fig. 243) indicate the method of arranging the regulators on the Jumna and on the Ganges Canals. On the Jumna Canal a regulator and drop gate are placed in a simple groove, and sleepers of scantling 6 inches square are dropped in the top of the gate. This has always acted efficiently, but time and labor are required in its manipulation. On the Jumna canals there is no great volume of water to contend with, nor is there as large a number

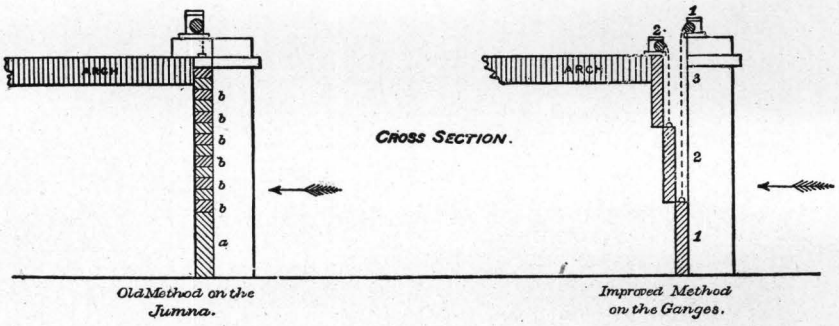
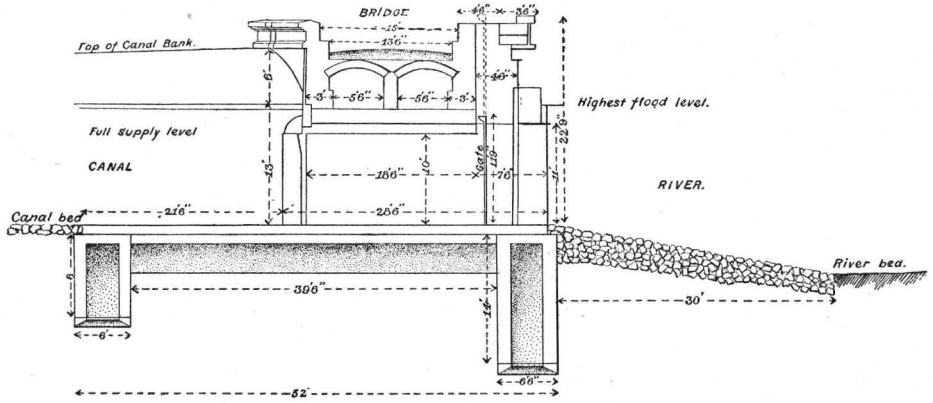


FIG. 243.—Regulating gates, Ganges and Jumna canals.

of bays as on the Ganges Canal. On the latter, as shown by the illustration, the bay is divided into three series of gates, the most advanced one having its sill at the level of the canal bed, and two higher series of gates, each having their sills revetted 6 feet and retrograding toward the face of the bridge. These are operated by separate windlasses over each. The two lower gates are quite independent of each other, the third or upper bay being closed by simple sleepers. The machinery attached to these gates is of the simplest character and readily understood by the commonest laborer, while it is not liable to disarrangement.

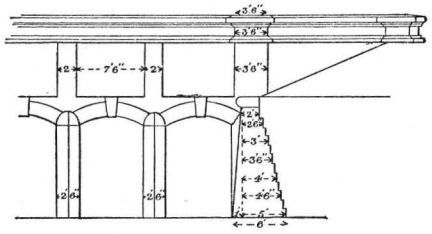
From the plan of the relative locations of sluice head (Fig. 243*a*) and regulating bridge, it will be seen that the triangle in front of the latter affords an immense backwater or eddy in which deposits of silt must necessarily take place. Designs have recently been submitted for a new regulating bridge which shall be a skew arch, the front face or entrance to the regulators being parallel to the channel of the Ganges and at right angles to the scouring sluices, the rear side being at right angles to the channel of the canal.

CROSS SECTION.



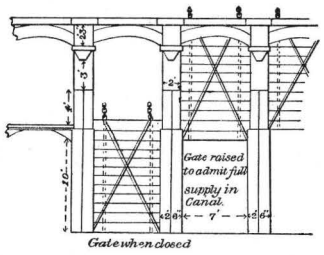
CANAL HEAD SLUICES.

ELEVATION.



CANAL HEAD SLUICES

RIVER ELEVATION.



NARORA WEIR, LOWER GANGES CANAL. DETAILS OF CANAL SLUICES.

An interesting and unique set of regulating gates, because of the great pressure under which they are worked, are those at the head of the Betwa Canal (Pl. CXXXIX), and attention is called to them in this place, though they will be more fully described later on. The regulators at the head of the Soane Canal are placed at right angles to the scouring sluices, though they are set back a short distance from the line of the curtain wall leading to the scouring sluices. The floor of these regulators is about 3 feet above that of the scouring sluices. The masonry work in connection with the head works of this canal is well constructed but perhaps too elaborate. These regulating sluices are designed to discharge 4,500 second-feet with a head of only 4 inches and a depth of 9

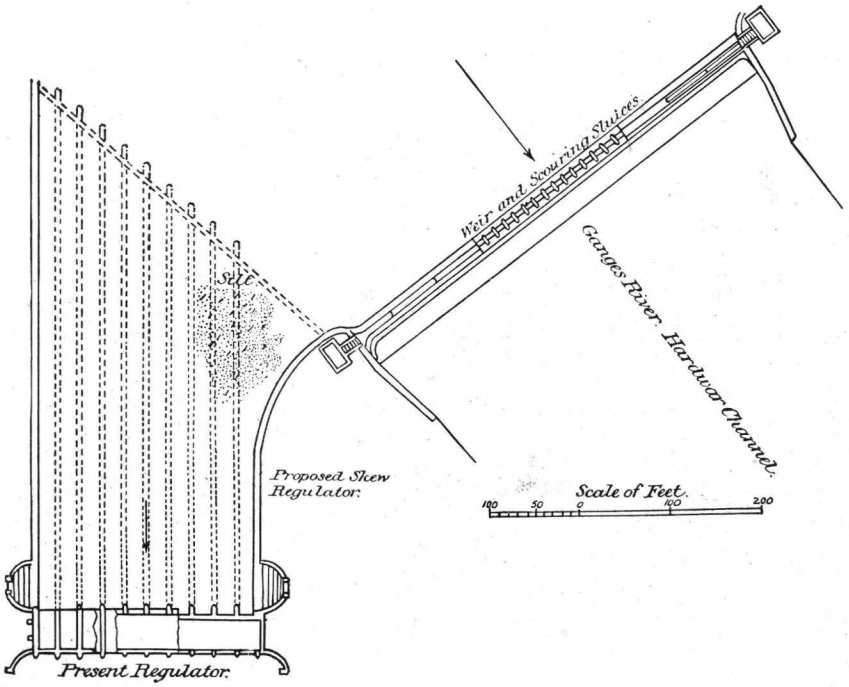


FIG. 243*a*.—Headworks, Ganges Canal.

feet of water. They consist of 24 openings, each 6 feet wide, and separated by the solid piers which support the bridge above. There are two shutters constructed of wood, opening vertically (Fig. 244). Usually only the upper gate is used, the chief deposit of silt thus taking place in front of the lower gate, where it is easily dredged out, but when the head of water is very low the lower gate is sometimes raised. The silt is thus flushed out and deposited in the canal, where it is still more easily dredged. These shutters are raised by a traveling winch supported on a handcar on rails on the bridge above. The plate indicates the mode of raising these gates and of fastening them together when both are to be opened.

At Vir, where the headworks of the Nira Canal are situated, the regulating gates are simple, giving a water way through seven separate bays, each 4 feet wide, and operated from a masonry bridge above (Fig. 254). These are so designed that under the lowest available head of 9 inches the full discharge required will be admitted to the canal.

The regulators at the head of the Lower Ganges Canal, like the weir and scouring sluices (Pls. CXX and CXXII), are founded on two rows of wells. Curtain walls founded on wells are carried along the banks of the river and canal for a short distance. The flooring of the regulators is well paved with substantial masonry from 3 to 5 feet thick and a rough loose-stone pavement is carried for some distance into the river above the regulators and 100 feet below them, the banks of the canal being revetted for some distance farther. The width at the canal head is a little greater than that of the canal, causing the velocity for a short distance to be

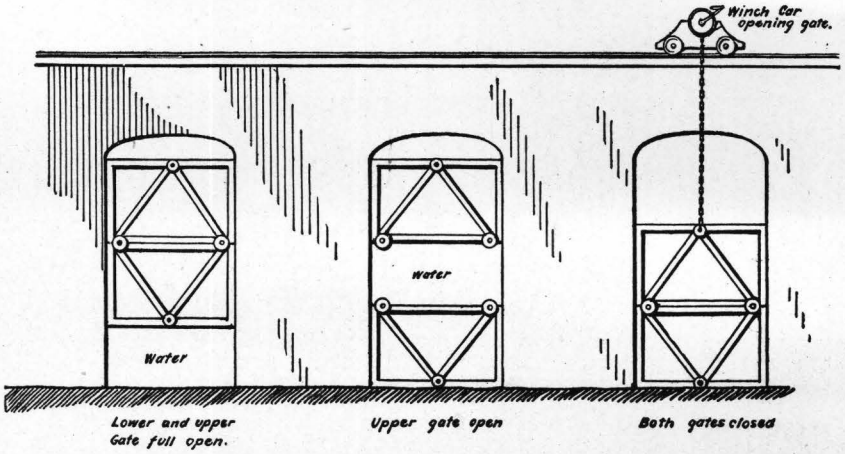
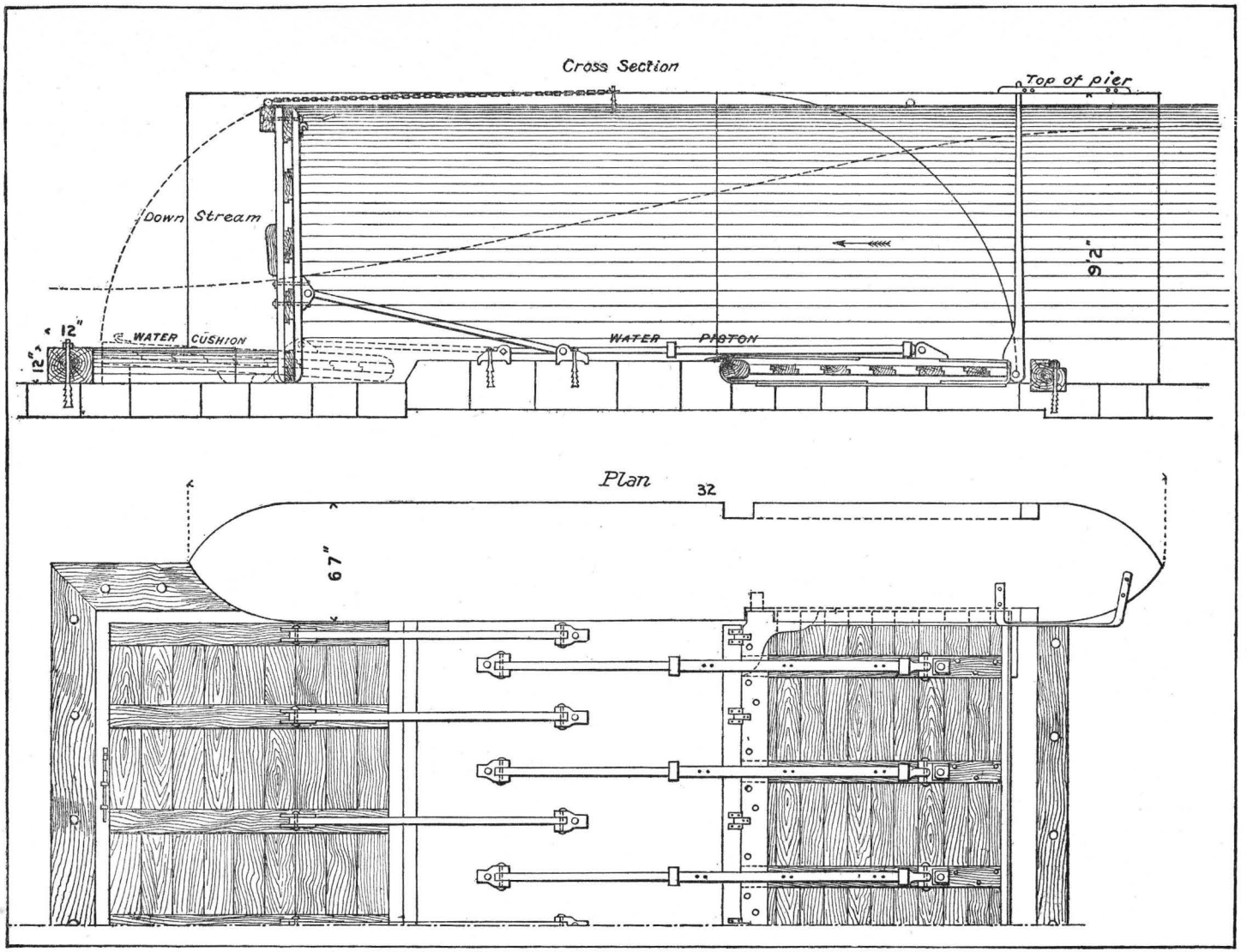


FIG. 244.—Regulating gates, Soane Canal head.

diminished, in consequence of which the majority of the silt is deposited at this one place where it can be most conveniently removed. The total width of the regulators at the head is 282½ feet. There are 30 bays, each 7 feet wide, separated by substantial masonry piers 28½ feet long by 2½ feet wide. The gates closing the entrance to the canal head are of iron and slide vertically. They are each 11 feet high, are raised by a winch traveling on the bridge overhead, and are closed by their own weight. In the piers on the upstream side of these gates are grooves in which planks may be inserted in order to reduce the head on the gates when operating them.

The regulator at the head of the Sidhnai canal consists of four 60° arches of 22·5 feet span, with jack piers 2·5 feet thick in the center, which divide the waterway into eight spans of 10 feet each. The arches spring from 6 feet above the floor. The floor is 1 foot above the crest of the weir, and as the needles on the top of the latter are designed to hold up



SOANE CANAL. AUTOMATIC SLUICE GATE.

7½ feet of water, 6½ feet can be forced into the canal. There is nothing novel in this regulator, the gates being made of wood bound with iron and sliding in cast-iron grooves. The lifting apparatus is a traveling winch working on rails on the top of the parapet of the bridge, so placed that the drum of the crab winch is centrally located over the gate to be lifted. There is an upstream set of grooves in the piers into which planks can be inserted to relieve the gate from pressure should it jam. Planks are generally used for regulating the supply in the canal, the gates being intended for use only when it is necessary to close the regulator quickly.

WELL FOUNDATIONS.

Wells and blocks may be considered as one and the same form of construction, though perhaps blocks are more properly rectangular wells having one or more well-holes in them, while wells proper are circular in plan with a single central opening. They are in reality brick caissons from 6 to 20 feet in diameter, the walls varying in thickness from 2 to 4 feet and of any required height. Blocks are rectangular brick cassions, perhaps 6 by 10 or 12 feet, with 2-foot or 3-foot walls, and subdivided into two or even four vertical passages or well holes. For the piers of the Solani aqueduct the blocks are 20 feet square and divided into four well holes. At the head of the Agra Canal they are rectangular, 13½ by 9 feet, and contain two well holes, each 4 by 3 feet. At the head of the Lower Ganges Canal they are round, 12 feet in diameter, with walls 2 feet thick.

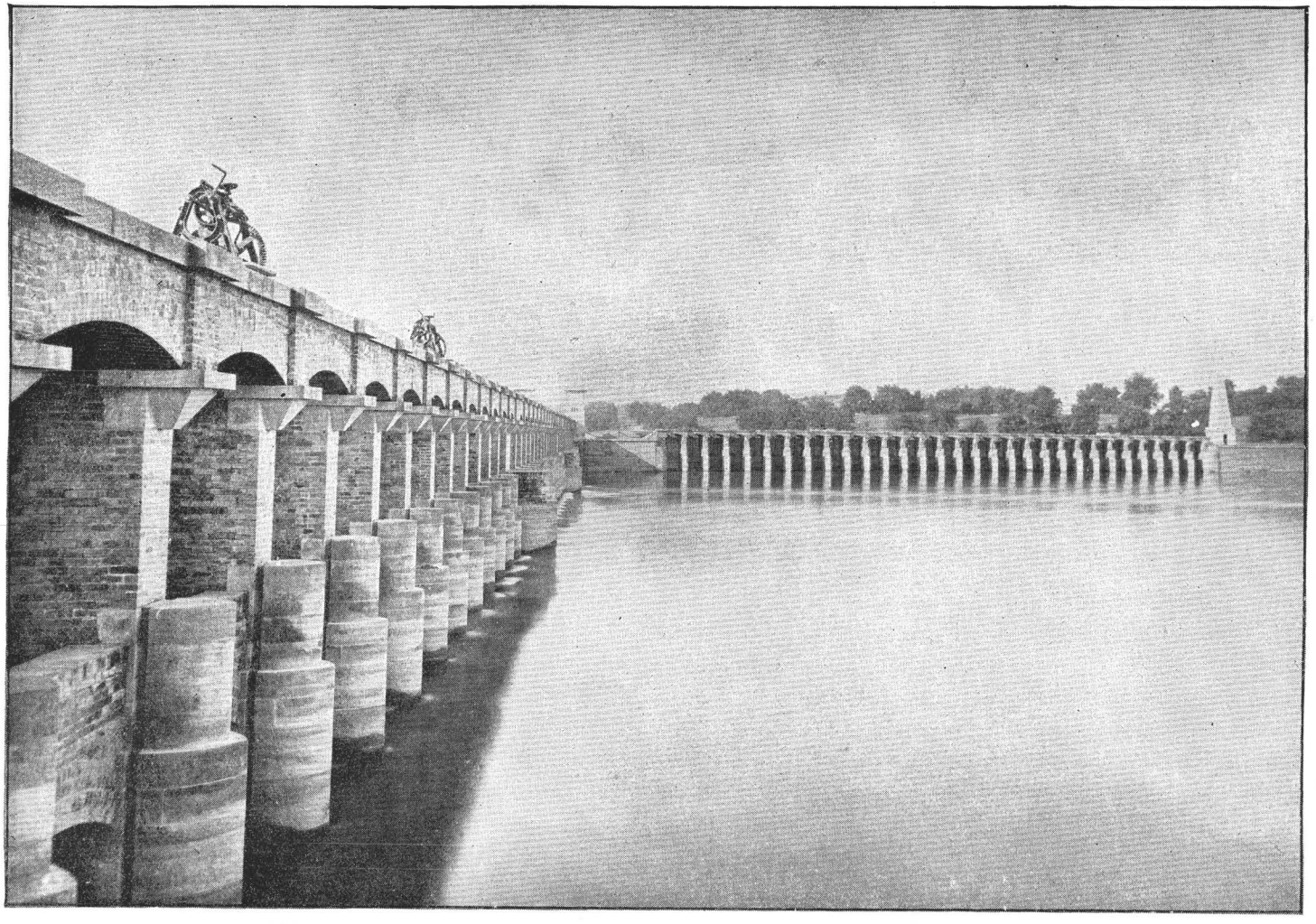
In sinking wells the water in the part of the river to be operated upon is usually temporarily dammed and the earth removed until the water surface is again reached. Curbing of bamboo of the size of the well is then laid, and on this the well is built up. It is commenced by placing on its lower edge a cutting surface of wood or iron, wedge shaped, with the cutting point downward. Into the top of this the masonry work is built. As the building continues the sand and gravel are removed from within by hand or by dredge and the well sinks by its own weight. Much difficulty is frequently encountered in sinking these wells, owing to their uneven subsidence or on account of meeting layers of earth of different character, which must be removed or the well so loaded as to cause it to sink vertically. When the well or block is sunk to the required depth it is usually filled with concrete, and thus becomes a solid pillar. The spaces between the walls are then protected by sheet piling, and after the removal of the sand, concrete is placed between them, thus forming a continuous wall. This method is simple and not costly. It is particularly effective in deep sand or in quicksand, and may be carried on by workmen with little risk of danger.

The depths to which wells are sunk differ greatly. In the case of the headworks of the Agra Canal no wells whatever were made under the weir, as it rested directly on the sand. At the head of the Soane

Canal the wells are sunk about 10 feet below the base of the weir; and at Narora, at the head of the Lower Ganges Canal, they were sunk 20 feet. Wells are built either in single or double rows, the distance between these varying according to the dimensions of the wells themselves. They have in some cases been connected by brick masonry arches, and the interspace below the arch filled with solid brick. This was done in portions of the head works of the Lower Ganges Canal.

The most striking case of the construction of wells as a foundation for a masonry superstructure is that of the wells for the support of the Nadrai aqueduct on the Lower Ganges Canal, over the Kali Nadi torrent. The whole structure of the aqueduct, including river and canal wing walls, is founded on wells, the cutting edges of which are sunk 51½ feet below the level of the Kali Nadi torrent at that point, the average depth of the wells being 56 feet. The wells are of three sizes, being 20 feet in diameter for the piers and canal land wings, 13 feet in diameter for the river piers and 12 feet for the abutments. There are 102 wells 20 feet in diameter, 44 wells 13 feet in diameter, and 122 wells 12 feet in diameter; or a total of 268 wells on this work. The total linear depth of well-sinking amounted to 15,008 feet. Accompanying are given illustrations showing some of the details of these wells (Pl. CXXIII).

The well curbs were generally constructed of wood, with wrought-iron bolts 1¼ inches in diameter projecting from them and built up into the brickwork. In the 12- and 13-foot wells only one dredger was worked at a time, and the average rate of sinking was 1 foot per day. In the 20-foot wells three or four dredgers could be used at once, and with this number the rate of sinking amounted to 1¾ feet per day. Building and sinking went on alternately in the construction, the brickwork being carried up in lengths of about 8 feet as the wells sank that much. When 25 feet had been sunk the brickwork was carried up the full height, 47½ feet above the cutting edge, and the sinking continued until clay was reached. On a well showing even the slightest signs of going out of the perpendicular, dredges were worked on the opposite side from that to which the well inclined. In extreme cases a "jham" was worked from a windlass on top, which stirred up the silt in the sump less than did the dredger and allowed a deeper hole to be made on one side. Only two or three of the 20-foot wells were 1 in 40, and the majority less than 1 in 100 out of perpendicular when the under dredging was stopped. In the lines of the abutments, where the 12-foot double rows of wells were only 2 feet apart, there was a decided tendency for each pair of wells to lean toward each other and for the curbs to separate. In some cases where the wells got out of perpendicular or failed to sink in the hard clay, it became necessary to load them with railway iron or a temporary superstructure of brick. To test their resistance against subsidence some of the less satisfactory wells, after they had been hearted with concrete, were loaded with a great tempor-



HEADWORKS, LOWER GANGES CANAL, NARORA.

ary superstructure of bricks, which in the case of one well weighed 1,451 tons (Pl. CXXIII). The total subsidence amounted to but $1\frac{1}{4}$ inches. After the well had gone through the blue clay and while dredging in the brown sand was in progress, inblows of the blue sand above the clay were of frequent occurrence. These were generally caused by the dredger being worked awkwardly. Sometimes the inblows were so rapid as to bury the dredger before it could be lifted, and at other times they were extremely gradual. These inblows frequently caused the well to incline from the vertical. When it was found that some of the 12-foot wells inclined from the vertical, advantage was taken of it to make them incline, so that when finally loaded with the superstructure and arch they would be in the best position to receive the arch thrust.

Mr. Beresford, the superintending engineer, in a note on "Frictional resistance to sinking due to lateral pressure of earth on the sides of a well,"[1] shows that the pressure Py exerted by earth against a vertical plane per unit of the breadth is

$$Py=\frac{Wx^2}{2}\cdot\frac{1-\sin O}{1+\sin O}.$$

Where W=the weight of earth per cubic foot, x is=to the depth the plane is sunk below the surface of the earth, and O=the angle of repose of earth. The values found practically agree very closely with those derived from this formula. From some computations it was found that the value of $Py=\frac{100}{2}\times 58^2\times 0.33\times 63=3{,}496{,}878$ pounds $=1{,}562$ tons, taking W=100 pounds; O=30° and the coefficient of friction of the masonry on moist clay as given by Rankine=0.33. Therefore the friction $F=1{,}562\times 0.33=515$ tons.

ESCAPES.

In order to establish a complete control over the water in a canal channel provision is made for disposing of any excess which may arise from sudden rains or floods, or from water not being required for irrigation. This is effected by means of escapes or short cuts from the canal to the river or other natural water way into which the excess of the water can be discharged. These escapes perform the additional service, in the case of streams carrying much sediment in suspension, of flushing the canal, thus preventing or removing excessive silt deposits. Col. Cautley, in speaking of escapes and their employment on the lines of distributaries, says:

> In times of flood, opening the heads of the distributaries relieves the main canals, and the former are in turn relieved by the escapes. Hence the distributary heads become the safety valves, and the escapes the waste pipes of the entire canal system.

[1] W. B. Gordon, Notes on Well Sinking, Nadrai Aqueduct, Public Works Dept. Northwest Provinces, India, p. 20.

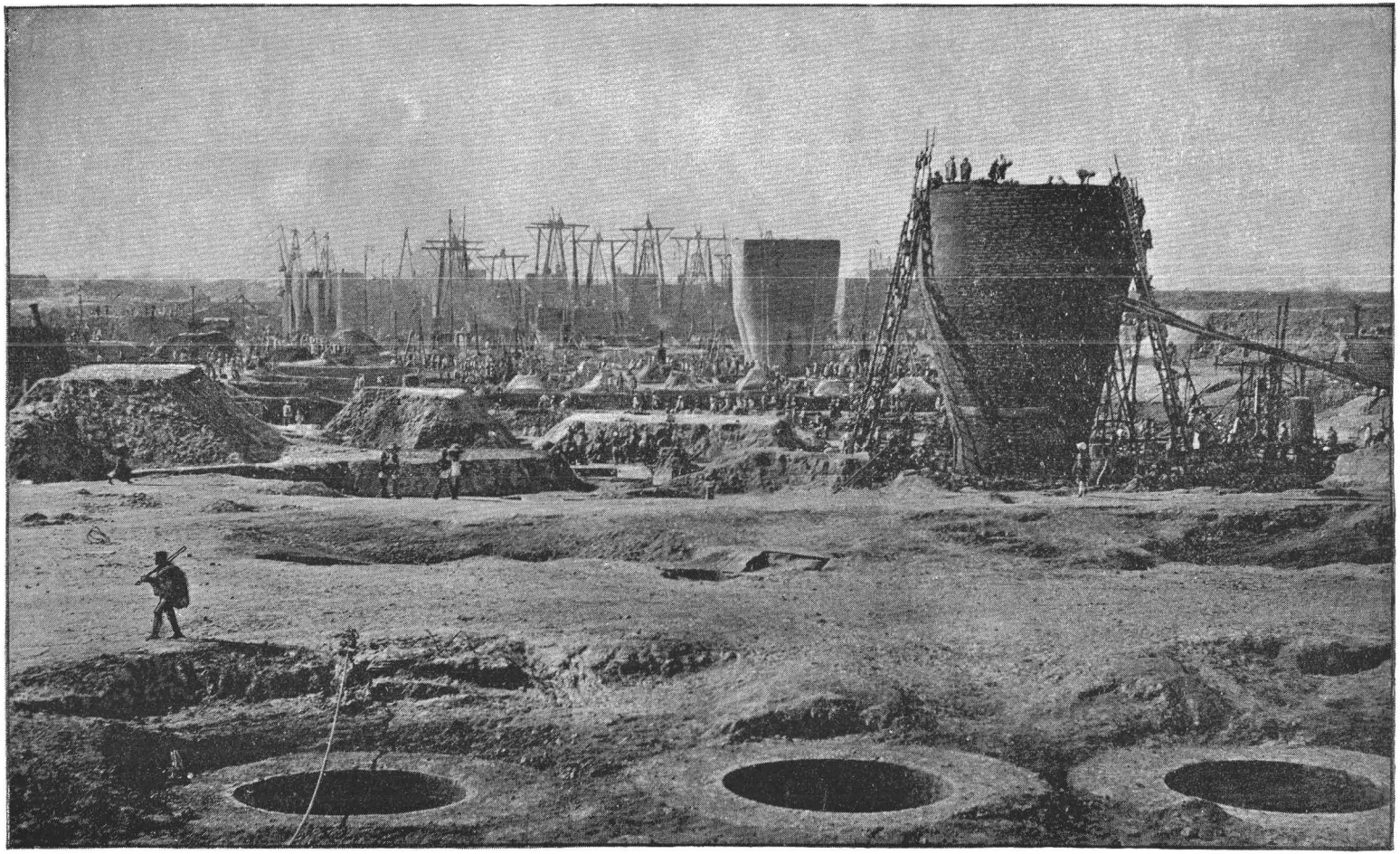
Escapes are provided at certain intervals along the entire canal line, and a double set of regulators are made at the point where the escape is taken off, as in the case of a branch canal or distributary. On the Ganges Canal they are projected at every 40 miles, though much depends on the convenience with which they can be made and the proximity of the canal to some water course into which the escape water can be conducted. They are also provided if possible at dangerous points, as above or along lines of heavy embankment where, in case of the bursting of the bank, much damage would ensue. The first main escape is always constructed at a distance of half a mile or less below the canal head, and when it becomes desirable to scour out the silt accumulated between the head and the escape, the latter is opened and a large volume of water admitted to the canal. This runs off through the escape carrying the silt with it. It is usual in such cases to decrease the slope of the canal for a short distance below its head to cause the deposit of matter carried in suspension between that point and the escape.

The escape cut must be sufficiently large and have enough fall to carry off the whole body of water which can reach it, so that if necessary the canal below the escape may be left dry for repairs without stopping its running above. The complete control of the canal waters by double escapes consists of the construction of a regulator at the head of the escape, and another one across the canal channel immediately below the escape. These escape heads are similar to the regulating bridges previously described and to the various regulators constructed at the heads of distributaries. When a heavy rain occurs on the line of a canal the irrigators cease to use the canal water, and as the flow can not be immediately stopped at the head works, great damage would be done by the suplus water but for the escapes, which act as though the head regulator of the canal had been brought so much nearer the point of application.

The Khutowli escape head on the Ganges Canal is an interesting example. It is at the sixty-second mile and consists of a channel excavated 60 feet wide and 3½ miles long. The masonry head consists of ten openings, each 6 feet wide, the height from the flooring to the soffit of the arch being 8½ feet. The flooring is 64 feet wide, 40 feet of which forms the tail, and is laid on a slope of one foot from the level of the canal bed. The banks of the works are protected by masonry revetments and guards of piling and rubble which protect the floor from the wear and tear of the current.

Col. Cautley made the following rules which should control the location and regulation of escapes on the Ganges Canal:

> With reference to position, the distance between the escapes is limited to 40 miles, considering that by adapting their capacity to the volume of water contained in this length of canal the facilities for regulation are ample. In the sandy tracts of the canal the number of the escapes is multiplied rather than having their water way increased. The sites of all escapes are fixed in such a position that the water



SINKING FOUNDATION WELLS, NADRAI AQUEDUCT, LOWER GANGES CANAL.

may be plunged into the bed of the receiving channel and that the high-water mark of the latter shall never interfere with the free discharge of the canal. The escape channel shall, when perfected, have, in addition to the initial slope of 12 inches from the bed of the main channel which is given to the tail of the escape head, a slope of bed equal to 1½ feet per mile.

FALLS AND RAPIDS.

As the natural fall of the country through which a canal runs is usually greater than the slope of the canal, it becomes necessary to compensate for this difference of slope. This is done by concentrating it at a few points where vertical falls or rapids are introduced. The location of these is usually fixed by the place where the canal becomes too high above the surface of the ground, while their exact position is made to coincide if possible with that of a bridge or similar work in order to economize masonry construction.

Ogee falls were first adopted on the Ganges Canal and are of the shape shown in the accompanying figure, the intention being to break the force of the fall of the water. They were about 8 feet high, but the shock of the fall proved so great that they have been modified to give two vertical falls, the lower of which drops into a water cushion. On the Ganges Canal were a number of ogee falls (Fig. 245) 15 feet high. These have been so remodeled as to give an upper fall of 5 feet, then a short level bench of 10 feet, and a vertical drop of 10 feet, ending in a shallow water cushion (Pl. CXXIV). These falls have a solid masonry floor 4 feet thick. On some falls the action of the water is lessened by making it play over a wooden grating. This reduces the shock by dividing the stream into a number of fine threads. Falls are invariably constructed of substantial masonry laid on a deep and firm foundation. The banks are protected by masonry and paving. The latter is carried for some distance below the fall both in the bed and on the sides, and the flooring terminates in a row of sheet piling. In broad canals like the Ganges the fall is generally divided into compartments by longitudinal dividing walls, so that when repairs are necessary one portion may be laid bare at a time. On the Ganges Canal most of the falls are constructed at points where bridges would be necessary, and to the lower side of the bridge the fall is attached. Below this the channel of the canal is widened out, the flooring and sides to the extremity of the

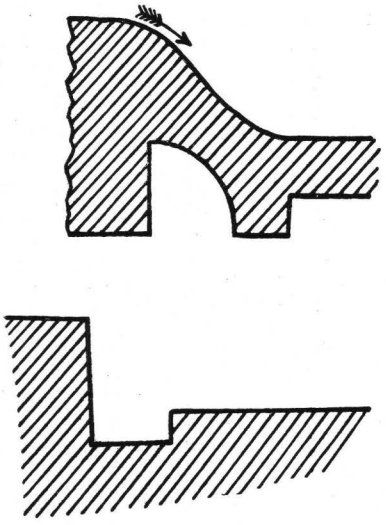


FIG. 245.—Ogee and vertical falls, Ganges Canal.

cistern in which the fall terminates being carefully and securely paved and revetted.

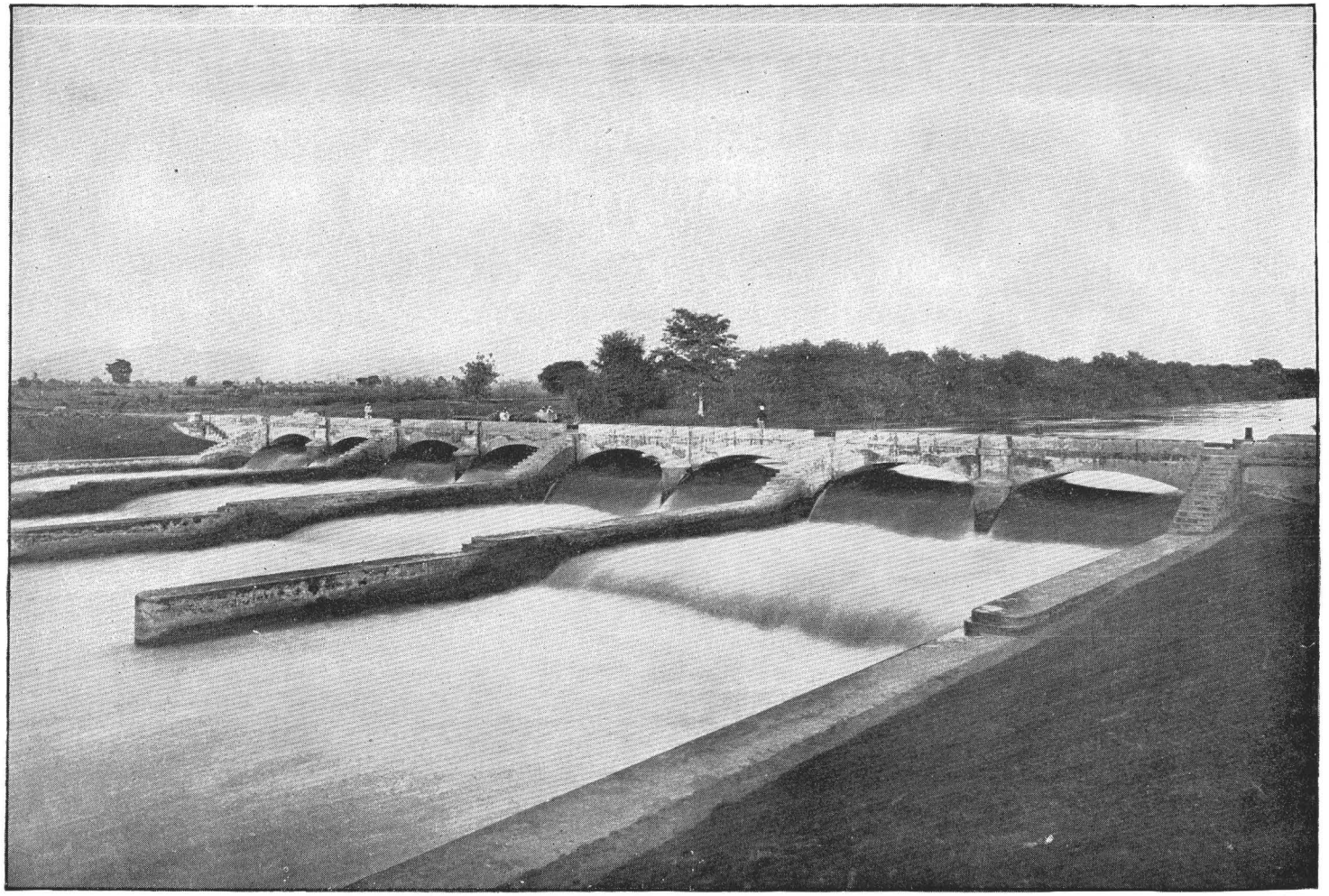
Experience seems to show that vertical falls with gratings, as used on the Bari Doab Canal, and terminating in water cushions, are the best that have been devised. The grating consists of a number of wooden bars, resting on an iron shoe built into the crest of the fall, and on one or more crossbeams, according to the length of the bars. These bars are laid at a slope of 1 on 3, and are of such a length that the full supply water level in the canal is half a foot below their upper ends. The dimensions of the bars used where the depth of the water is 6½ feet are as follows: Lower end one-half inch broad by three-fourths of an inch deep; upper end one-fourth inch by three-fourths inch deep. They are supported on beams 1 foot broad by 1 foot deep. At first these beams were 6 inches apart, but it has since been found best to increase this distance a trifle, and now 18 bars are placed in a 10-foot bay. The bars are undercut from the points where they leave the shoe at the crest of the falls in such a manner as to make each space an orifice in a thin plate.

The effect of a fall at the end of a canal reach is to increase the velocity and to diminish the depth for some distance above the fall. This increase of velocity produces a dangerous scouring on the bed and banks of the canal, and is guarded against by heading the water up at the crest of the fall by means of sleepers dropped in grooves of the piers, thus increasing the height of the fall. The narrowing of the canal banks at the fall produces the same effect. The better method, however, is to raise the crest of the fall by a masonry weir, and the height necessary to raise it is found by the following calculation, given by Col. Dyas:

$$H=\left(\frac{900\ a^2\ d}{l^2\ s}\right)^{\frac{1}{3}}-125.8122\frac{d}{s}$$

in which H is equal to the height of the water above the crest of the fall; a is equal to the sectional area of the open channel; d equals the hydraulic mean depth of the same; l is equal to the length of crest of the fall, and s equals the length of slope to a fall of one in same. When gratings are used these act instead of a weir in checking the velocity of the water, and the method of spacing them is such that the velocity of no one thread of the stream shall be either increased or retarded by the proximity of the fall.

On the Soane Canal, where there are many locks, the falls are nearly always introduced at the points where the locks occur (Fig. 246). The main line is carried through the locks, and the waste weir or branch channel is carried around them, and in it the surplus water over that which is required for the operation of the lock is conducted. In this branch channel a fall must be constructed. In one case noticed, where there were two locks with a total lift of 20 feet, the fall was constructed in three bays. The channel was 40 feet wide and the falls were built



ASAFNAGAR FALLS, GANGES CANAL.

of substantial brick masonry terminating in a deep cushion below. On the Agra Canal are several interesting falls, perhaps the most elaborate of which is the Kushuk fall, on the Bata escape (Pl. CXXVI). This is a masonry fall, or rather two falls terminating in water cushions, the total height of which is 27 feet. The total length of the masonry work is 190 feet, and the depth of the concrete flooring is 3 feet, terminating on a well, on which the toe of the apron rests.

Instead of falls, rapids have been constructed with great sucess one the Bari Doab Canal (Pl. CXXV). The slope of the rapid is paved with loose bowlders, confined by walls of masonry built at intervals of 40 feet longitudinally across the stream. From experience on these rapids it has been found that dry bowlder or rockwork is not to be depended on for velocities over 15 feet per second, and that over this the slope must be modified or masonry be used. On the Bari Doab Canal rapids were adopted wherever bowlders were procurable at moderate expense.

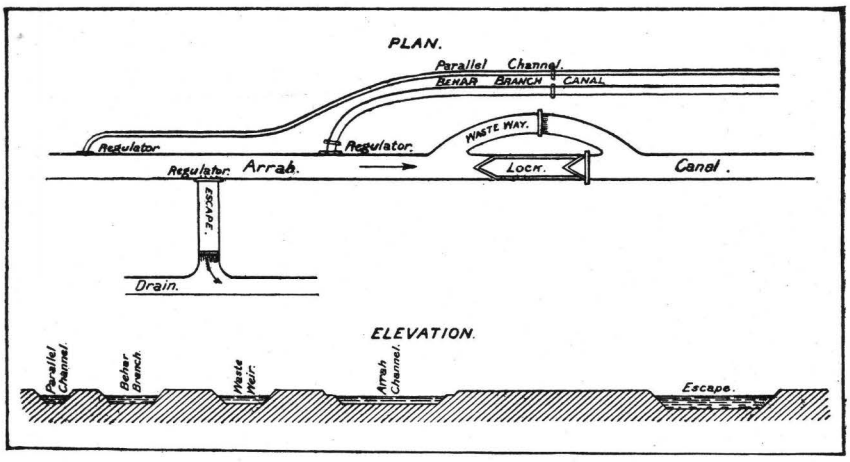


FIG. 246.—Soane Canals, Bengal. Arrangement of branches and escape at Dunwar.

Bowlders form the best material for the flooring of a rapid. Brickwork should not be used with currents of high velocity, as the best bricks do not stand the wear and tear for any time, certainly not for service in contact with velocities exceeding 10 feet per second. The bowlders were generally grouted in a good bed work of mortar and small pebbles or shingle where velocities above 15 feet per second were employed. The tail walls on these rapids are of peculiar construction for the purpose of turning back the eddies and of protecting the canal banks from the direct action of the water. Beyond a point where the heaviest action occurs and where the greatest width is given the tail works, the banks incline toward each other so as to direct the set of the stream to the middle of the canal. The tail walls are not kept to their full height throughout, but gradually become lower and lower, till they disappear altogether where they reach the same level as the bed

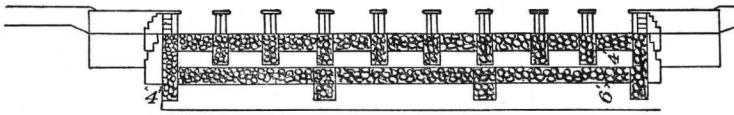
of the canal. In case no tail works are given, the banks are faced with bowlders or piling for a length of perhaps 300 feet below the rapid. On distributaries and their branches falls and rapids are resorted to, as on the main canals, differing only in details of design.

DRAINAGE WORKS.

In canals where the diversion line is carried along the sides of hills or slopes, great difficulties are sometimes encountered in passing the side drainage which crosses the canal lines. Much can be done by diverting water courses or constructing short drainage cuts emptying into natural drainage lines. When the drainage can not be diverted it may be passed in one of several ways. If the stream is at a lower level than the canal the latter may be passed over it in an aqueduct, which in most cases will involve the construction of some embankments before the stream channel proper is reached. If the canal and stream meet at the same level the latter may under exceptional circumstances be permitted to enter the canal. This will necessitate the introduction of proper regulating works below the canal crossing, and an escape or dam on the opposite side to the inlet. In the case of very small streams entering a canal at level, an inlet only is necessary, the surplus water being passed off through the first escape in the canal channel. If the stream encountered is at a higher level than the canal it is generally carried over the latter in an aqueduct, which is called a superpassage. In the case of nonnavigable canals, less elaborate drainage methods than those described may be employed, and modifications of these methods are used, as when the canal is carried under the stream in an inverted siphon, or a combined siphon-aqueduct has been constructed.

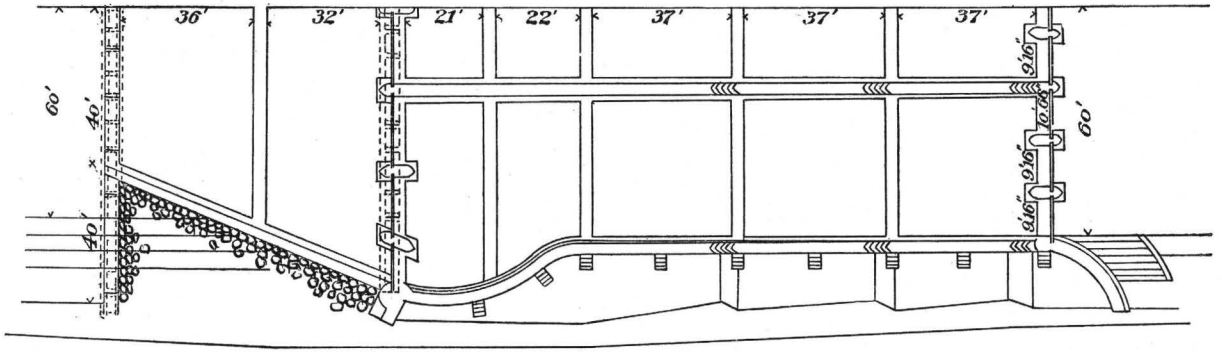
By means of simple diversion of the course of a stream, much expense may be saved. An instructive example of diversion is that of the Chuki torrent on the Bari Doab Canal. At the time of the construction of the canal this torrent had two outlets. Just above the crossing of the canal the main channel divided, one channel running into the Beas and the other into the Ravi River. The latter was embanked close to the bifurcation by bowlder dams and spurs protected by masonry revetments. By this means the whole of the water was forced to flow into the Beas and the expense of the work of crossing the canal was saved. Another instance is that at the head of the Betwa canal. The first 6 miles of this is protected by a drainage channel 15 feet wide at bottom and 6 feet deep, which runs parallel to the canal and carries the drainage into a small stream whence it is let into the Betwa River. At the Betwa head works a creek enters the river and this was blocked up by a large embankment and turned back by a cut through which it entered the river above the head works.

Aqueducts differ from bridges only in having to carry a water chan-

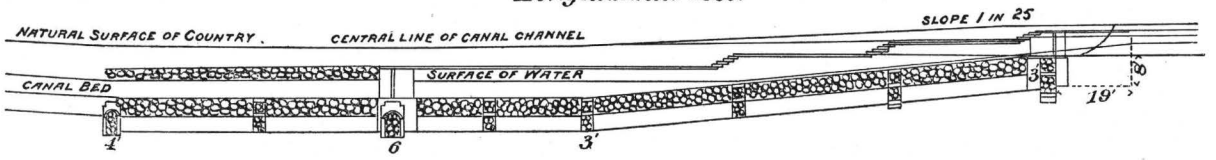


Transverse Section at Crest and Tail or at commencement and end of slope.

Half Plan



Longitudinal Sect.



RAPIDS, BARI DOAB CANAL.

nel instead of a railroad or roadway. The bridge portion may be of wood, iron, or masonry. In India masonry is almost exclusively employed because of its relative cheapness and permanency. On the Soane Canal are several interesting aqueducts, one of which, across the Thor Nulla, carries the Buxar Canal on a well constructed masonry structure (Fig. 235). The total height of this aqueduct is 38½ feet and exclusive of the wings or retaining walls is 155 feet long, the width exclusive of wings being 54 feet. The water way of the aqueduct is 42 feet wide on top, 40 feet at the bottom, and 7 feet in depth. The water way for the torrent beneath the aqueduct is constructed almost as an inverted siphon, the bed having an inverted arch beneath the piers. There are four spans, each 30 feet wide by 20 feet 9 inches high, the arch above supporting the aqueduct. The height of the piers to the springing of the arch is 12 feet and the rise of the arch is 6 feet. The piers are each 6½ feet wide. The object of the invert is, that should a greater flood occur than is estimated for, the openings may act as siphons. They are estimated to carry 10,000 second-feet.

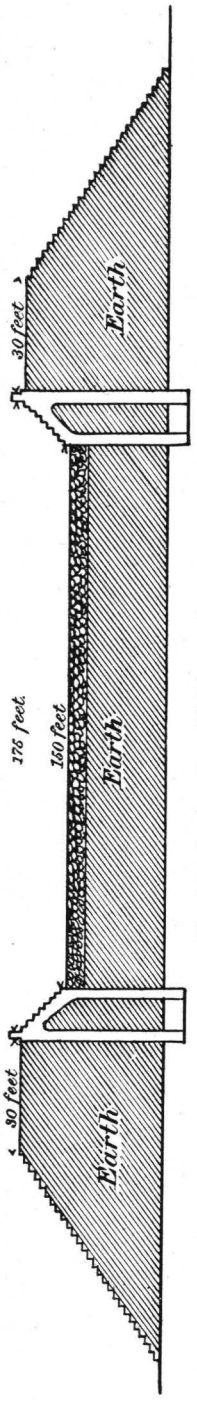


Fig. 247.—Cross-section of Solani aqueduct, Ganges canal.

One of the greatest and earliest aqueducts constructed is the Solani Aqueduct on the Ganges Canal at Roorkee (Pl. CXXVII). This consists of an earth embankment 2¾ miles in length across the Solani Valley, and about 16½ feet high, its greatest elevation above the river bed being 24 feet. This embankment, as shown in the sketch (Fig. 247), is 350 feet wide at the base and 290 feet wide on top, and on this the canal banks are formed. The outer edges of these banks are 30 feet wide and 12 feet deep, and are lined throughout by masonry or revetments of stone. The exterior slopes of the embankment are 1 on 1½, and have been made with great care. The total length of the upstream revetted channel is 10,713 feet; that of the downstream channel is 2,723 feet and between these embankments is built the masonry aqueduct, the total length of which is 920 feet, with a clear water space between piers of 750 feet in length, consisting of fifteen spans of 50 feet each. The breadth of each arch parallel to the channel of the river is 192 feet and its thickness is 5 feet. The arch is in the form of a segment of a circle with a rise of 8 feet,

and the piers are raised on foundation blocks of masonry, sunk 20 feet in the river bed. The greatest height of the aqueduct proper above the river valley is 38 feet. The water way of the aqueduct is formed in two separate channels, each 85 feet wide; the outer walls of masonry are 8 feet thick and 12 feet deep, the aqueduct being intended to carry 12 feet of water. The velocity through the aqueduct is $3\frac{2}{3}$ feet per second.

Perhaps the most magnificent aqueduct yet constructed is that built across the Kali Nadi at Nadrai which carries the waters of the lower Ganges Canal over that river. The first aqueduct at this place was much smaller than the present one. Before the great flood of 1885 it was calculated to permit the passage of 30,000 second-feet through the five bays into which this water way was divided, and it was founded on the natural channel of the torrent. In 1884 an extraordinary flood occurred which discharged nearly 100,000 second-feet under the aqueduct, and greatly injured it. Repairs were at once commenced and slight alterations made in order to increase the channel. On the 2d of October, 1884, a flood level was noted on the upstream side corresponding to a reading of 22·2 feet on the downstream gauge, the difference of surface level above and below the aqueduct being $3\frac{1}{2}$ feet. The mean velocity of discharge in this flood was about $10\frac{1}{2}$ feet per second. This work had scarcely been commenced when, on the 17th of July, 1885, another and greater flood occurred. This flood is fully described in notes made at the time by the executive engineer, Mr. W. Good.[1]

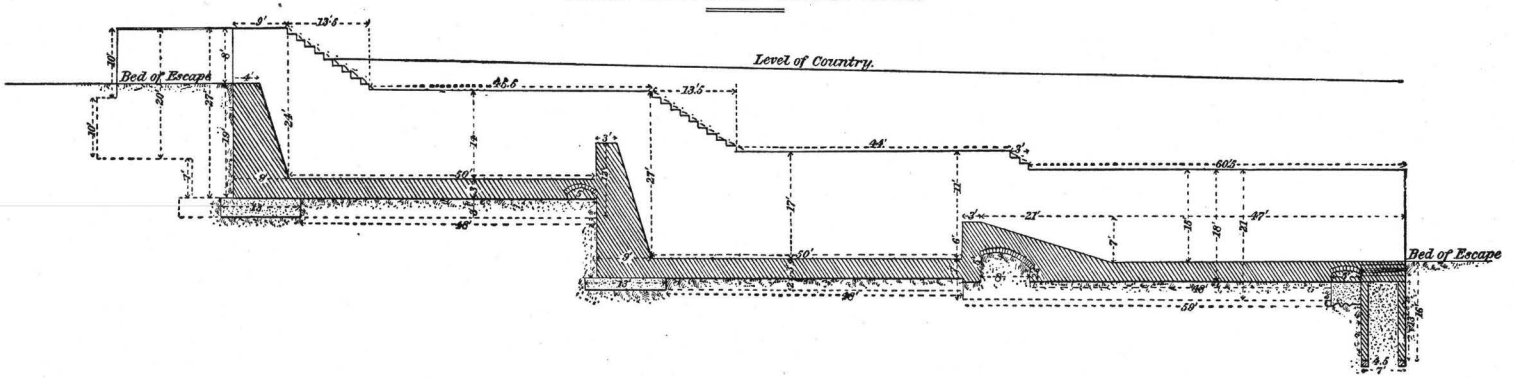
Early on the morning of the 17th the river began to rise and the water level rose in a wave 4 feet high and carried away part of the revetment. Other waves 10 or 15 feet high surged over it, and the whole of this revetment work and the abutments collapsed. Shortly afterward the piers were carried away and parts of the aqueduct felt into the stream. The velocity was terrific. The water in the main stream was piled up in waves 20 feet high at intervals of 100 feet apart. By three in the afternoon 100 yards of the canal bank had been carried away and all of the aqueduct had been destroyed. The level of the water rose from 4 o'clock in the morning to 3 o'clock in the afternoon a total height of 23 feet and had a velocity of over 18 feet per second. From estimates made by Mr. Good the discharge of that flood was probably 135,000 second-feet, and during the rain storm (which lasted three days), an average of 22 inches of rain fell on the whole catchment area. The greatest fall occurring in one day, the 16th, was 20 inches on some portions of the basin.

In estimating for an aqueduct to replace the old one, this flood was considered as the greatest which was ever likely to occur, and

[1]Failure of the Kali Nadi Aqueduct, Records of the Government of India, Public Works Department No. 240, Calcutta, 1888.

AGRA CANAL

CROSS-SECTION OF KUSHUK FALLS.



the new aqueduct as now finished is estimated to discharge under it 140,000 second-feet, with a velocity of 8 feet per second, thus requiring a water way of 22,430 square feet. This is equivalent to a run-off of 55 cubic feet per square mile of catchment, the total area of which is 3,025 square miles. The water way for the canal on top of this aqueduct will carry 3,175 second-feet.

The aqueduct (Pl. CXXVIII) consists of 15 masonry spans each 50 feet long, supported on wells. The maximum pressure on the foundation wells of the piers does not exceed $2\frac{1}{2}$ tons per square foot. Under the aqueduct is sunk a concrete floor 5 feet in thickness. The total cost of this work was about $1,523,000.

On the Ganges Canal are two of the largest as well as the most interesting superpassages constructed in India, one for carrying the Puthri torrent and the other the Ranipur torrent over the canal. In the construction of a superpassage especial care must be taken to give its bed such a slope that it shall not be filled up by the deposit of sediment, while the masonry and revetting of the banks must be carried a sufficient distance on each side of the canal up and down stream to protect the foundations of the work.

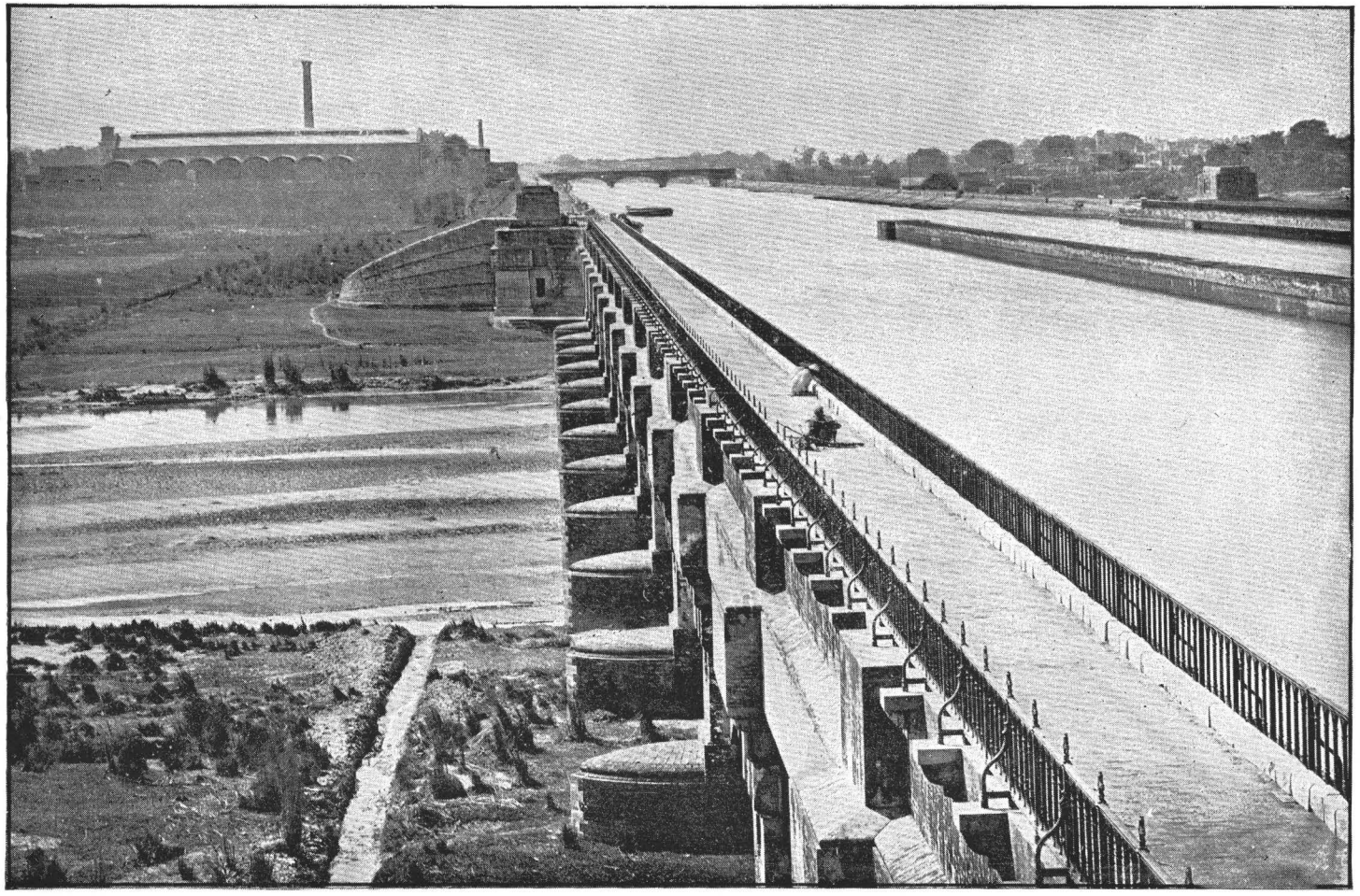
The catchment basin of the Ranipur torrent is about 45 square miles, its average width being $4\frac{1}{2}$ miles and its total length 10 miles. At the point where the superpassage is constructed there is an Ogee fall with a drop of 9 feet, the base between the piers supporting the superpassage being used as a portion of the masonry construction of the fall. (Pl. CXXIX.) The foundations of the upper and lower levels are protected by lines of piling and box work; the former have a width of 10 feet and the latter of 70 feet. The flooring of the superpassage from the crown of the arches to its bed is in its thinnest place 3 feet thick, and the parapets are 7 feet wide and 4 feet high. These continue inland from the body of the work a distance of 100 feet on each side, expanding outward so as to form wings for keeping the water within bounds. The superpassage is 300 feet long and provides a water way for the torrent 195 feet wide and 6 feet deep.

At the Puthri superpassage the torrent of that name drains an area of about 85 square miles and discharges a maximum flood of 15,000 second-feet. This superpassage consists of an aqueduct, under which the canal passes in nine bays, each 25 feet wide. The width of the superpassage is 296 feet. This water way, as it now appears, was made too wide, and accordingly the decrease in the velocity of the torrent at this point, which in the natural channel is 16 feet per second, has caused considerable silting and the superpassage has been constantly filling up. This error has been obviated by decreasing the water way by the construction of masonry groynes projecting from the side parapets of the superpassage out into the stream at right angles to its course. This has nearly remedied the evil, as the silt previously deposited is now being rapidly cut away.

The Sasoon superpassage (Pl. CXXX) on the Sirhind Canal, whereby the Sasoon torrent is carried over the canal, drains an area of 24 square miles. The discharge of this stream is estimated at 7,750 second-feet, and a water way has been provided 150 feet wide by 6½ feet deep. The difference in level between the bed of the canal and the torrent is 21·9 feet, of which 7 feet are depth of water in the canal, 10 feet headway up to soffit of arch, 3 feet the thickness of the arch, and 1·9 feet brick flooring. The canal channel is spanned by three central arches, each of 45 feet span, and two at the sides, each of 32 feet span. There is an aggregate water way for the canal of 184 feet, but the mean water way of the channel is only 177 feet. The side walls or parapets of the superpassage are 10 feet high and 5 feet thick at base. The mode of construction of this superpassage is indicated in the accompanying sketch showing its cross section.

An interesting mode of disposing of drainage is by a drainage reservoir, as is done on the Agra Canal. Several streams cross the canal at a certain point. They are, however, all disposed of through one channel by constructing an embankment on the upper side of the canal, so that a reservoir is made. The object of this reservoir is not storage, but drainage. The embankment is of earth and about 40 feet high. The bottom or sill of the superpassage, which carries the flood water over the canal, is about 30 feet above the bottom of the reservoir, the object being that the lower 20 feet of the bed of the reservoir can be cultivated and supplied from this water. A large revenue is returned to the Government from the lands cultivated in the reservoir bed after the waters have been drawn down through the superpassage. This superpassage is constructed of boiler iron. It is 99 feet long, 30 feet wide, 10 feet deep, cross braced by angle iron on top, and supported by two piers each 5 feet thick. It is well built and supported and the slope is steep, giving a high velocity to the water. The connection between the ends of the superpassage and the abutments is made of heavy sheet lead, to accommodate the changes due to expansion of the iron and to prevent leakage. After flowing through this superpassage the water falls vertically 12 feet, and then 25 feet into the old channel of the river Jumna.

The Rutmoo torrent is passed across the Ganges Canal by a level crossing. (Pl. CXXXI.) This consists of a simple inlet at the torrent entrance to the canal and of a masonry outlet dam and escape regulator in the canal bank opposite the torrent inlet, while there is another regulating bridge across the channel just below the inlet. (Fig. 248.) By this means the flow of water is easily regulated, the amount admitted to the canal below the inlet being controlled by the regulator in the canal itself and the superflous water being discharged through the regulating breach or dam in the canal bank. This dam consists of 47 sluiceways, each 10 feet wide, with their sills flush with the canal bed. These are flanked on either side by overfalls of the same width with



SOLANI AQUEDUCT, GANGES CANAL.

their sills, 6 feet higher, and on the extreme flanks are platforms 10 feet above the canal bed. These elevated platforms are 17 feet long and connected with the revetment on the canal banks by inclined planes of masonry. This escape dam is practically identical in construction with the ordinary scouring sluices at Myapur and other places. The water way through the sluices up to the height of 6 feet is 470 feet wide, and between the levels of 6 and 10 feet it is 570 feet wide. Above that it is 800 feet wide. The closing and regulating of the opening in this sluiceway is conducted by means of slash boards fitting into grooves. The sluice gates are dropped rapidly, being constructed on a plan similar to the Soane scouring sluices, but more crude in their method of manipulation. When not in flood, the water in the torrent is carried under

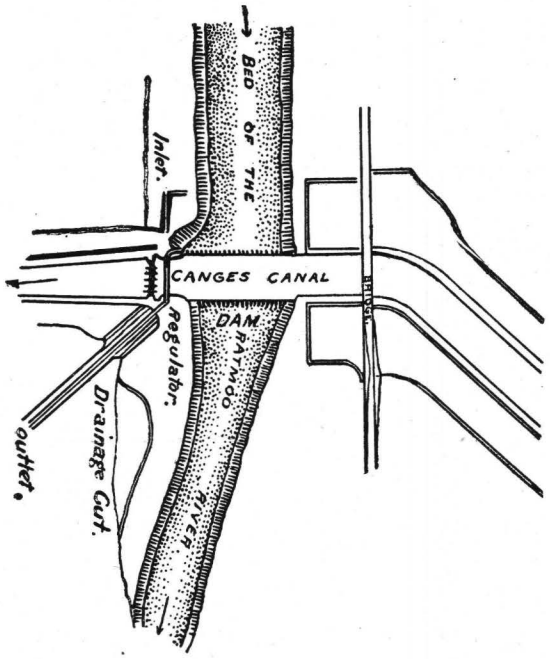


FIG. 248.—Plan of Rutmoo crossing, Ganges Canal.

the canal and returned to the Rutmoo torrent below it by means of a little drainage tunnel or inverted siphon about 500 feet long. Owing to the high velocity of the floods in the Rutmoo torrent, there is no deposit of silt in the canal, the greater part of the silt being carried straight through it by the rush of the flood waters. The torrent in late years has been cutting badly on the downstream, and to stop this retrogression of levels 5 masonry bars have been put across it, each about 200 yards apart. These are composed of cribs filled with bowlders, and have acted as contemplated. The maximum flood anticipated and discharged through the Rutmoo torrent is 25,000 second-feet. The regulating bridge across the canal below the crossing has ten water ways, each

of 20 feet, and in addition to this there is a roadway over it forming a bridge. There is about a mile of revetment walls, all resting on blocks or wells sunk to a depth of 20 feet below the canal bed. This is protected by numbers of piles and cribs filled with bowlders.

The Kao Nulla on the twenty-first mile on the main western Soane Canal is passed by a siphon aqueduct. This torrent is subject to great floods. They are estimated on the basis of 6 inches of run-off on the 57 miles of catchment, and the highest velocity is 8⅓ feet per second. The siphon passage for the flood provides 1,103 square feet of water way disposed in 20 openings, each of 54 square feet. This work consists of substantial masonry carried well beneath the ground under the bed of the torrent and above ground for the support of the aqueduct, and is

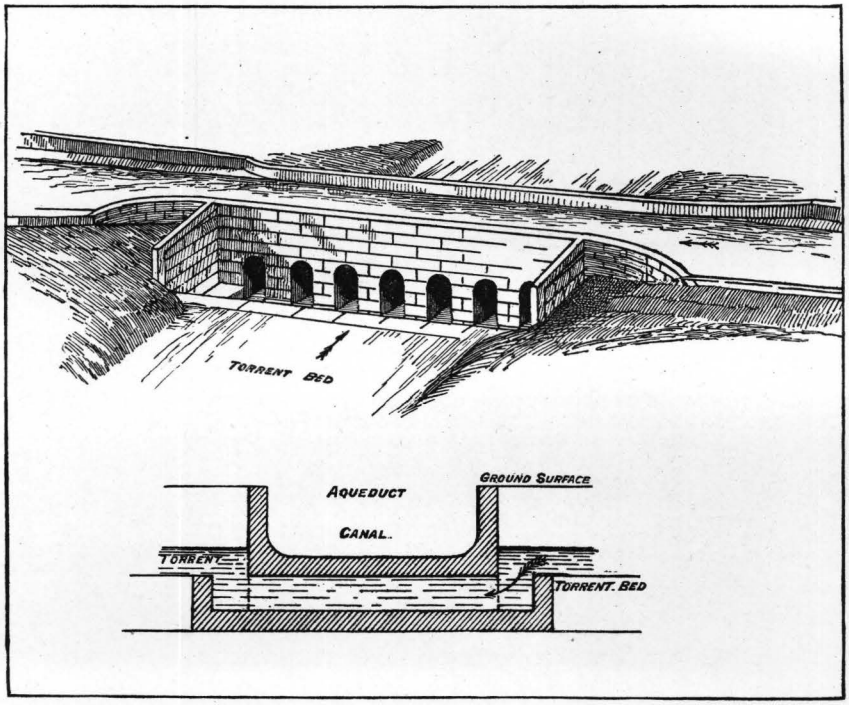
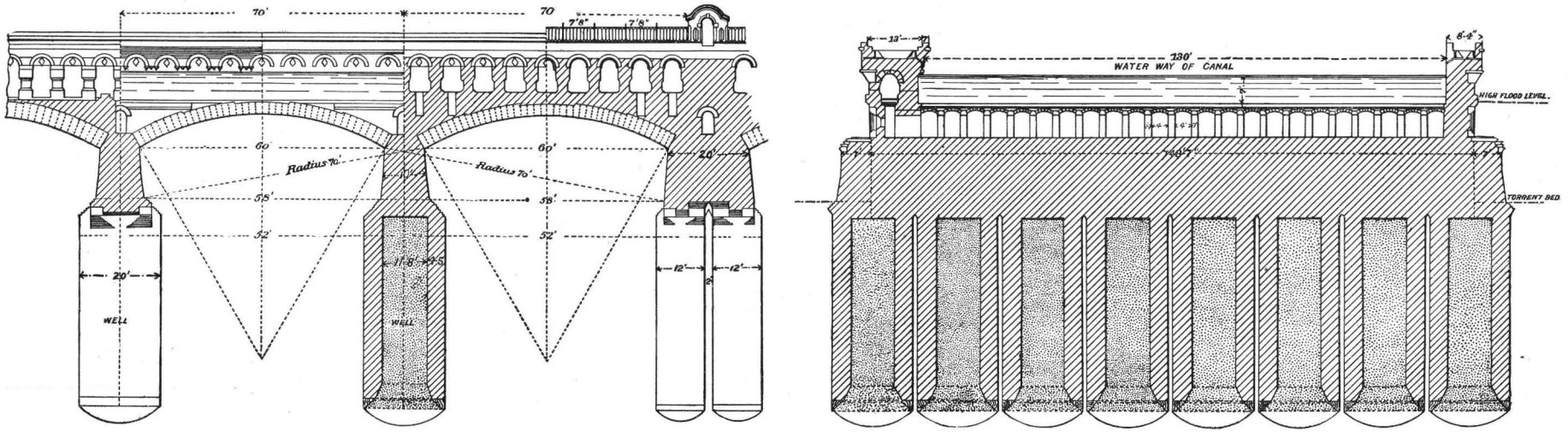


FIG. 249.—Kao Nulla siphon aqueduct, Soane Canal.

only a semisiphon carried under the aqueduct, as indicated in the accompanying sketch (Fig. 249). A similar work is that of a superpassage and siphon on the line of the Nira Canal whereby the torrent is carried over the canal, the latter being in an inverted siphon. This work is indicated in Fig. 256.

DISTRIBUTARIES.

Like the main canals, the distributaries or laterals are invariably designed and laid out by and are under the control of the canal engineers. From these the farmers take their private water courses and channels



NADRAI AQUEDUCT, LOWER GANGES CANAL.

to their fields. Sir P. T. Cautley thus speaks of them in connection with the Ganges Canal:

> In our irrigation system the trunk and main canals with their great branches play the part of a reservoir to the distributaries. The latter hold the relation to the main canals of a system of distributary pipes in a town water supply, and the village or private water courses play the part of service pipes.

Distribution from a canal is most economically effected when the latter runs along the summit of a ridge so that it can supply water to its branches and to private channels on both sides of it (Pl. CXXXII). This location in the case of a large canal can happen only in occasional instances, but the secondary or distributary branches taken from these principal canals can and should be made to conform to dividing lines between water courses. The capacity of the distributary which then traverses each separate drainage divide is proportioned to the duty it has to perform, the bounding streams limiting the area it has to irrigate.

For the more complete and efficient distribution of water the engineer treats them as of as much importance as the main branches themselves. Attention is devoted to the character of the soil traversed, to the alignment, to the safe and permanent crossing of natural drainage lines, and to so maintaining the surface of the canal with relation to the ground as to command the largest irrigable area. In all well designed distributary systems the capacity of the channels is exactly proportioned to the duty to be performed, the cross-sectional area being diminished as the quantity of water to be carried is decreased owing to its diversion by private water courses, though a sufficiently large margin is usually allowed for future possible development.

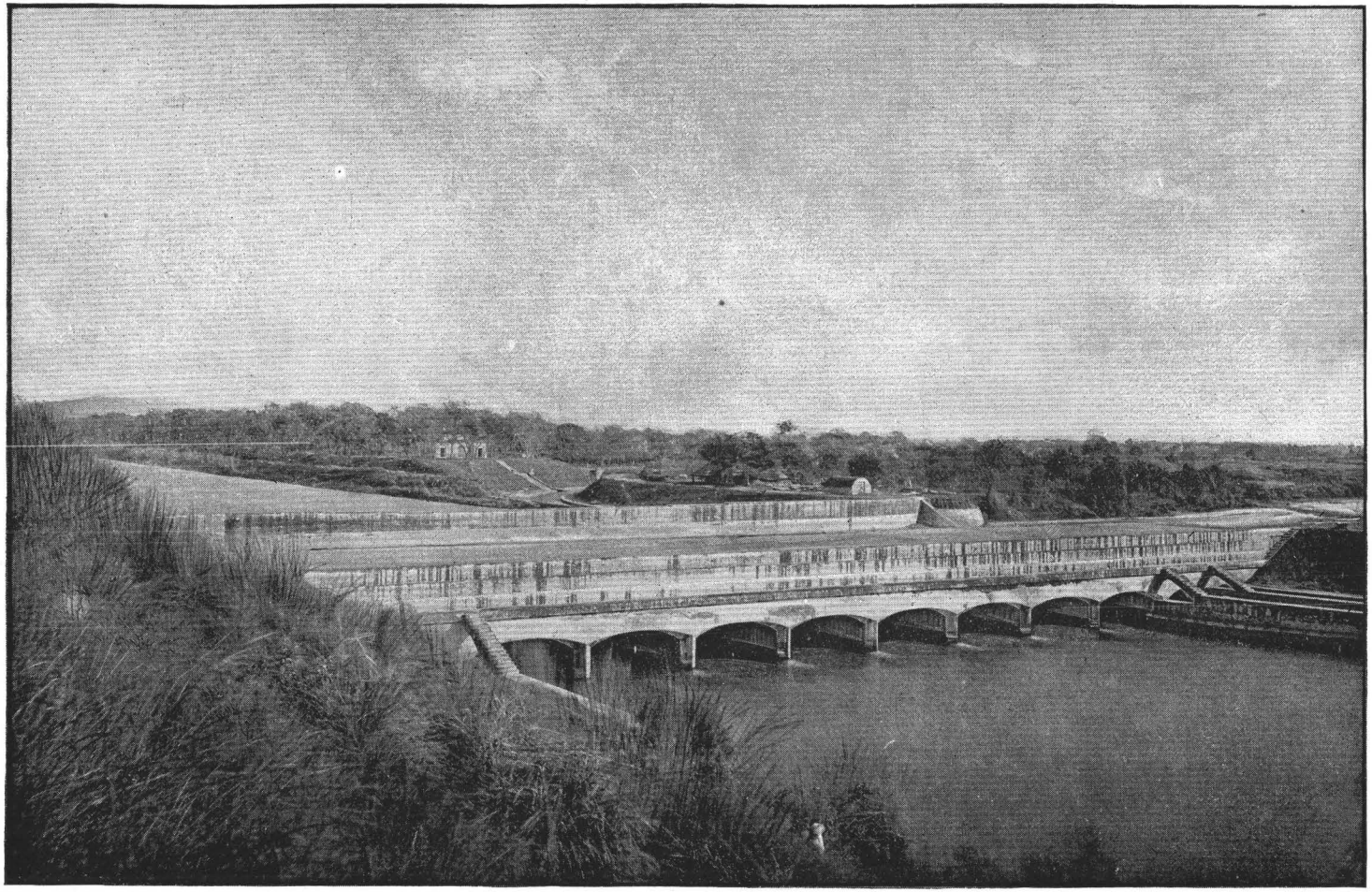
It is usual to take off the water of a distributary from the main canal as near the surface of the latter as possible. That is, the bed of a distributary should not be on a level with the bed of the main canal, the object being, first to get the clearest water possible, which is found nearer the surface, and secondly, in order that the bed of the distributary may be kept at as high a level as possible to admit of surface irrigation throughout its length. In level country great care is always taken in designing these distributaries that the natural drainage lines in which they tail shall be sufficiently large to accommodate any flood volume it may be necessary to pour into them, so that the distributary may be rapidly relieved during times of storms and the drainage lines shall not become clogged and flood the surrounding country. The slope of a distributary is usually planned to be as nearly as possible parallel to that of the district it traverses in order to avoid costly embankments and to insure the surface of the water being above that of the country. Falls are sometimes rendered necessary by the profile of the country, as is the case on larger canals, while escapes are introduced every 8 to 10 miles.

Distributaries as designed on the great Ganges Canal have been made to conform as far as possible to a general design which may be outlined as follows: The heads have been constructed at the points where bridges

or falls were necessary, in order to economize in masonry construction. This location also insures their better inspection. The beds are generally from 2 to 3 feet above those of the main canal from which they are taken. These heads are designed as mere open gateways with grooves for the introduction of shutters or planks. No further design has been attempted for the regulation of discharge. The distributaries are divided into main lines and feeders. The first or main lines run parallel to the canal on both sides, and these parallel lines are met in their passage downward by feeders coming from the different distributary heads in the neighborhood. This principle of constructing parallel channels to the main canal is one which would not recommend itself for use in the United States, as the chief object, or rather the cause of their employment, has been the navigative character of the main canal. As the main canal must necessarily have a very low slope in order that the velocity will not impede navigation, and as these main canals at their heads below lock are usually sunk some depth beneath the surface of the adjacent country, it becomes practically impossible to distribute water from them, and accordingly the parallel lines have been employed, which, keeping near the surface of the country, facilitate the distribution of the water to other minor channels. Where the canals are not primarly designed for purposes of navigation these parallel channels may well be dispensed with, though they are found on nearly all of the larger Indian works.

According to Maj. Brownlow, R. E., the greater the amount of water discharged by a distributary the smaller will be the proportion of cost of maintenance, for a channel 12 feet wide discharges more than double that of two channels each 6 feet wide, while the cost of patrolling and repairing the banks will be half that of the two smaller ones. Experience proves that irrigation can be most profitably carried on from channels 18 feet wide at the bottom and with about 4 feet depth of water. On the eastern Jumna Canal, during the years from 1858 to 1860, the expenditure on all the distributaries of 12 feet head width and upwards was 0·123 of the revenue, while on all those below 12 feet it was 0·223 of the revenue, or nearly double the first. The relative value per cubic foot per annum from the same experiments, on channels of respectively 12, 6, and 3 feet in width was as 10:7:4. Increased action of absorption in small channels, with diminished volumes and velocities, accounts for the difference. The depth of water accordingly should be seldom less than 4 feet, and the surface of the water should be kept at from 1 to 3 feet above that of the surrounding country, not only to afford gravity irrigation, but because the loss by absorption is thereby diminished. This was shown in the experiments referred to in the previous part of this paper, under the heading "Duty and Absorption."

Indian engineers unite in condemning the practice of raising the water in the channels to the surface of the country by means of dams or stops made by introducing planks into grooves made for that purpose. This practice, they say, converts a freely flowing stream into a series of stag-



RANIPUR SUPERPASSAGE, GANGES CANAL.

nant pools, encouraging the growth of weeds, the deposit of silt, and an unhealthy condition of the neighborhood; and it is, moreover, extremely wasteful of water, since much of the latter is dissipated because of the loss of head. In designing the canal banks the width of the top of the bank should be sufficient to admit of easy inspection. On moderate-sized distributaries, such as those just referred to, $4\frac{1}{2}$ feet may be taken as the minimum width, and wherever the dimension of the channel will permit it, this width should be increased. Should the cutting be so deep that a berm is necessary, it is always well to let the latter slope away from the canal and be drained off through the bank; the top of the bank, likewise, should slope away from the canal, and not drain toward it, as in times of heavy storms much silt may be deposited in the canal from this local drainage.

Ordinarily the water for the village ditches is taken from the distributary by means of hollow wooden or iron pipes let into the banks of the canal and nearly flush with its bed. These are stopped at the outlet by a valve or plug. The heads of the distributaries on the modern canal systems are more carefully designed. They are usually constructed of substantial masonry works let into the canal banks, and closed by a valve or other easily controlled shutter. In the Northwest provinces a series of standard designs have been prepared, an illustration of which is given (Pl. CXXXIII). The heads of the minor branches or the private water courses are, like those of the distributaries, usually placed where the existing masonry works occur as at falls or bridges, while the private channels head in simple wooden or iron outlets. Substantial masonry falls are constructed at such points as the grade of the surface of the country makes necessary (Fig. 250). These are usually simple vertical drops into a masonry well, and the scouring is generally lessened by creating a water cushion at the bottom of the fall.

In the Punjab and elsewhere rules have been laid down for the construction and estimate of the masonry works on distributaries. Among others are these: Siphon barrels shall have a sectional area equal to the bed width plus one-half the full supply. Siphon wells shall have the same area as above, the depth being equal to $1\frac{1}{2}$ times the fall supply. The depth of the cistern at the foot of a fall in order to form a water cushion shall equal one-third of the height of fall, plus the full depth of the water. Thus with a fall 4 feet deep on a canal carrying 5 feet of water, the cistern depth will equal $\frac{1}{3}(4+5)=3$ feet. The minimum cistern length is equal to three times the depth counting from the drop wall to the reverse slope, which latter will be 1 in 5. The width of the cistern must be twice the mean depth of the water in the channel, or twice the bed width plus the full depth.

While the water rate is at present charged in India according to the area irrigated and the crop raised, it is universally conceded that it would be fairer to charge for the water according to the quantity used,

as it can make no difference to the canal proprietors what becomes of the water after it has been delivered and paid for. The difficulties in the way of delivering water by actual measurement have been insuperable, chiefly because no practicable method of measuring water under a constantly varying head has yet been devised. On all the older es-

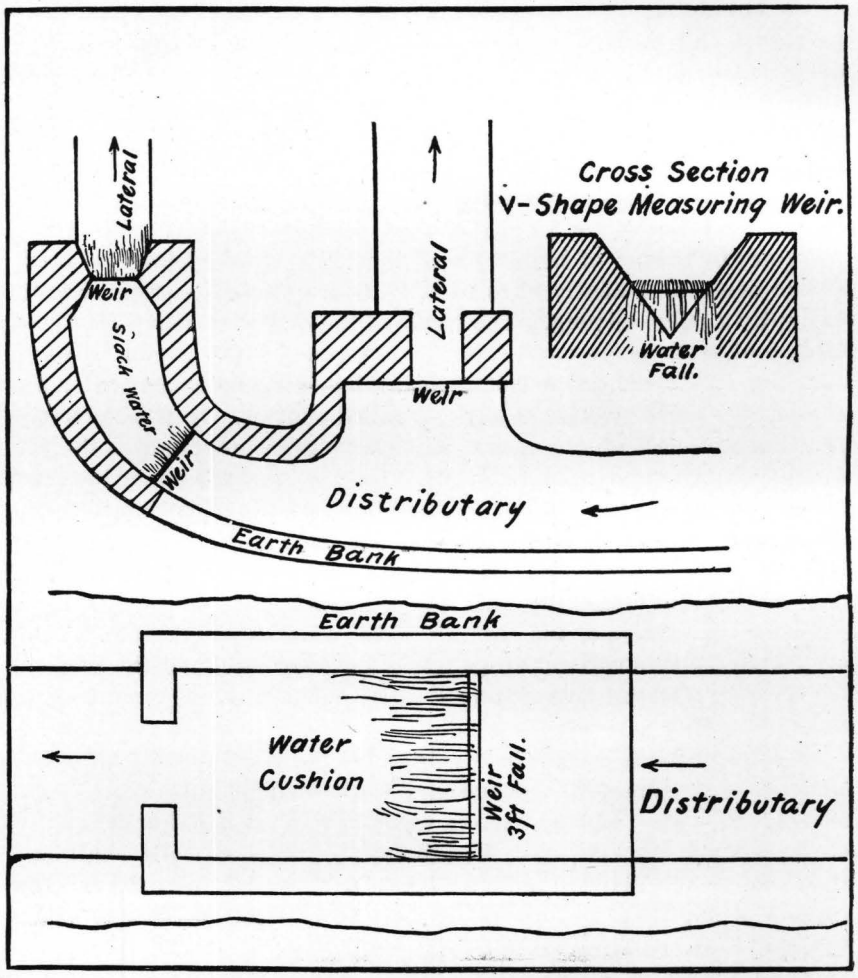
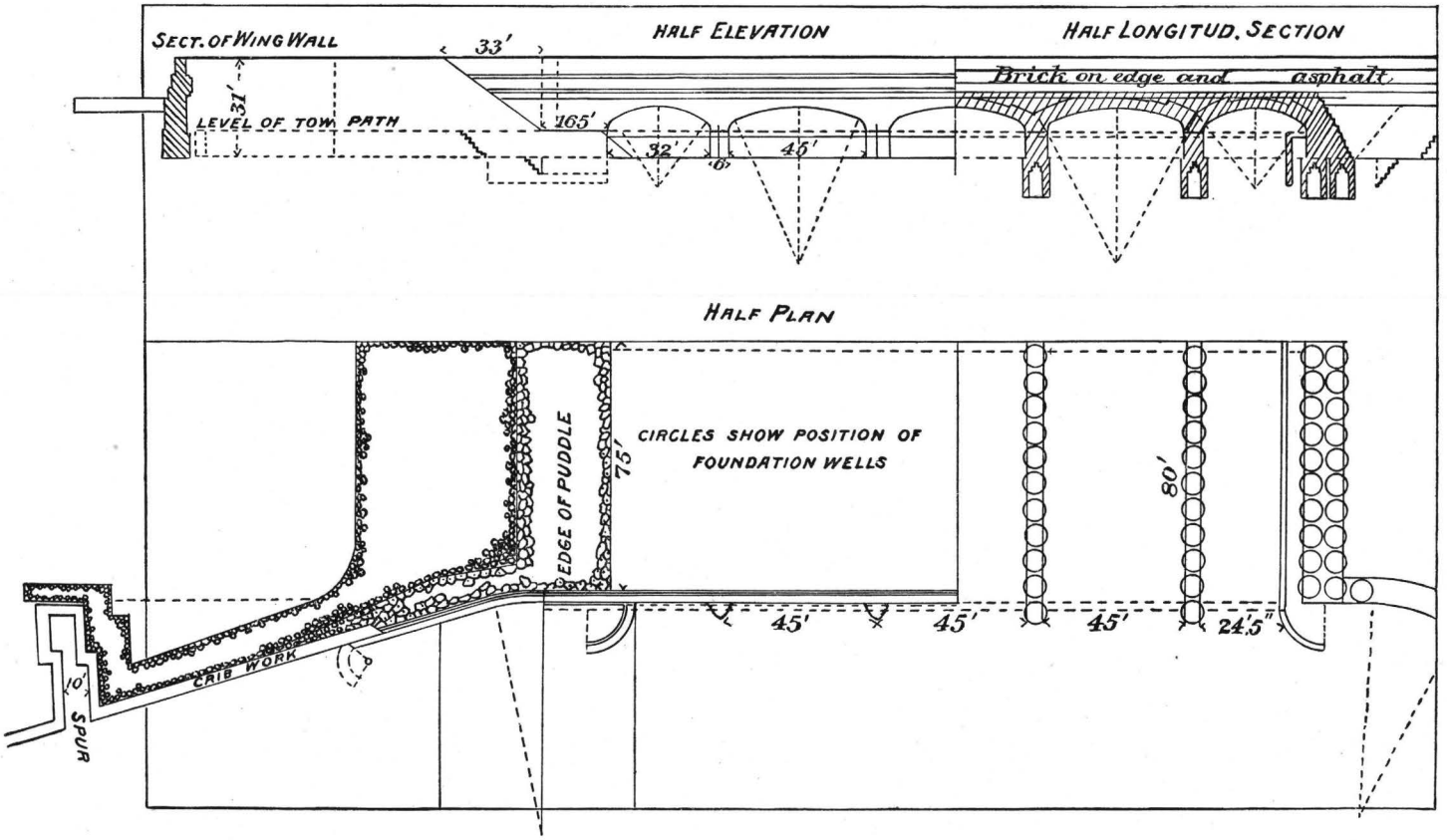


FIG. 250.—Plans of distributing head, Mutha Canal, Bombay.

tablished canal systems, especially when the supply entering the head of the canal is insufficient for the demand, a system called "tateels" has been established. This may in general be said to consist in a mode of regulating the amount of water given to the irrigators by the canal officers closing their outlets for successive periods of time in regular rotation. Each cultivator is compelled to take the water when his turn



SASOON SUPERPASSAGE, SIRHIND CANAL.

arrives, be it in night or day, or else lose his share of water at that time. It is considered the best practice to impose these tateels on long portions of a distributary at once, as short ones have very little effect in forcing water down to the tail of the canal. In their operation an irregular period of rotation is employed. Thus the outlets may be closed in the first length of the canal for four days, on the second portion for three days, and so on, and then this order may be reversed, the period of rotation being such as to change the length of closure along various portions of the canal. One advantage of the imposition of tateels is, that by affording a constant but moderate supply in the distributaries the embankments are kept moist and are thereby less liable to crack, and the growth of weeds is to a certain extent checked.

The measurement of the quantity of discharge into any distributary is made by one of several methods. V-weirs are usually constructed at the heads of these if the expense of the masonry will not be too great. Wherever falls or masonry headworks exist V-weirs can be cheaply added to the structure. For smaller channels standard-sized pipes let into the banks of the canal to draw off the water are used, and the discharge through this orifice under a given head is known from experiment. In larger distributaries the volume discharged is usually obtained by measuring a short length of bank, and, knowing the cross section, the velocity is determined by floats on this known length. The methods in use are generally rather crude and unsatisfactory. For, though the sectional area of the outlet is known, little or no attempt is made to regulate the pressure. The majority of these larger outlets are masonry tubes, from 10 to 20 feet long, and the friction in these is considerable. The outlets are rarely so arranged that the pressure on the head can be regulated, as is done in the measuring boxes employed in California and Colorado. The Indian engineers hold that the ordinary Italian module is not applicable to their distributaries because of the fluctuation in the height of the main canal and because of the amount of silt carried in suspension, which closes the tail and impedes the circulation of water.

METHODS OF APPLYING WATER.

There is little that is novel to American irrigators in the modes employed by the Indian agriculturist of applying water to crops. The chief peculiarity which at once strikes the observer is the great care with which each crop is handled and the expense with which the private ditches are frequently aligned and constructed. Being an old country, and one in which both land and water are valuable, and the various individual holdings being small, each cultivator having but a few acres, rarely over 5, sometimes less than 1, to look after, it is a frequent occurrence to see the cultivators irrigating their crops from their ditches by means of wooden scoops or wicker baskets with which they toss the water out of the ditch and scatter it over the land. On sugar cane, rice, and the more expensive grain crops the action of

gravity is brought into greater play and private channels are so laid out that the natural flow of water will carry it over the crops.

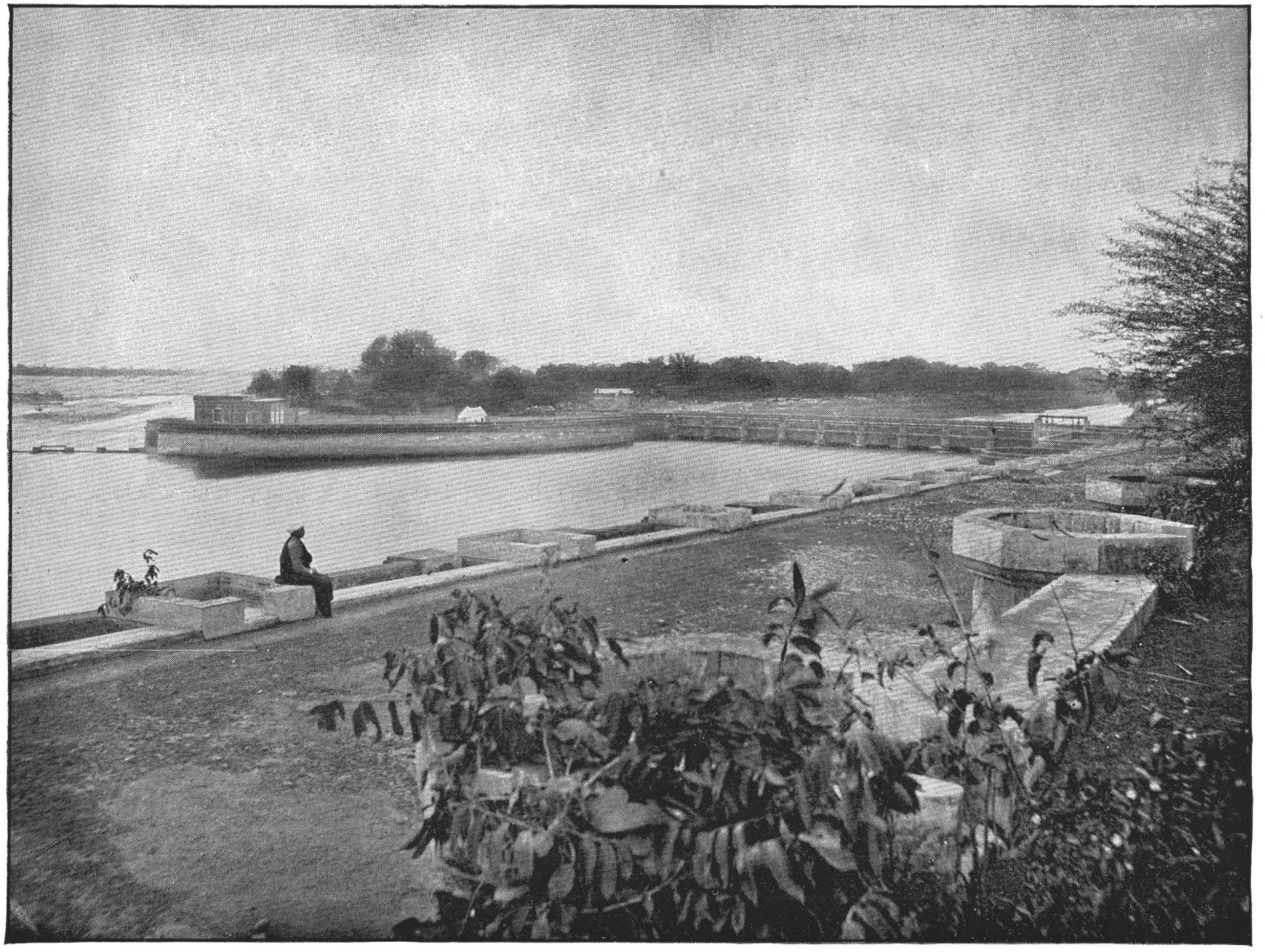
In irrigating from wells the water which is raised is usually emptied into a basin or shallow tank excavated in the earth, which may be lined with puddle, or, as is frequently the case, with masonry. From this basin the water is conducted at first through masonry or well constructed earth ditches to branch channels, which are ordinary runways roughly excavated in the soil.

Rice is everywhere irrigated by dividing the land into small squares or blocks in an irregular checkerboard fashion. These are usually not less than 20 and rarely 100 feet square, depending largely upon source of supply and slope of country. These blocks are separated by low earth banks about 1 foot in height with cuts opening through them from one block or field to another. Where the slope of the surface is very light extensive fields may occasionally be seen within one block. On hillside country the steeper slopes are terraced by the construction along a contour line of a low embankment about 1 foot in height. These terraces retain the water from floods or storms, submerging the rice crop to a depth of several inches, thus acting as miniature tanks. In the more level rice country the various blocks are flooded from the canals, the rice always being submerged to a considerable depth.

In irrigating sugar cane an effort is usually made to obtain a freer flow of water than can be obtained by the above method, though as in the case of rice cultivation this crop requires a great deal of water and it is permitted to stand to a depth of several inches over the surface of the ground. Wherever the slope will permit, numerous cross furrows are plowed or narrow ditches run throughout the field of grain or cane in such a manner as to permit the water to flow in a thin layer over the soil, that which is not absorbed being caught up and utilized by the next lower ditch. Excepting in the irrigation of rice or occasionally of sugar, the land is almost invariably divided by some method of gridiron work of furrows and ditches as will most conveniently cover the area to be irrigated, excepting in cases where the water is sprinkled by hand.

In an interesting paper discussed by Mr. Baldwin Latham before the Institution of Civil Engineers,[1] he gave a novel description of the circulation of water in soil as shown by some experiments which he had made with the object of discovering the precise difference between the application of water in rice irrigation where it stands stagnant on the land and other irrigations where a constant currrent is kept moving. The result of these experiments showed that where a surface velocity was created it would promote a circulation of water throughout the soil, a matter of considerable importance, as by that circulation manurial matters were equally distributed while other material was removed

[1]Discussion of Irrigation in Northern India. Proceedings of Institution of Civil Engineers, London, Part I, vol. 35, 1872.



RUTMOO LEVEL CROSSING, GANGES CANAL.

which was not required by the plant, and which if allowed to stagnate would produce those ill effects shown when cultivating rice. The experiments were conducted in a water-tight glass tank which was filled with fine silver sand into which was poured a solution of perchloride of iron. Over this a solution of nutgalls was allowed to pass slowly and the course of the circulation could be readily followed, as the point of contact of the two mixtures produced tannate of iron or ink which portrayed a perfect diagram of every stage of the experiment. The result of the experiments showed, among other things, that where there was an inclination of the surface resulting in the production of natural currents over it, a circulation through the soil took place.

In another tank experiments were made giving the conditions of a rice irrigated field. The same materials were used, but the tank was kept level, and it was found that after six months' contact no discoloration of the sand had taken place to a greater depth than one-fourth of an inch, showing there had been no displacement of the water occupying interstitial spaces in the sand. Mr. Latham said that the circulation of the water through the soil, on all land having an inclination, had a marked beneficial influence on irrigation, as conclusively shown from the practice adopted for generations in the irrigated districts of Piedmont and Lombardy, Italy, where, as the headwaters are left, it is customary to increase the natural slope of the irrigated beds in order to create a greater velocity, and hence a greater circulation through the soil.

CHAPTER VI.

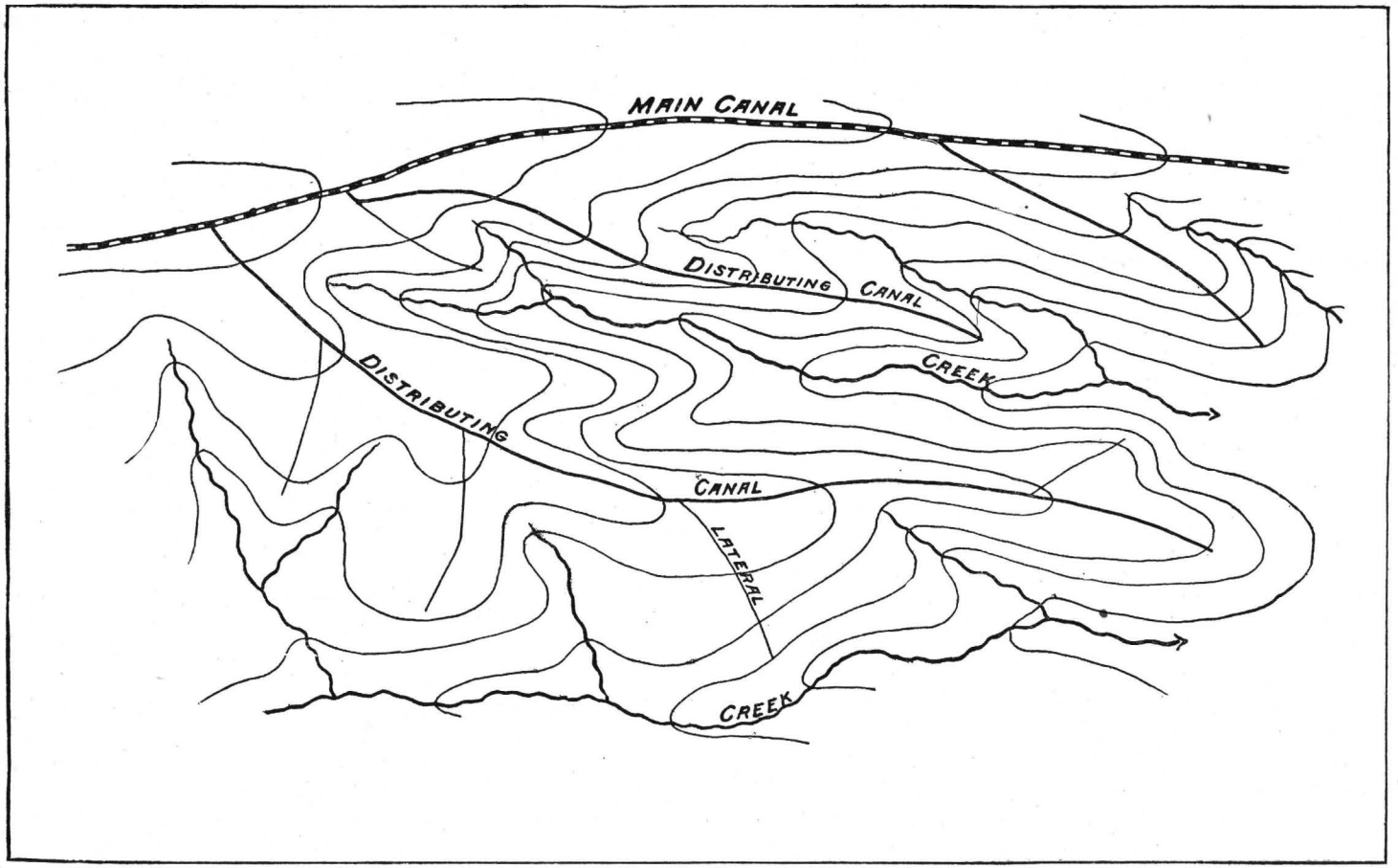
STORAGE WORKS.

CLASSES OF WORKS.

The employment of storage works in connection with irrigation projects is resorted to in order that an assured constant supply of water of a given amount may be furnished by their aid to any area of irrigable lands during each and every season, regardless of the amount of rainfall occurring and of the question whether it be an abnormally wet year or one of unusual drought. Where great perennial streams flow through land to be irrigated there is never any necessity for the addition of storage works as a protection against the failure of the water supply, but where valuable lands are to be irrigated and the source of water supply is from intermittent or very small streams it becomes necessary to supplement the perennial flow occurring in these during the irrigating season by the storage of the flood or waste waters lost during the remainder of the year. This end is attained by damming the stream in some place where it will flood a broad valley and create a large artificial lake or reservoir, or by diverting its waters to some depression or other reservoir site where it can be conveniently stored.

Two classes of storage works are generally referred to by Indian engineers, namely, reservoirs and tanks. There seems not to be any set rules for distinguishing the two, as works sometimes called tanks are frequently larger than the largest reservoirs. Merely for purposes of convenience in discussing the subject the author will adopt the common practice of considering reservoirs as bodies of water retained by a dam constructed wholly of masonry, while tanks are storage works, the dams of which are constructed wholly or in part of earth. Reservoirs are usually deeper than tanks, and are constructed on running and flood streams, while tanks are generally shallower, and they are constructed on minor and unimportant streams, the flood discharges of which are so small that all the water can be either stored or safely wasted, thus not endangering the integrity of the dam, or they are constructed in depressions on the plains or interfluves adjacent to the streams from which water is diverted to them.

In general, works for storage purposes may be filled from canals diverted from some large stream or filled directly from the discharge of the catchment basin of the stream upon which they are located. The location of, necessity for, and probable return from the construction of a



DRAINAGE MAP, SHOWING ARRANGEMENT OF DISTRIBUTARIES.

storage work is always a subject which receives much careful thought, both from the engineering and financial departments of the Indian Government, before the work is finally sanctioned and undertaken. Many different considerations have first to be discussed and weighed in deciding the location. The work should be placed at a sufficient elevation above the lands which it is intended to irrigate to allow the delivery of the water to them by natural flow. The storage work may be so situated that it is immediately adjacent to these lands, in which case a very short canal will serve them, or it may be at some distance from the lands to be irrigated, thus requiring a long line of canal. Again, the storage water may be turned back into the natural drainage channel when required, and be permitted to flow down to the neighborhood of the lands where it will be again diverted for irrigation purposes. The second case mentioned may be very expensive if the canal line be long, but the last is invariably the most expensive method, as it is wasteful of water, the loss of which is greater by absorption and evaporation than in a well constructed canal, while there is incurred the additional expense of a diversion weir at the point where the stream is turned from the natural channel into distributing canals.

Having decided upon the location of the lands to be irrigated, and knowing their area, the first consideration attacked by the engineer is the location of the storage site. This may be discovered after much time has been spent in making trial surveys and investigations. In order that it shall be desirable for its purpose, it must be of such a character that the cost of its construction will not be prohibitory. In considering the source of the water supply from which to fill the storage work, a thorough hydrographic survey of the catchment basin above the reservoir is necessary in order to discover the maximum and minimum precipitation, the percentage and rate of run-off, and the total quantity of water available for storage. Stream gaugings should be maintained for a few years, and all possible effort made to discover the volumes of maximum floods as well as the total quantities of water discharged. To these ends a good topographic survey is first executed, as from the maps thus constructed the relation can best be studied between the irrigable land and the reservoir site and the latter and its catchment area. These maps enable the engineer to measure the areas of the catchment basins and to calculate the discharges from these areas, provided the rate of run-off is known. The Indian Government has already constructed over most of its territory a good topographic map, on a scale of 1 mile to 1 inch, upon which the topography and outlines of hills and valleys are indicated in hachures, and numerous elevations are marked at prominent towns, passes, and mountain peaks. In addition to this, much of the more densely inhabited portion of the peninsula has already been surveyed and mapped for revenue purposes, on the large scale of 4 inches to one mile. With the aid of the latter map it is possible to determine with much accuracy the various fields and

plats of land which are to be served by the irrigation scheme and their general relation to the distributory channels, while the smaller scale maps enable the engineer to solve all the general problems in connection with the catchment basins, streams, general location of storage site, and the general course which the distributing canal or other medium must take in order to conduct the water to the lands to be irrigated. Such maps as these are of the greatest possible service in the designing of any scientific and general scheme for the development of the irrigation resources of a country, and enable the engineer, like the general in command of an army, to muster all his forces, look over and conceive at a glance the problem to be attacked, and decide upon the best mode for the utilization of all the resources at his command for the general good of the whole area to be served.

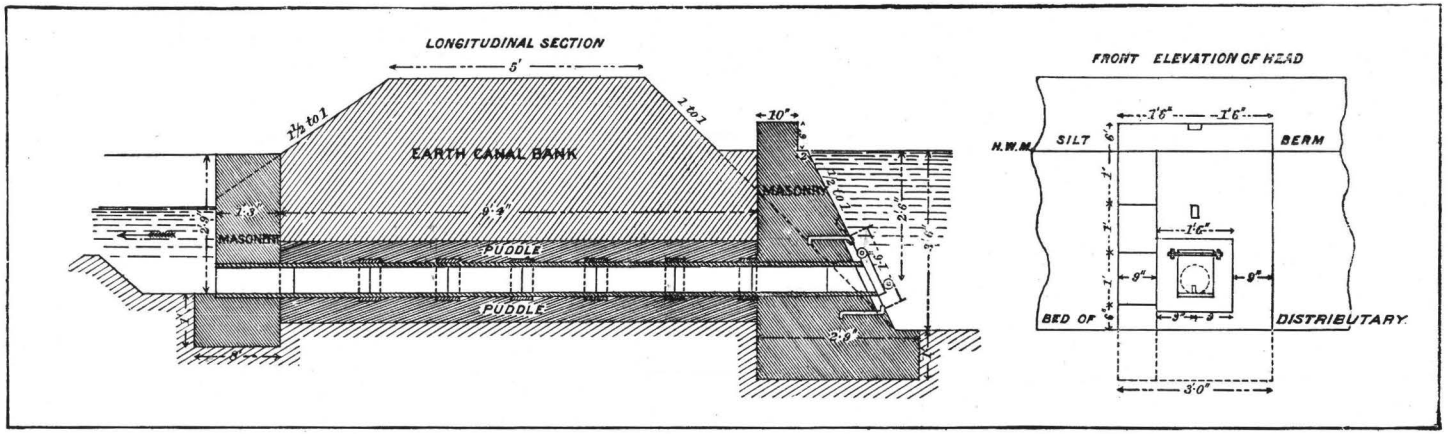
After the preliminary problems have been solved the more detailed considerations are investigated. In locating the dam site it is necessary, first, to have above it the largest possible basin or valley, with as low or flat a slope as is obtainable, in order that a maximum storage capacity may be had. The site should be so chosen that it shall require the shortest possible dam to close it and yet afford a sufficiently wide wasteway to discharge the maximum flood without injury to the dam. Finally, it must be so located that the geological formation shall be favorable. The dam must not be founded on a porous formation, and, if of earth, the material of the abutments and foundation must be of suitable quality to afford an impervious connection. If a masonry dam, it should be founded on solid rock. A study of the general geology of the neighborhood in order to ascertain whether the valley which is to be used as a storage site is an anticlinal or cynclinal valley, or one produced by simple erosion, is of great importance as indicating the dip of the rock underlying it and the possible value of the same as a nonconducting medium for the water stored in the valley. Material for the construction of whatever class of dam is decided upon must be convenient to the site in order to reduce to a minimum the cost of transportation and construction.

In studying a catchment basin the Indian engineer has recourse to a few simple formulas to assist in determining the flood discharge from the area under consideration, and as a check on the results obtained from local observation. The following are two of the formulas most used:

Ryves's formula, $D = C \sqrt[3]{M^2}$.

Dickens's formula, $D = C \sqrt[4]{M^3}$,

in which M represents the area of the catchment basin in square miles. C is a coefficient, depending for its value upon rainfall, soil, slope of ground forming the basin, etc. D is the resulting discharge usually shown in terms of cubic feet per second. It should be borne in mind, however, that no such formula can be strictly applicable with the same coefficient to areas of varying sizes, even in the same part of the coun-



STANDARD MASONRY OUTLET FOR DISTRIBUTARIES, PUNJAB.

try and under the influence of the same intensity of rainfall, unless the other circumstances, such as the slope of the ground, character of the soil, etc., be approximately similar. The chief difficulty will be found in the selection of a suitable coefficient, and a few of these for different districts in India, which correspond in general characteristics to the arid region of the United States, are here given:

In regions where maximum recorded rainfalls of from 3 to 6 inches in twenty-four hours have occurred, the coefficients for Dickens's formula, which have been settled upon, are about as follows:

Maximum rainfall 3·5 to 4 inches, in flat country, $C = 200$; mixed country, $C = 250$; hilly country, $C = 300$; and for a maximum rainfall of 6 inches C varies between 300 to 350, according to the nature of the country. The corresponding number of inches of drainage for a standard area of 5 square miles from these figures would vary, for the first group between 5 to 7·5 inches, and for the second group between 7·5 to 8·5 inches. For Ryves's formula the coefficient varies between 400 and 500, and for very hilly areas where the maximum rainfall is high it may reach as high as 650. The flood discharges are invariably proportionately less for large basins than for smaller ones.

A very interesting paper on this subject of maximum flood discharge from catchment areas was read by Mr. James Craig before the Institute of Civil Engineers in 1884.[1] The details of the argument entered into in this paper are too elaborate to be presented here. In general they are an amplification and discussion of results obtained from variously-shaped catchment basins, showing new methods of determining the loss of discharge other than those obtained by the two formulas given above.

In order to show the character of the detail connected with the various investigations and problems to be solved when the value of or necessity for the construction of the storage work is under consideration in India, attention will be called to a few of the questions which the Indian engineer is directed by his superiors to investigate. These points and others not included herein are laid down by Gen. Mullins, chief engineer of irrigation for the Madras government in India, for the guidance of engineers in that presidency.[2] The general circumstances of investigation are whether the valley or drainage area under consideration is partially occupied by tanks or is unoccupied. There will be some prima facie evidence available about particular sites or what the inhabitants suppose would be suitable sites. It may be desired to supply water to a definite area of new land to be irrigated or to land which had a previous supply which has been stopped by the silting up or destruction of existing tanks.

In the preliminary information the average rainfall of the country and its character are obtained from any records which may be in ex-

[1] Maximum flood discharge from catchment areas. Proceedings Institution Civil Engineers, vol. 80, part 2, 1884–5, London.

[2] Irrigation Manual, page 55. E. F. Spon, London, 1890.

istence. The irrigation duty of the drainage area in square miles or some other unit is discovered, and the quantity of water derivable from this unit of catchment area and the average rates of assessment for irrigable lands. The preliminary investigation includes, as before stated, a study of the atlas sheets of the survey of India and of the revenue survey maps, an examination in detail of the country in order to ascertain the most suitable reservoir sites, and an examination of the drainage lines thence downward. The grounds on which sites will usually be considered are that the valley shall have a moderate longitudinal slope, with moderate transverse slopes on either side of the axis of the valley, and must admit of a moderate length of dam with suitable abutments at either end, a probable moderate depth of water and corresponding height of dam, and suitable material for the formation of the dam, and possess facilities for the disposal of surplus, preferably by wasting over detached saddles through rock soil or subsoil. Land below the site must also be available for irrigation, and there should be an absence of much or valuable cultivation and of villages within the probable area of the water spread. Whether water storage may be obtained on financially advantageous terms will depend largely on the difference between the values of the land when irrigated and when not irrigated. In order to ascertain this difference in value it is necessary in India, as in America, to know what area a given quantity of water can irrigate, what that area will pay for the water, and what the storage and distribution of the water will cost.

In various discussions of storage capacity and water duty, hereafter to be entered into, the author will for convenience use the storage unit employed by the U. S. Geological Survey, 1 acre-foot. This is 43,560 cubic feet, or the quantity of water which will cover 1 acre in area to a depth of 1 foot. In dealing with large quantities of water, such as those stored in great reservoirs, it is inconvenient and troublesome to speak of capacities in millions or billions of cubic feet, and the much smaller figures which will be dealt with by using the acre-foot as the unit of measure make the subject-matter more intelligible. Likewise the area of land irrigable from a given amount of storage water can be more conveniently considered; that is, the duty of the storage water can be spoken of in more convenient terms if we refer to the duty performed per acre-foot. Thus, in portions of Colorado the duty of an acre-foot, providing the distance which the water has to be carried to the land is not so great as to cause excessive loss by absorption, may be stated as being $1\frac{1}{4}$ acre-feet per acre.

As an instance of the cost of storing water, the investigations of the Bombay engineers show that, in favorable cases where water has been stored in reservoirs of the first class, 56,700 cubic feet or about $1\frac{1}{3}$ acre-feet of water has been stored at an average cost of $1. The cost of the water, however, when served to the field will be considerably above this, as the loss due to evaporation and absorption in the reser-

voir during storage period and the loss due to the same causes in conveying the water through the canals to the fields to be irrigated must be included in the estimates. In this same locality in Bombay after considering these losses it appears that about 38,000 cubic feet of water can be stored at an average cost of $1.

RESERVOIRS.

Before entering into a description of the details of construction of various notable reservoirs employed in India for the storage of water for purposes of irrigation it will be well first to look at some of the financial results and general statistics relating to these works. In the following table, compiled from the irrigation revenue report for Bombay for the year 1888–'89, is given the principal data in connection with the chief reservoirs of that presidency, namely, Bhatgur and Lake Fife:

Reservoir works, Bombay.

	Bhatgur.	Lake Fife.
Area of catchment.....square miles..	128	196
Average annual rainfall.....inches..	145	31·5
Available contents.....acre-feet..	126, 500	75, 500
Surface area.....acres..	3, 584	3, 630
Area commanded .....do ...	307, 560	94, 087
Area irrigated .....do...	108, 600	55, 000
Height:		
Above foundation .....feet..	127	.....
Above river bed.....do...	106	97·8
Main canal.....miles..	103	88
Distributaries.....do...	108	70
Total cost	$3, 138, 000	$3, 306, 500
Area irrigated:		
Summer crop.....acres..	4, 210	7, 220
Autumn crop.....do...	14, 350	2, 545
Total.....	18, 560	9, 765
Percentage double cropped	.....	8·7
Discharge utilized.....second-feet..	134·8	156·4
Area irrigated, per second-foot of discharge utilized.....acres..	106·5	16·3

The following table gives some of the figures connected with the water supply of the irrigable land served by these two projects for the year 1889:

	Nira canals.	Mutha canals.
Rainfall on irrigable lands .....inches..	15·1	31 5
Duty, autumn (four months) .....acres..	106·5	60·5
Cost of water measurement per acre.....cents..	1·5	4
Loss of evaporation in tank.....feet..	.....	4·5
Maintenance cost per acre irrigated .....cents..	31·0	.....

The working expenses on the Nira canal for the year 1888–'89 were $69 per mile on the main canal, or 31 cents per acre irrigated. The returns realized were from plantations of trees on the canal banks, $231, and the water rate charged during the same year was 37 cents per acre irrigated, or $56 per second-foot of discharge at the canal head.

On the Mutha canal $960 were realized during the same year from the plantations maintained on the canal banks, while the water rate per acre irrigated was $3.91 or $260 per second-foot of discharge entering the canal head. As will be noticed, the water rate levied on the Mutha canals was very high relatively to that on the Nira, and also very high as compared with that charged on any other canal system in India. The cause of this was the great amount of sugar cane cultivated along the canal, a crop requiring a great amount of water to mature it.

In the following table are given some of the revenues derived from the cultivation of the various crops on the Nira and Mutha canals:

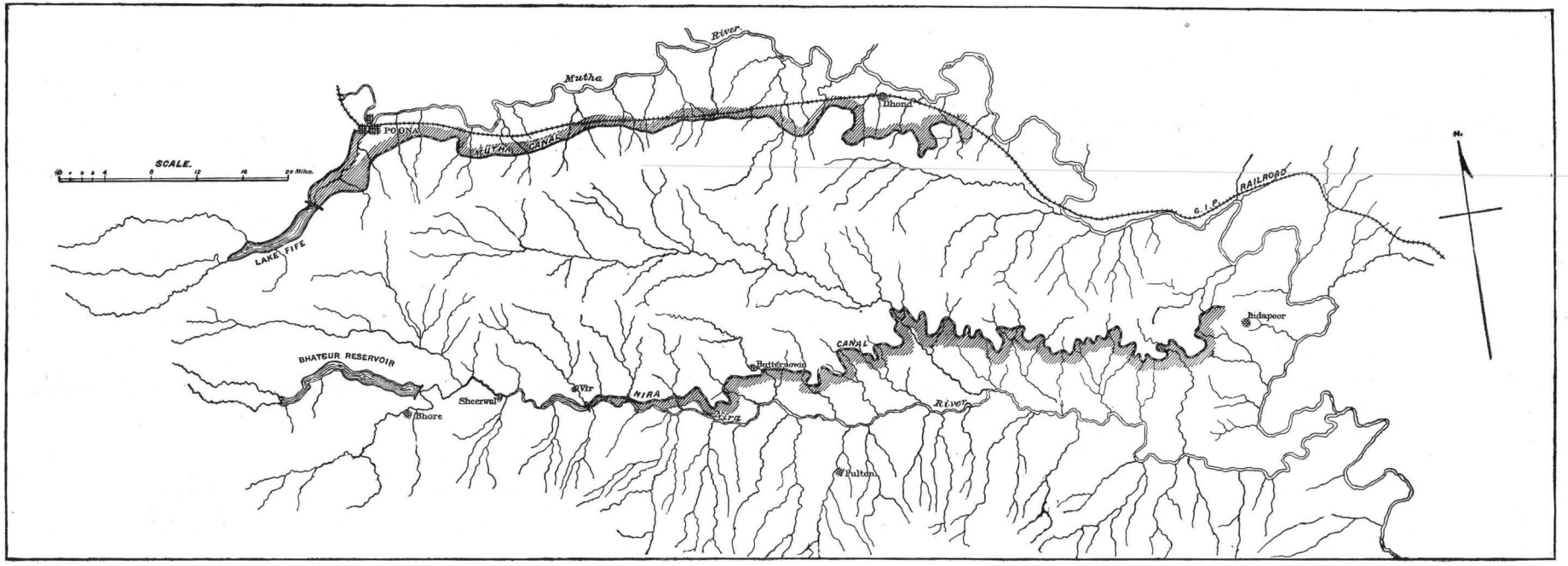
Crops.	Nira.		Mutha.	
	Acres.	Value.	Acres.	Value.
Wheat	3,190	$37,200	2,861	$17,800
Sugar	143	7,100	4,277	649,000
Jowar	10,320	86,000	854	5,300
Bajri	3,038	30,200	1,336	6,000
Beans	783	5,200	440	5,100
Total	17,474	165,700	9,768	683,200

MUTHA PROJECT.

The Mutha canal scheme was first proposed by Col. Fife, R. E., in 1863, with a view to irrigate a large district in the neighborhood of Poona and to furnish the water supply of that city and cantonment. The Mutha River, a tributary of the Bhima, rises in the Western Ghauts, 30 miles east of Poona. The rainfall on the Ghauts above Poona is seldom less than 200 inches per annum and has never been known to fail. Plans and estimates for the project were finally submitted in 1868 and in the latter part of that year the construction of the work was commenced.

The scheme comprises (Pl. CXXXIV) a large storage reservoir, Lake Fife, on the Mutha River, 10 miles west of Poona, with two canals, one on each bank of the river. It is the reserve storage supply from this reservoir which assures an unfailing flow of water in the canals, as the rainfall is always more than sufficient to fill the reservoir. The canal on the right bank is 99½ miles long, and is designed to discharge 412 second-feet at the head; however, its usual discharge is somewhat less, while if necessary it can be increased to as much as 535 second-feet. This canal passes through the town of Poona and commands 147,200 acres of land entirely within the dry zone of the Deccan, where the rainfall seldom exceeds 20 inches. In this area the variations in the rainfall and risks of drought are as great as the absolute rainfall is small. The left-bank canal is but 14½ miles in length and extends but a short distance beyond the town of Kirkee. It commands an area of 4,300 acres and the discharge at the head is 38 second-feet.

The reservoir is formed by a masonry dam founded on solid rock. This dam is constructed of uncoursed rubble masonry. Its total length



PLAN OF MUTHA AND NIRA IRRIGATION PROJECTS, BOMBAY.

is 5,136 feet, of which 1,453 feet are used as waste way. Its height above the river is 98 feet, while its maximum height above the foundation level is 108 feet. The crest of the waste way is 11 feet below the top of the dam, thus giving a maximum storage depth of 87 feet. The dam backs the water up the valley a distance of 14 miles. The available contents of the reservoir are 75,500 acre-feet, and the area of water surface exposed is 3,681 acres. In order to command a sufficient elevation the beds of the canals are taken off at an elevation of 59 feet above the river bed or bottom of the storage reservoir. Thus the available depth of storage is but 29 feet. The river above the reservoir has a catchment area of 196 square miles, over which the rainfall is so great that only one-sixth of the whole discharge of the river is used. The design of the dam is unquestionably crude. As at first constructed it was 14 feet wide on top, with straight slopes on either side of 2 on 1 downstream and 20 on 1 upstream. The dam soon showed signs of weakness, and to strengthen it a great bank of earth 60 feet wide on top and 30 feet high was piled up against its lower face. The line of the dam is built in several tangents, with changes of top width for each, according to the height of that portion of the dam, the points of juncture of the various tangents being backed up by heavy buttresses of masonry. The cost of this structure was about $1.75 per cubic yard, and its total cost was $630,000. While under construction a temporary wall of masonry was erected at some distance below the main dam in the river bed, which was built up to a height of 50 feet. The object of this was to form a temporary water cushion for the floods to fall on so that they should not undermine the main dam while the waste ways were being prepared.

The discharge of water from the reservoir into the right-bank canal is regulated by ten sluices, each 2 feet square. These sluices are closed by iron shutters and are operated by means of capstan and screw from the top of the dam. There are in addition eight circular sluices, each 2 feet 6 inches in diameter, which are 1·33 feet lower than the canal sluices and are designed to supply water to turbines for mill power. These latter discharge into the canal through the turbine chamber. Three sluices of a similar pattern to the canal sluices mentioned are at the opposite end of the dam, for the supply of the left bank of the canal.

The right-bank canal has a bottom width of 23 feet and depth of 8 feet, though its usual supply of water is about 5 feet. Its fall is 4 inches per mile to Poona, at which place there is a drop of 2·8 feet, which is utilized by means of an undershot water-wheel to drive pumping machinery for the supply of water to the town. The canal is carried through Poona in a tunnel excavated in rock. At the fifty-first mile the canal supplies Matoba tank, which is constructed as a relief work and commands an area of 8,550 acres of irrigable land.

The Mutha project was designed and has been operated as a productive work, and was constructed from borrowed capital. As originally

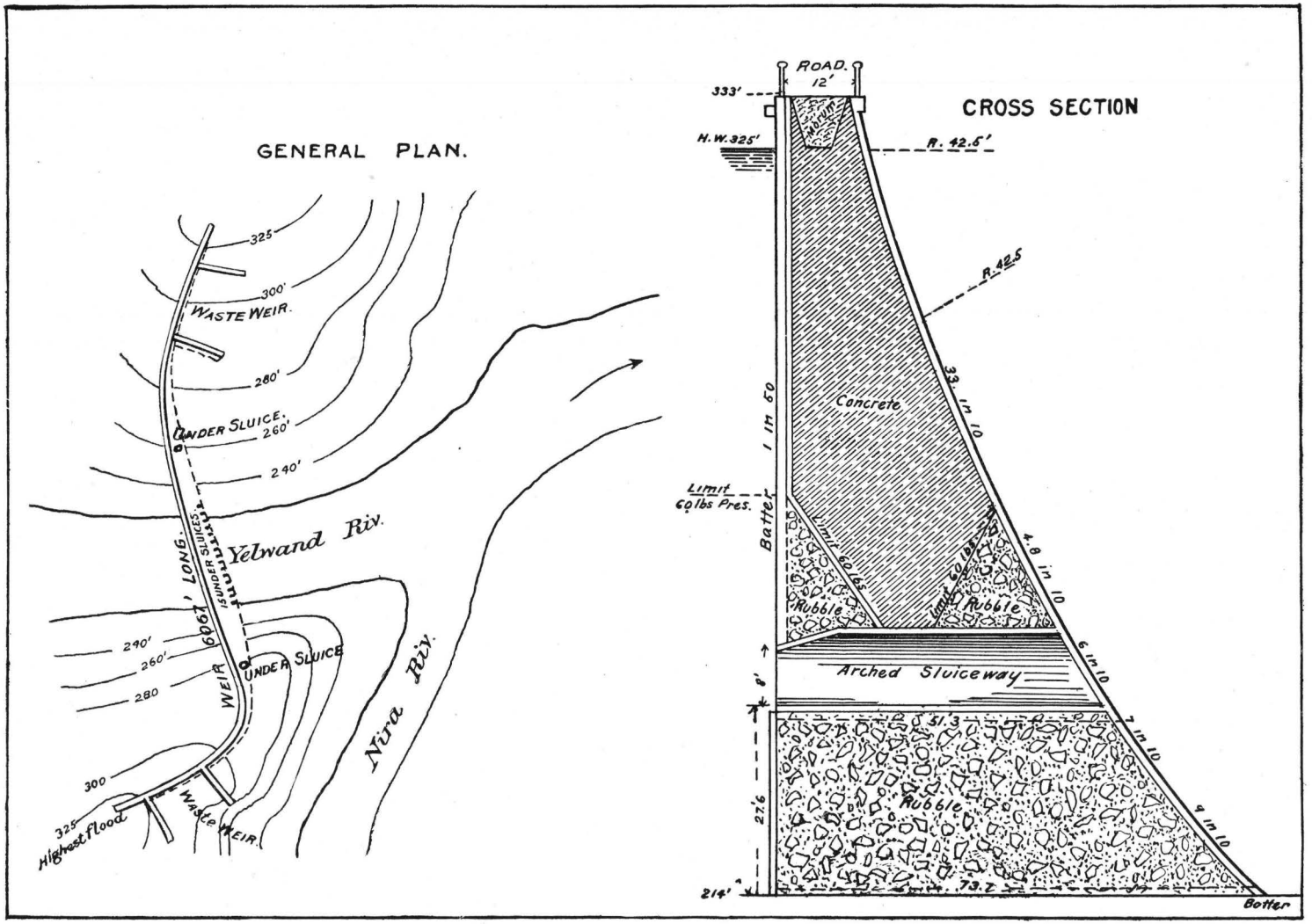
estimated for, the total cost of the work, including land compensation, was to have been $2,664,000. The estimated revenue, including the revenue from mill power and water supply to the city of Poona, was to have been $207,000, or 7·78 per cent on the capital outlay. The total cost of this work to the end of 1889 has been $2,082,000. The working expenses were, in the year 1889, $2.08 per acre irrigated; the gross revenue from irrigation was $37,000 and the total net revenue was $72,000, including the revenue from all other sources, or 3½ per cent interest on the capital invested.

NIRA PROJECT.

Bhatgur reservoir is located in the Presidency of Bombay, about 40 miles south of Poona, on the Yelwand River just above its junction with the Nira. The topography of the country thereabouts, in its physical characteristics, its climatology, and the appearance of its vegetation is very similar to that in northern Arizona in the neighborhood of Peach Springs or Hackberry. It consists of high mesas or table-lands, terminating in abrupt and nearly perpendicular rock slopes, and cut into by deep canyons, which open out rapidly onto broad bottom lands and valleys, leaving the mountain masses standing out boldly like the ruins of great old fortresses.

The frequent failure and the general uncertainty of rainfall in the portion of the Poona collectorate, through which the upper Nira River flows, caused Col. Fife to turn his attention to devising some means for supplying this district with water for irrigation. Surveys made under his direction in 1863 showed that the system of small tanks which had been generally considered applicable to this region was, financially speaking, impracticable, as the slopes of the smaller valleys are as high as from 30 to 50 feet per mile. The result of the detailed surveys then made was that these tanks at best afforded but a limited area of irrigation, while a tolerable site for a tank was almost invariably occupied by gardens irrigated from wells, thus rendering the land expensive.

Preliminary surveys for the Nira project were made in 1864, but were soon discontinued. They showed that the canal must commence near the town of Shirwal. In 1868 a committee was appointed to investigate this scheme further, and the result was that it reported the district to be drought-stricken, and said it would be advisable to have surveys made at once for the construction of a reservoir on the Nira River, with a canal from the same. Surveys were resumed in the same year under Lieut. Buckle, R. E. These were continued for some time, and were finally taken up by Mr. J. E. Whiting, C. E., under whose direction the project was finally constructed. Mr. Whiting's observations and surveys proceeded until 1871. They included the examination of several different sites and comprised detailed surveys not only of these sites, but of river-gauging and rainfall observations and the cross-sectioning of the valley along the canal line. The scheme as finally submitted, and as now constructed, consists of a reservoir on the Yelwand River and



BHATGUR DAM, NIRA SYSTEM, BOMBAY.

of a canal heading at Vir, on the Nira River, 19¼ miles below the reservoir site, the canal being 129 miles long and discharging 945 second-feet at the head. (Pl. CXXXIV.)

The catchment basin above the dam site has an area of 128 square miles, and the fall of the river bed within the reservoir limits is 5 feet per mile. The water in the reservoir is backed up the valley a distance of 15 miles, and its total capacity is 126,500 acre-feet. The dam is 4,067 feet in length, and is composed of the best uncoursed rubble masonry laid in hydraulic cement. It is 127 feet in height above its foundation and its crest is 8 feet above high-water mark. Its extreme bottom is 74 feet wide, and the top is 12 feet and is intended to be used as a roadway. The dam is designed on a modern cross section, by a formula very similar to M. Bouvier's. (Pl. CXXXV.) When full, the pressure on the toe is 5·8 tons per square foot, or 90·8 pounds per square inch, and when empty is 6·7 tons per square foot on the heel of the dam. The water supply is such that this reservoir can be filled eight times in the year. Accordingly, it is evident that there is an immense volume of water to be wasted. The alignment of the dam curves in an irregular manner across the valley, so as to follow the outcrop of rock on which it is founded. These foundations are excavated to a depth of 2 feet in the solid rock, which has required an excavation sometimes as deep as 30 feet in order to reach homogeneous material. The greatest flood over the dam may be 50,000 second-feet, and this is passed off by two waste-ways and twenty undersluices. The waste-ways are constructed at either end of the dam, in the body of the dam itself, and are arched over so that the roadway is continuous above them. Their total length is 810 feet, and the flood may pass 8 feet in depth through them. The northern waste-way, that on the left bank, consists of forty-five arches of 10 feet span each which can be closed by automatic falling gates. The waste-way at the south end consists of thirty-six arches, with the same dimensions and construction as the others. Jutting out from the main dam on the downstream side, in such a manner as to inclose these waste-ways, are constructed walls of masonry which guide the discharged flood water into separate channels, which carry it into the rivers below the main dam.

Of the undersluices, (Pl. CXXXVI), fifteen are constructed in the center of the dam at its deepest point and are placed 17 feet apart, each being 4 by 8 feet in dimensions, with their sills 60 feet below the high-water line. With this enormous head these undersluices will discharge 20,000 second-feet, which is an average maximum flood, and they have successfully withstood several years of flood without injury to the joints of the ashlar masonry with which they are lined. Under full head the velocity through these sluices is 36 feet per second. Above this row of fifteen undersluices, and near the surface slope of the valley, are two others of the same dimensions, one 2 feet above the main row and the other 50 feet above the main row. These sluices are constructed, as

are the main sluices, with a lining of the best ashlar masonry, with pointed joints. They are closed by iron gates, which slide vertically. These gates weigh 2 tons each, and are operated by steel screws worked from above by a female capstan-screw operated by hand levers. The gates are protected from injury by floating objects by means of stout gratings of wood on the upstream entrance. There is 30 feet of idle space below the undersluices, and this is expected to fill up with silt.

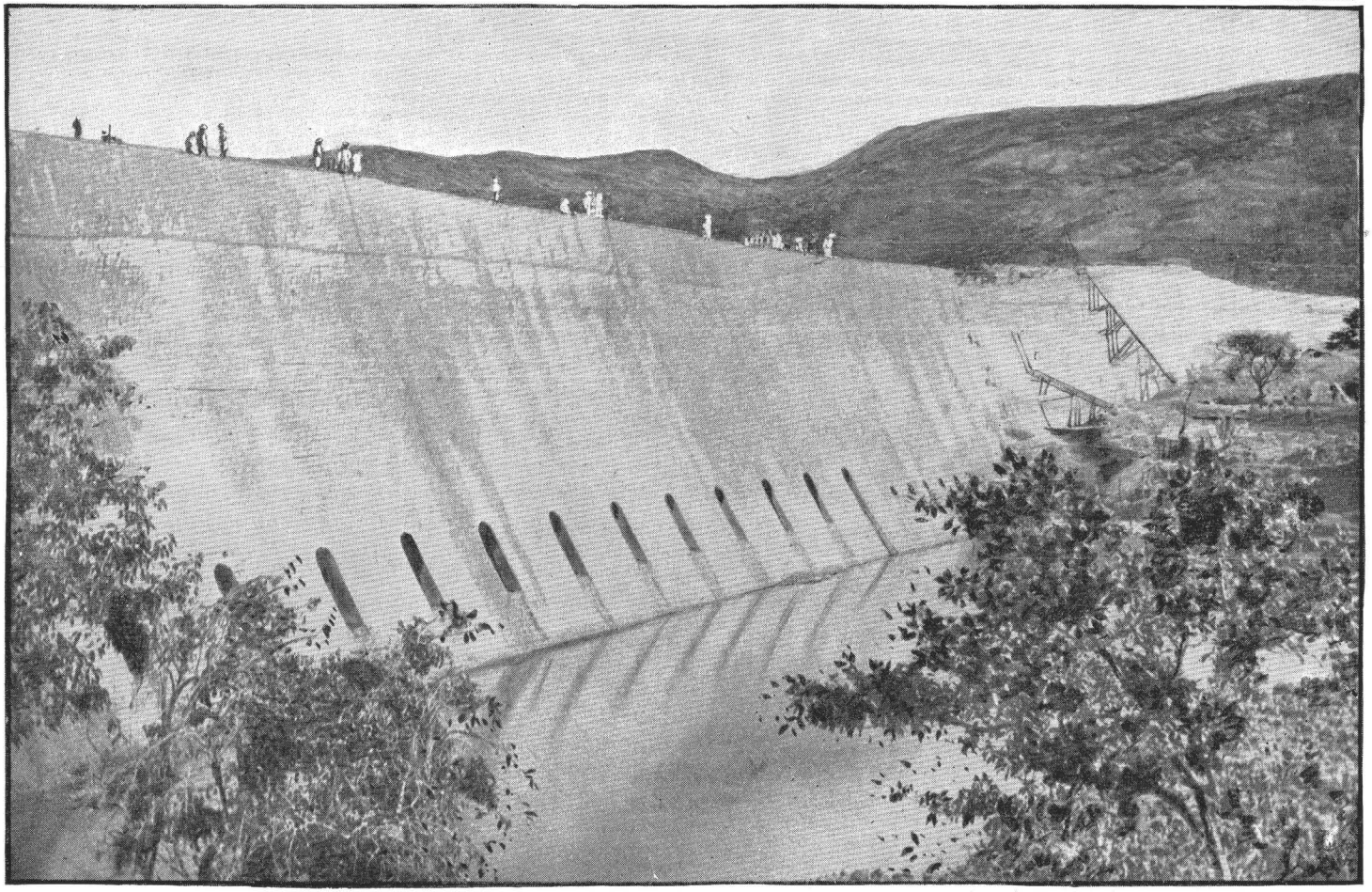
The object of these sluices is primarily to discharge the water of the reservoir, which then flows for nearly 20 miles down the Nira River to the diversion or pickup weir at Vir, which turns it into the head of the Nira canal. Fewer sluices would have accomplished this end, but additional ones were constructed with the object of keeping the reservoir above them free from sediment. This can be accomplished only by leaving the sluices open when much sediment is carried in suspension, and it is very doubtful if they would clean the reservoir of silt if it were once permitted to fill up.

Mr. A. Hill, superintending engineer, says of the scouring effect of these sluices:

> Scouring sluices have little effect unless the area of the openings is great compared to the area of the floods. To remove silt already deposited they are useless, as has been proven by the manner in which they have silted up at Lake Fife and at Vir and other places where their area is small compared with that of the area of the floods. At Bhatgur they are intended not to remove silt deposited already, but to prevent its deposit by carrying it off while in suspension. If the dam is high and the discharge of the undersluices will keep the flood level below the full supply level, then they will be efficient. If the dam is low and the sluices will not keep the flood level below full supply level, they will have little effect.

Experience on the Betwa reservoir and elsewhere bears out these conclusions, with the addition that their scouring or preventive effect is felt a very few feet to either side of the sluices, and silt will deposit close to their entrance. In other words, they do little more than keep an open channel above them.

The automatic sluice gates which are to be used on the wasteway of this dam are peculiar, and are well worth describing. They are patented by Mr. E. K. Reinold, their inventor, and their object is, that when the flood reaches its maximum height, 8 feet below the crest of the dam, the gate shall be entirely open, and as the flood subsides the gate shall automatically rise until it is entirely closed, thus adding to the reservoir capacity by the depth of the wasteweir. The gates are 8 by 10 feet, and they thus increase the depth of this reservoir by 8 feet. Where water is valuable such an expedient may be of the greatest financial importance. As yet, none of these gates have been in actual operation on any great work, but the writer saw a large model in successful operation, and it was considered so satisfactory by the Government that they were willing to introduce it on this work.



BHATGUR DAM, NIRA SYSTEM, BOMBAY.

The gate has two contact surfaces, one on the standard face against which it presses and one on the face of the gate. These surfaces slide parallel to each other and are the surfaces of inclined planes. The gate rests on wheels running on rails and the axes of these wheels are

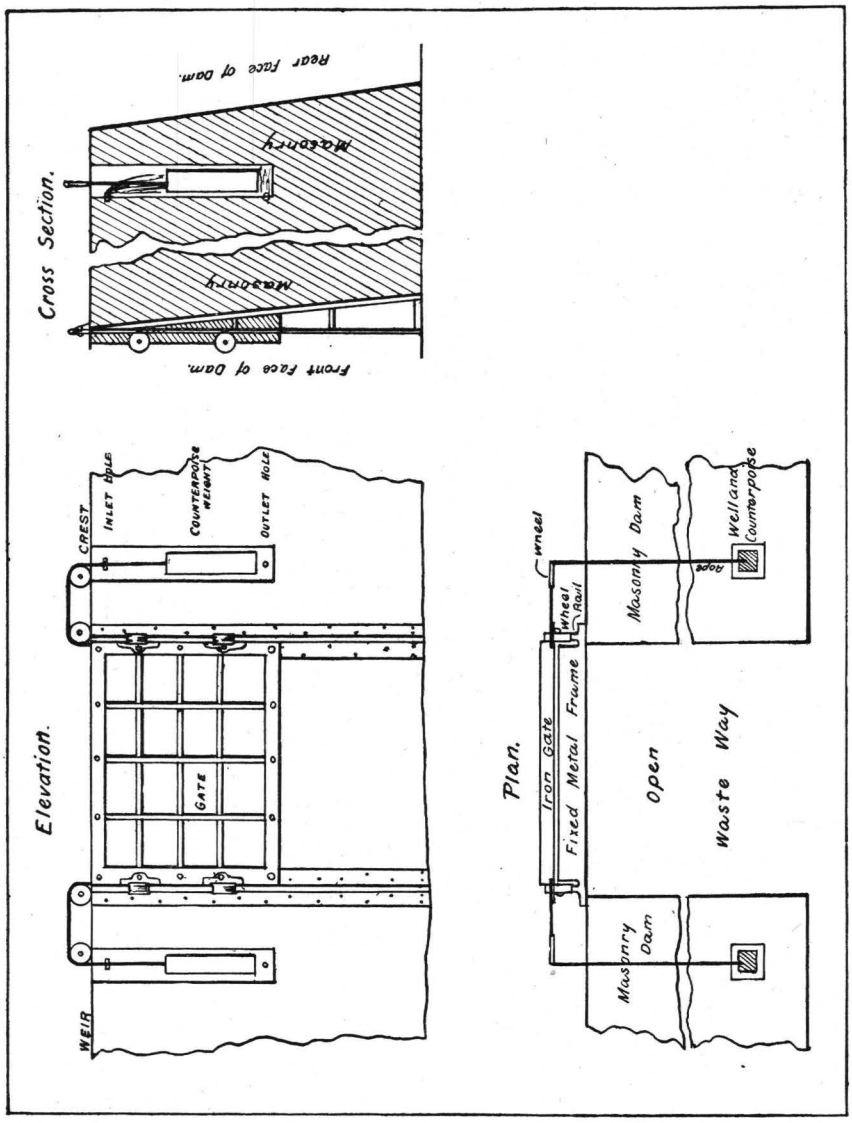


FIG. 251.—Diagram of Reinold's automatic weir gate.

parallel to the line of rails and at a slight angle to the contact planes, so that the latter do not touch until the gate is fully raised or closed, thus permitting by leakage a large amount of the flood water to run out of them until the last moment. The accompanying illustration (Fig. 251) explains the operation of the gate. It is automatically ope-

rated by means of counterpoises balanced in water cisterns, the weight of which exceeds the weight of the gate by a little more than the amount of the friction, and they act by displacing their volume in water in the cisterns in which they plunge, thus lessening their weight by that of this volume of water. As the water flows over the top it flows simultaneously into the cast-iron boxes in which the counterweights hang through inlets placed on a level with the gate top. This water entering the cisterns reduces the weight of the counterpoises, and the gate then being the heavier sinks, opening the waste-way. When the water ceases to enter the boxes, owing to its having fallen below the level of the inlets, it soon runs out from holes at the bottom and the counterweights then become heavier than the gate and lift the latter. Giving the proper weight to these counterpoises is one of the important details of the apparatus.

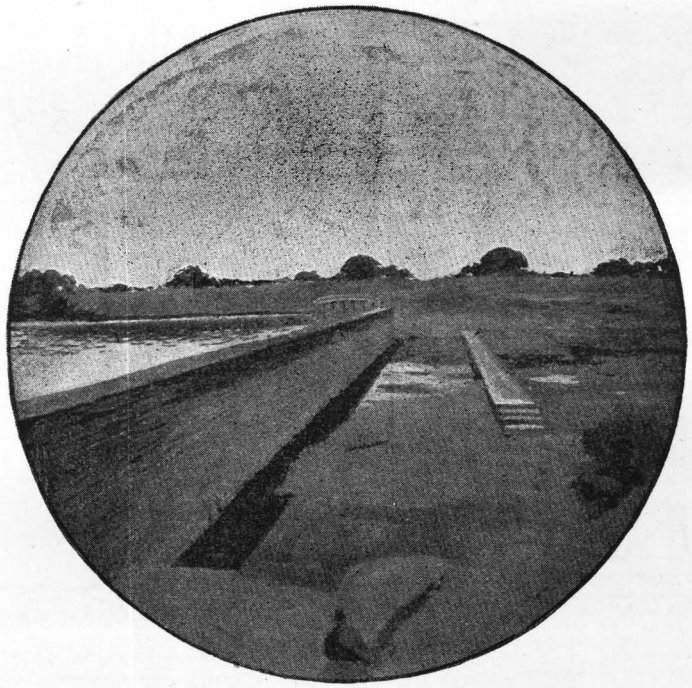


FIG. 252.—Vir headworks, Nira system, Bombay.

The Nira canal heads at Vir, 19¼ miles below the reservoir (Fig. 252.) The river bed between these two points being of a rocky character, little or no loss from absorption takes place. The pick-up or diversion weir is constructed across the Nira River at its junction with the river Vir, and it crosses both of these streams and the point of land between them (Fig. 253). The total length of the weir is 2,340 feet, and its greatest height above the foundation is 43½ feet. The dam is constructed of uncoursed rubble masonry and is 9 feet wide on top (Fig. 254). The rear slopes are

8 feet on 1 for 20 feet, and 6 on 1 for the remainder or lower part. The upstream face has a uniform batter of 20 on 1. At no place is the mean thickness less than half the weight of the dam. The main weir consists of two straight portions connected by a curved wall over which the water will not flow. This wall extends through the point of land connecting the two rivers, and a channel 126 feet in width is excavated below it connecting the rivers. The weir is founded on solid rock throughout, but to form a water cushion and break the force of the great flood which

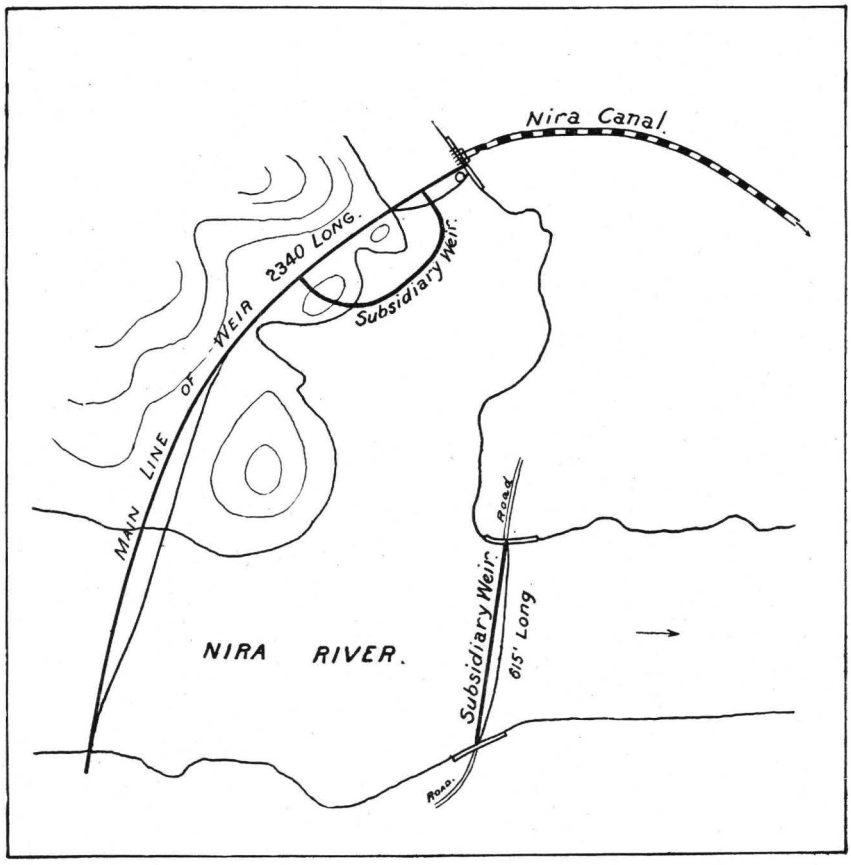


FIG. 253.—Plan of headworks, Nira Canal, Vir.

passes over it, a subsidiary weir situated 2,800 feet below the main weir is provided. The total length of this subsidiary weir is 615 feet, and it is 24½ feet high, with its crest 20 feet lower than that of the main weir. It thus forms a permanent water cushion 20 feet deep below the main weir. Like the main weir, this subsidiary weir is constructed of the best uncoursed rubble masonry, and has a roadway on top. During a maximum flood it is estimated that the cushion will be 32 feet deep when the overfall will be only 8 feet.

The catchment basin above this diversion weir is 700 square miles and the greatest flood estimated to pass over it is 158,000 second-feet,

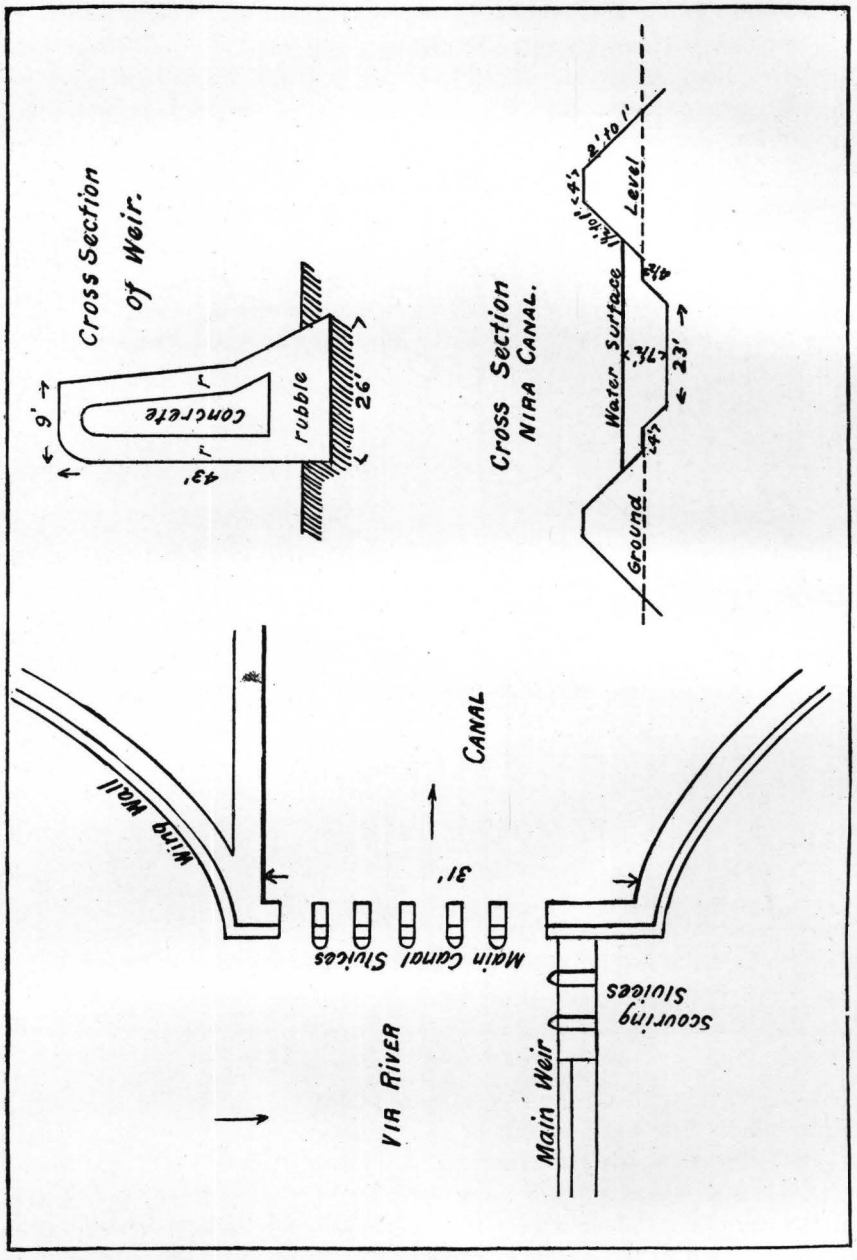
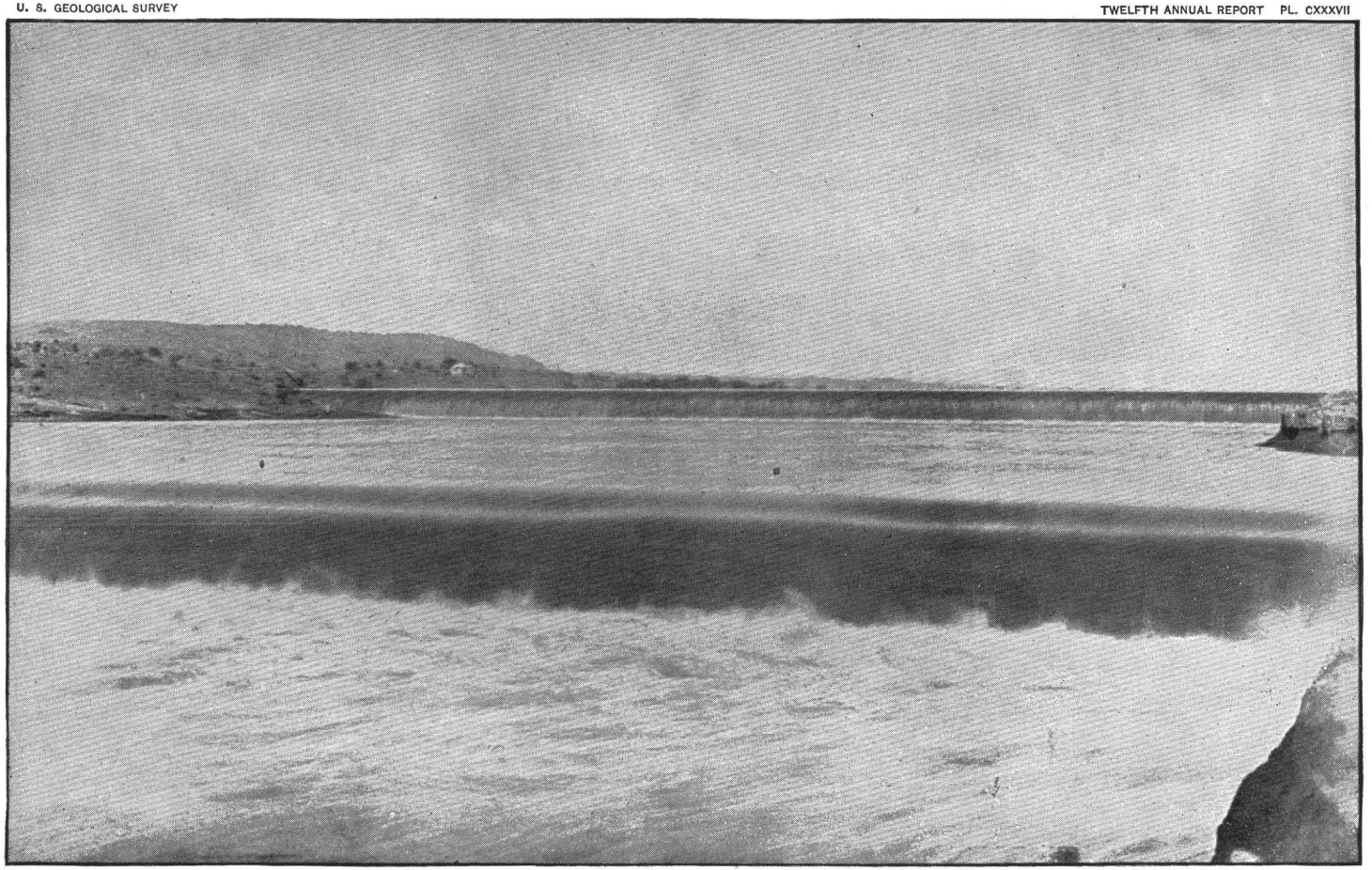


FIG. 254.—Plan of regulator head and cross-section weir and canal banks, Nira Canal.

corresponding to a run off of nearly half an inch per hour. The greatest flood which has occurred rose 8 feet over the crest of the main weir and



MAIN AND SUBSIDIARY WEIRS, NIRA SYSTEM, VIR, IN GREAT FLOOD.

13 feet in depth over that of the subsidiary weir (Pl. CXXXVII). The main weir backs the water up the Nira River a distance of 12 miles to Shirwal and impounds about 1,400 acre-feet, or sufficient to afford a reserve supply for the canal for a few days. It is expected, however, that this basin will silt up in the course of time. The canal heads from the left bank of the river at right angles to the river Vir (Fig. 253), and in a portion of the weir just below this head it has been found necessary to construct a second subsidiary weir of trifling dimensions which catches the direct flood from the Vir on a water cushion (Fig 252).

The canal after leaving the head gates makes a long sweep through a low ridge, curving until it is parallel to the river. In the cut through

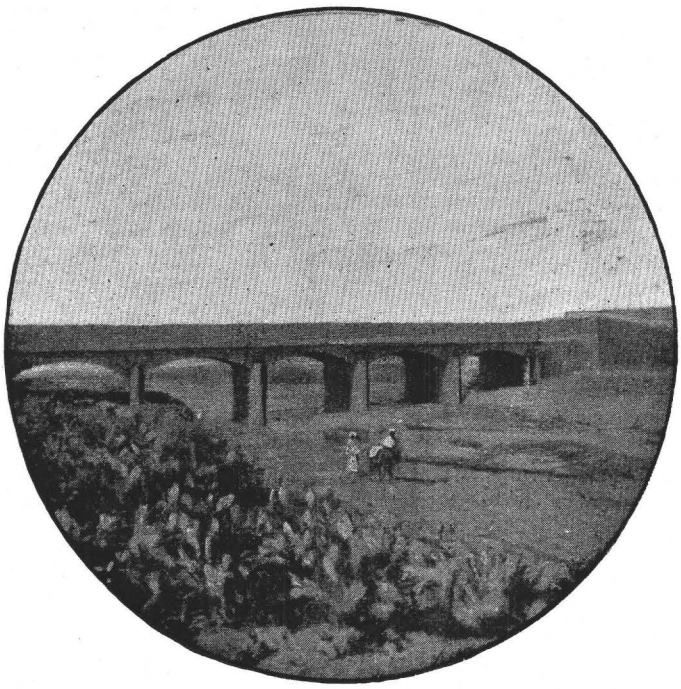


FIG. 255.—Kurra aqueduct, Nira Canal.

this ridge, which is 400 feet in length, the average depth of excavation is 50 feet. The velocity in the canal averages 1·8 feet per second. The regulating sluices (Fig. 254) at the canal head are 7 in number each 4 feet wide and have an available head of 9 inches. In the weir adjacent to the head regulators are a set of two scouring sluices which have not a sufficient area to remove silt which may deposit, but which act as all other scouring sluices in keeping open a clear channel past the head of the canal. At its head the bottom width of the canal is 23 feet, the depth of water 7½ feet, and the discharge ordinarily 470 second-feet, while the fall is 6 inches per mile. As at present constructed the main canal is 103 miles long and controls an irrigable area of 300 square

miles. There have been constructed 175 miles of distributaries commanding a portion of this area. The slope of the canal increases to 3 feet in a mile in rock cuts with a corresponding cross sectional area. In earth where the canal cross section is small the greatest fall is 18 inches in a mile. Accompanying (Fig. 254) is given a cross section of the canal showing the way in which the bermes and banks are formed.

Numerous cross drainages are passed in the line of the canal, the largest works being aqueducts over the Kurra River and the Wargaon and a superpassage over the Jewhar torrent. The Kurra aqueduct (Fig. 255) consists of 20 arches of 30 feet span each. The discharge of the

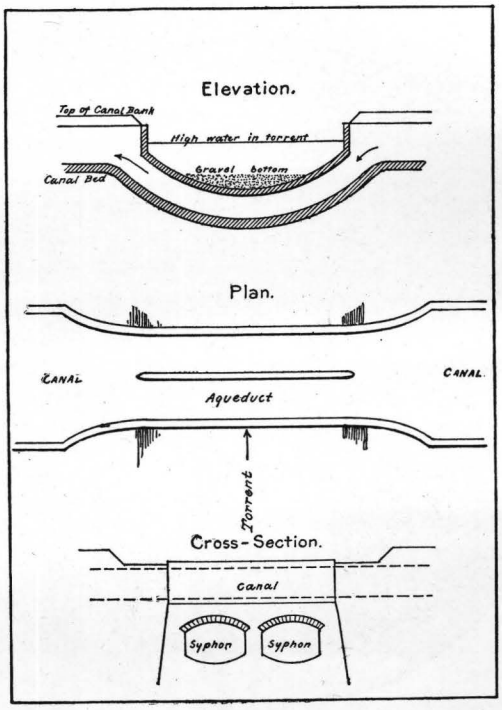


FIG. 256.—Nira Canal, siphon superpassage.

river is estimated to touch the crowns of the arches at a velocity of 9 feet per second through them. The superpassage for the Jewhar torrent is novel (Fig. 256) and has an advantage over weirs, as the silting of the canal is avoided. This structure differs from an ordinary superpassage in being in solid rock, thus acting as a weir; also in the canal being carried under without any great drop or fall. The canal clears the arching to avoid loss of velocity; in this it differs from siphons. There is extra velocity and consequent narrowing of the water way. Regarding the aqueducts, it may be observed that, like the superpassages, the object has been to make them as narrow as possible without sacrificing too much fall, and the narrowed channel is smoothly paved and grouted.

It is estimated that the acceleration along this steep incline, together with the original velocity of approach, gives the requisite speed before the water enters the aqueduct. An inclination is given along the aqueduct sufficient to maintain this velocity and carry the water across, but directly the passage is cleared the canal is gradually widened and gets its regular fall per mile.

The total outlay on the Nira project to the end of the year 1888 was as follows:

Canals, distributaries, etc	$526,000
Bhatgur reservoir (uncompleted)	355,000
Twenty-three sluice gates and the subsidiary weir	32,000
Canal headworks at Vir	125,000
Nineteen aqueducts	140,000
Two siphon superpassages	22,000
Seventy-five small weirs	92,000
Hydrants, turbines, etc	40,000
Compensation for land	116,000
Total	1,428,000

In the same year the working expenses on this canal amounted to 31 cents per acre irrigated. The gross receipts from all sources amounted to $3,600, being a net deficit in the revenue of $2,600, which sum is chargeable to the protection of the country against famine.

BETWA PROJECT.

The first proposal for the construction of a canal from the Betwa River was made by Maj. Gen. Strachey in November, 1855. The question was again considered after the mutiny in 1859, but nothing was done until 1867, when Lieut. Home, R. E., was directed to conduct the inquiry.

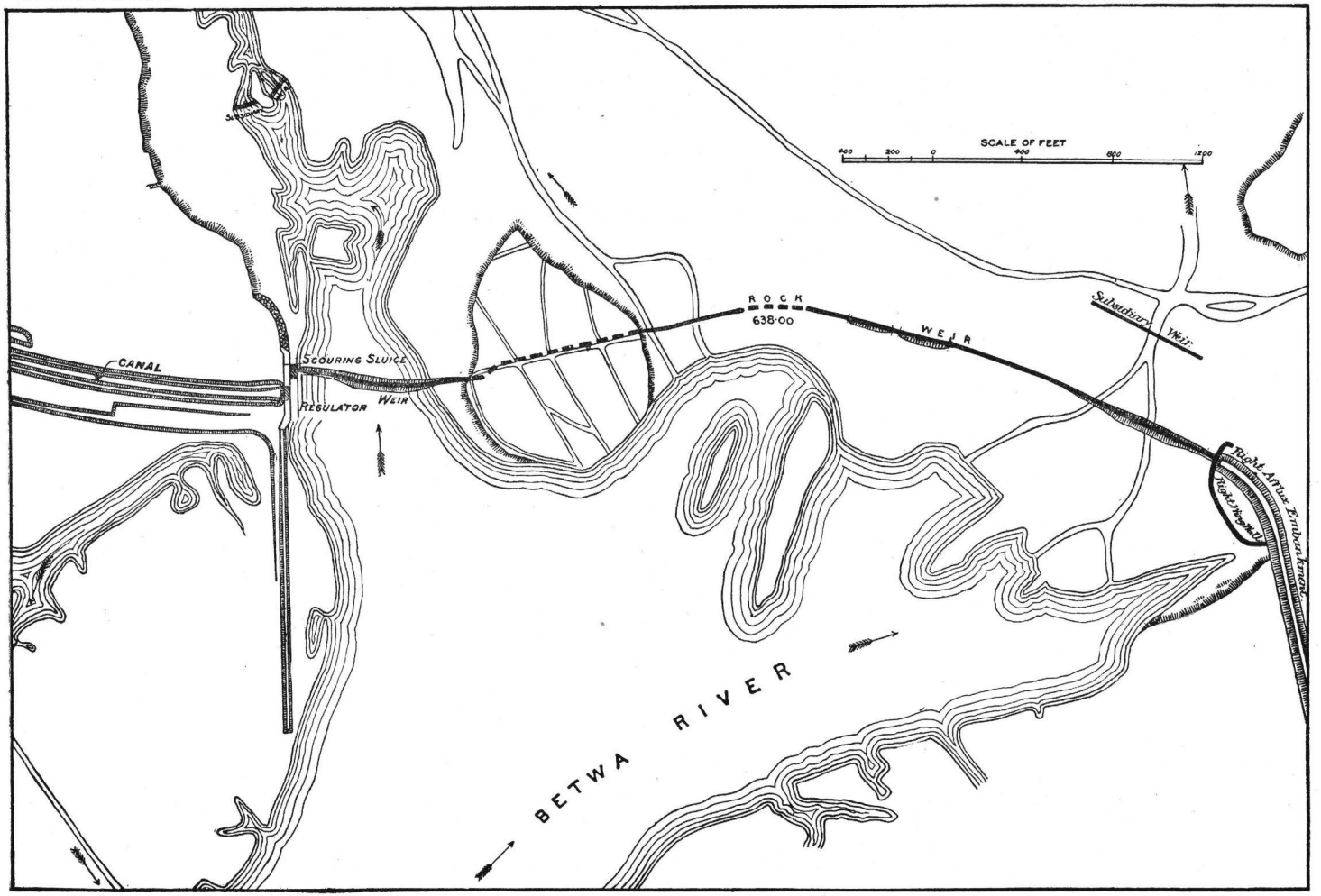
Lieut. Home made examinations in 1867 and 1868 and submitted a preliminary report which showed that it was practicable to utilize the waters of the Betwa River for irrigating a tract in Bundelcund, in the Northwest provinces, lying between the rivers Jumna, Pahuj, and Betwa, whereupon more complete investigations were ordered. The examination was continued by Lieut. Bagge and estimates submitted. Further examinations were made later, in 1869, by Mr. Anderson, under the general direction of Col. Greathed, chief engineer, and the conclusions arrived at by him were that Parichi was the best position for a diversion weir; that for four or five months of the year 1,000 second-feet could be depended on even during years of minimum rainfall, but that final further examination was advisable. In November of the same year Lieut. Bagge submitted a detailed project and estimate of the Betwa Canal, including a provision for water storage. The estimates were so high that the project was shelved, especially as there was no prospect of the enterprise realizing more than from 3½ to 4 per cent interest on the expenditure. Finally in November, 1873, the Government sanctioned the estimates restricting the canal to wet-weather irrigation without provision for navigation and without being supplemented by storage.

The works of the canal were designed and carried out under these general plans, but were afterwards modified so as to include a storage reservoir and irragation throughout the year. Various sites were chosen and discussed for the location of the storage works, that at Khoord being the most favorably considered for some time, but finally Parichi, a site previously decided upon for the diversion weir, was accepted as the best location.

The area covered by the Betwa canal system is about 1,500 square miles. The surface formation of the bench land covered is very peculiar. The highlands border on the valleys of the Pahuj and Betwa rivers, while the lowlands occupy the central part, being drained by two seperate channels which unite as they approach the River Jumna. Owing to the irregularity of the rainfall and the excessive fertility of the soil on this area of land, it is difficult to make a canal project remunerative without supplementing its perennial discharge with storage water, since during the ordinary season of the year, when the river flows an abundant stream of water, the rainfall on the irrigated area is sufficient for most of the needs of the agriculturist. The site chosen for the diversion weir is an excellent one, the unusual width of the river bed at this point affording an ample waste way for the great floods which may be expected during certain periods. It was necessary to design the storage dam as an overfall weir throughout its entire length, as the maximum flood to be discharged amounts to 750,000 second-feet. A rocky barrier or ledge runs across the bed of the river at this point and forms an excellent foundation for the weir. The river has a straight run between good stiff banks, and there is a plentiful supply of good building stone in the neighborhood.

For the first 20 miles the canal runs in a direct line, and is in an excavation varying in depth from 5 to 40 feet. This portion of the line is fortunately in earth and may be considered as purely diversion line, being too deep for purposes of flow irrigation. The first 6 miles of the canal are protected by a drainage channel parallel to it, which catches the discharge from the various small streams crossing it at right angles to the direction of the canal. Through this first portion of its length the cross section of the canal is 20 feet at the bottom with a depth of 12 feet of water. The first 3 miles below the head are revetted both on the banks and the bed of the canal. This revetment consists of a paving of loose stones carefully laid by hand. No silting of any importance takes place in the canal, as the water is admitted to it only during the season of moderate discharge in the river, and as it is taken from the storage reservoir most of the sediment has been previously deposited. The growth of weeds, however, is rather excessive, owing to the low slope of the canal, and the latter is periodically closed in order that the weeds may be cleared by hand.

One of the principal branches, the Hamirpur branch, is designed with a bottom width of 15 feet for the first 30 miles, and a depth of water



BETWA PROJECT. PLAN OF DAM AND HEADWORKS.

at head of 6 feet, its slope being 1 in 3,000, which gives a velocity of $1\frac{3}{4}$ feet per second, and a discharge of 340 second-feet. From this point on the branch diminishes gradually in dimensions and carrying capacity, the slope being continually altered so as to give an average velocity throughout of about 3 feet per second. Another main branch, called the Kathund branch, has a bed of 30 feet and a depth of 6 feet, and is designed to carry 500 second-feet of water.[1]

The local drainage met in the first few miles is disposed of by means of a parallel drainage canal having an inlet into the canal, and by another channel near the canal head discharging into the Betwa River. There are two drainage siphons, one in the seventeenth mile and one on the Hamipur branch. The siphon on the main canal will discharge 1,300 second-feet and is provided with five vents of 30 square feet, which head the water up $1\frac{1}{4}$ feet and discharge it with a velocity of $8\frac{1}{2}$ feet per second. The falls along the lines of the canal and the bridges are of the usual pattern described elsewhere.

The minimum discharge of the river may be taken as about 50 second-feet, while the maximum discharge may be as great as 750,000 second-feet. The average rainfall over the irrigated lands is 35 inches. The gross area of land commanded is 523,000 acres and the culturable area is 348,000 acres, while the area irrigable is 150,000 acres. The expenditure on the works, including all charges to the year 1888, was $1,400,000. These works include 19 miles of main canal, 163 miles of branch canals, and 380 miles of distributaries. The duty performed in 1887 during the fall crop was 67 acres per second-foot of the discharge at the head, or 76 acres per second-foot of the discharge utilized. The principal crops raised were wheat and barley, with a small amount of pulses, indigo, and opium.

The weir alignment has been skilfully located so as to make the most of the rocky barrier which crosses the river at the point where it is constructed. (Pl. CXXXVIII.) The weir is placed on the ridge of this reef, which curves away from the left flank and is convex upstream, so that the water will be thrown toward the middle of the channel. The height of the weir above the river bed varies between 0·4 of a foot and 60 feet, except on the left bank, where the rock was higher than the sill and had to be cut down. The total length between the steps on either protected bank is 3,296 feet and it is calculated to produce an afflux in extreme flood of 6·5. The cross section of the weir as at first proposed is a trapezoid with sides of equal slope, viz, 10 horizontal to $25\frac{1}{2}$ vertical, the top width being $10\frac{1}{2}$ feet. The chief engineer, Col. Greathed, did not approve of this cross section, but decided that the downstream face of the weir should be nearly vertical in order that a 6-inch film of water passing over the weir would fall clear of the toe, and in order to increase the stability of the weir it has been extended up

[1] The Betwa Canal project in the Northwest Provinces, Records of the Government of India, Calcutta, 1877.

stream somewhat. The up-stream edge has been rounded in order that driftwood may pass over without obstruction and injury to the masonry, and a curve has been given to the up-stream face, instead of a batter, in order to facilitate the passage of water and drift.

The accompanying section of the weir (Fig. 257) is for the highest part. Fifteen feet has been adopted as a convenient and uniform width for the top, which is coped with ashlar 18 inches thick, the upper blocks being not less than 15 inches wide and weighing about 1 ton each. The body of the weir is built of rubble masonry coursed on both faces, the minimum dimensions of the stones being 9 inches long, 8 inches wide, and 6 inches high, with a due proportion of bond stones. The ashlar is set in Portland cement and the rubble in native hydraulic-

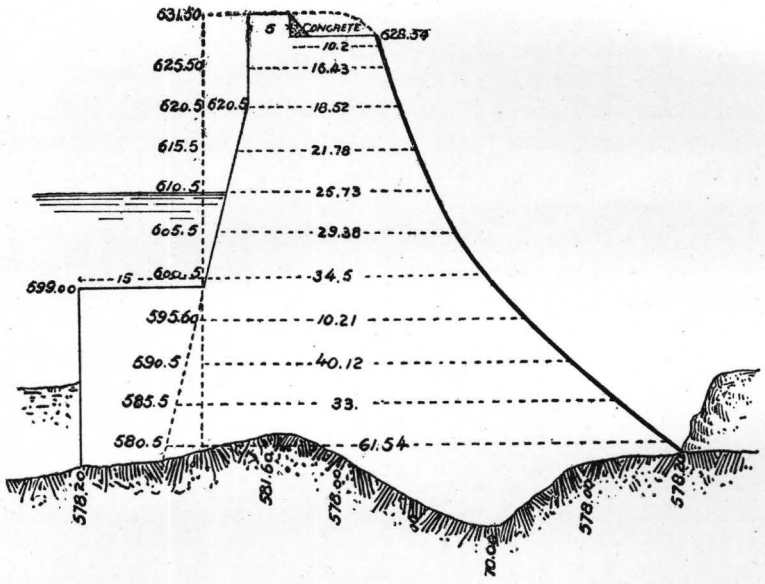
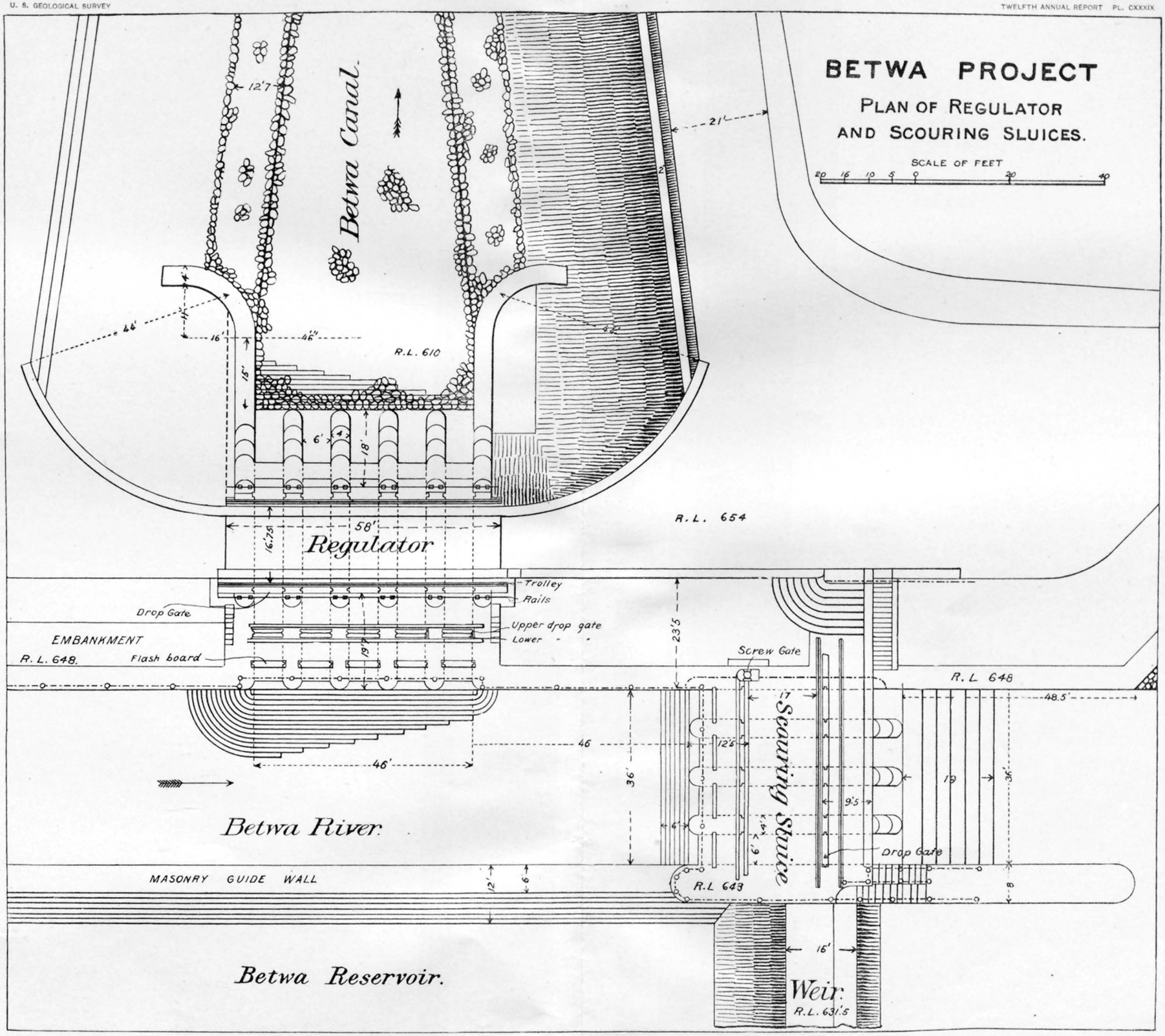


FIG. 257.—Cross-section of Betwa weir.

lime cement. The body of the weir appears to be unnecessarily thick and heavy, especially is this true of the great block of masonry which is placed at the toe. The cross section, however, was considered by the engineers to be necessary, owing to the steepness of the slope of the river and the magnitude of the floods which it discharges.

As shown by the accompanying plan of the river and of the weir crossing it (Pl. CXXXVIII), the latter is constructed in 3 different lengths, separated by a large island, on which it abuts in one place and by a rock which projects above the surface of the water in another place. The deepest portion of the channel is adjacent to the left bank, and the greatest height of the weir at this point, including foundations, is somewhat over 60 feet. At the toe of the weir on the down-stream slope is built out a great block of masonry from 15 to 16 feet in width,


BETWA PROJECT
PLAN OF REGULATOR
AND SCOURING SLUICES.
SCALE OF FEET
20 15 10 5 0 20 40
Betwa Canal.
12'7"
21'
2'
44'
16'
16"
R.L. 610
15'
6'
18'
58'
16'.75
Regulator
R.L. 654
Trolley
Rails
Drop Gate
Upper drop gate
Lower
EMBANKMENT
R. L. 648.
Flash board
19'
23'5
Screw Gate
R. L 648
48.5'
17
46
46'
12'6
36'
Scouring Sluice
19
36'
9'5
6'
6'
6'
Drop Gate
Betwa River.
MASONRY GUIDE WALL
12'
6'
R.L 643
8
16'
Weir.
R.L. 631'5
Betwa Reservoir.

which is intended to receive a portion of the jar caused by the impact of the flood water passing over the weir. Adjacent to the left bank a row of undersluices, 4 in number, are constructed in the weir itself, the object of which is to give a scour past the canal head, thus keeping the latter free of silt. The canal itself heads just above these undersluices, the regulator consisting of 5 openings, arranged with a double tier of gates, one above the other, in such manner that either the upper or lower series may be used at will according to the depth of water in the reservoir.

Below the portion of the weir across the main channel is constructed a subsidiary weir at a distance of perhaps 1,400 feet, the object of which is to back the water up against the main weir, thus producing a water-cushion on which the floods shall fall. The extreme height of this subsidiary weir is about 18 feet and the height of overfall from the main weir to the water-cushion formed by it is $21\frac{1}{2}$ feet, though in time of flood this will be reduced to 8 feet. The top width of the subsidiary weir is 12 feet and its walls are nearly vertical on the down-stream side with a slope of about 10 on 1 up stream. The main body of the weir between the island and the narrow right-bank channel is very low and the overfall is on to a solid rock bed. It was accordingly not necessary to construct a subsidiary weir below this portion of the weir, but across the right-bank channel, where the height of the weir nearly approaches that at the extreme left bank, a secondary subsidiary weir has been constructed at a distance of about 200 feet below the main weir, and with the same object and same crest level as the subsidiary weir just described.

The available net storage depth of the reservoir is $21\frac{1}{2}$ feet, and its capacity above the canal bed is 36,800 acre-feet, though it has been found that the lower 6 feet of depth is of little service, as the head above is not sufficient to force the water into the canal with sufficient freedom to make it practically available.

The undersluices which are constructed in the main body of the weir opposite the canal head are placed at right angles with the face of the canal-regulator in order to give sufficient scour along the canal head to prevent the deposit of silt. The height of the face wall is given a margin of 6 feet above the calculated afflux level. The undersluices consist of 4 vents, the bottoms of which are on a level with the sill of the canal and are each $16\frac{1}{2}$ by $16\frac{2}{3}$ feet in dimensions. The piers of the undersluices are 5 feet thick in order to support the great superincumbent weight of masonry. The abutments, piers, arches, cut-waters, etc., are of ashlar, the rest of the work being of rubble masonry, the up-stream face being pointed with Portland cement. A peculiar curve is given to the upper face of the piers between the sluice-vents forming a venar-contractor in such manner as to pass the water with the least friction through the sluice-ways. The sluices are each closed by a series of two plain drop gates, the up-stream set of gates being oper-

ated by a screw by means of hand levers from above, the lower openings being closed by slash boards let into grooves in the piers.

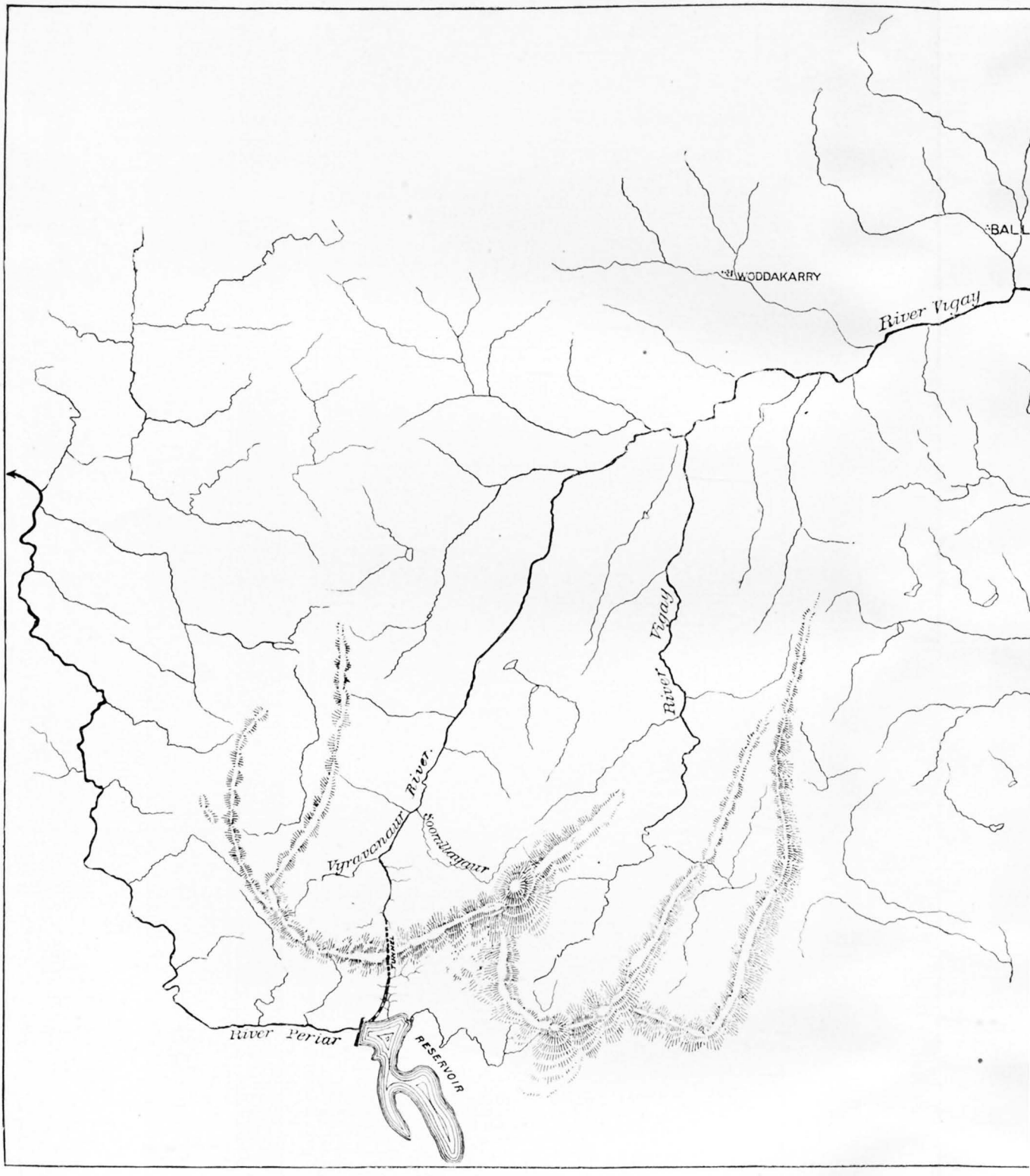
The gates of the regulating sluices of the canal are of such cross-sectional area as to admit 1,000 second-feet of water. The number of openings in the regulator is five, each 6 feet in width by 5 feet in height, and, as before stated, are two decks in height, being closed by separate gates in such manner that either the upper or lower series of gates may be opened at will, according to the depth and pressure of water in the reservoir. Below the main regulator gates, which are operated by screws by means of hand levers worked from above, are a set of two safety drop gates, which are raised by means of a traveling winch. The accompanying drawings (Pl. CXXXIX) illustrate some of the details of construction of the regulating and flushing sluices. These regulating gates, like those of the flushing sluices, are constructed of the best rubble masonry, finished with ashlar. The total cost of the head gates and flushing sluices was $100,000, while the main weir, inclusive of the subsidiary weirs, cost only $160,000.

The left flank of the river is protected up and down stream by a wing wall, the former 140 feet long, and the latter 75 feet long. The whole length of the wing walls is founded on rock, and excepting the parapet they are constructed chiefly of rubble masonry. In order to avoid inundation by the afflux caused by the weir, embankments have been constructed on both sides of the river. The top width of these is 20 feet and the center of each is hearted with a puddle wall 3 feet thick.

The Betwa project was sanctioned as a protective work. The total expenditure on it up to the end of 1888 was $1,360,000, the total revenues from irrigation were $9,300, and the total working expenses were $30,000; while the net revenue account showed a deficit over all receipts, including those from irrigation, of $20,000. This work has been in operation but a few years and the revenue has been constantly increasing in amount relative to the working expenses.

THE PERIAR PROJECT.

The Periar project for the irrigation of the Vigay Valley, in Madras presidency, is probably the most interesting illustration of the combined storage work and irrigation canal system to be found in India, especially as it was sanctioned as a protective work. The project (Pl. CXL) includes the construction of a dam to close the valley of the Periar River to store 300,000 acre-feet of water; of the construction of a tunnel through the watershed dividing the valley of the Periar from that of the Vigay River for the purpose of drawing off the water from the reservoir, with the necessary sluices and subsidiary works for controlling the passage of the supply of the Periar down the valley of the tributary called the Sooroolly, by which it reaches the Vigay; and finally, the construction of the works necessary for the regulation and distribution of this supply for the irrigation of 140,000 acres of land in the Vigay Valley.



THE PERIAR PROJECT, MADRA

This great enterprise has not yet been completed, nor is it in partial operation even, but work is rapidly being pushed on various portions of the project and it will soon be in active operation. The area of country which will be irrigated by it was described by Maj. Ryves, R. E., in his early report on the project in 1867, as being about 1,200 square miles in extent with a population of nearly half a million. Up to the present time irrigation has been practiced from native tanks, most of which, however, have become very shallow, and from which the waste of water by evaporation is at least 30 per cent. In very good years the water supply from the Vigay itself is sufficient to irrigate 20,000 acres. Agricultural operations in this region are rarely rewarded by a good crop, although the land where water can be provided is of the most fertile character. During the famine of 1876 as much as $600,000 was expended in relief in this district.

The idea of utilizing the water of the Periar for the irrigation of the Vigay is an old one. It was first reported in 1808 by Sir James Caldwell, who condemned the project as decidedly chimerical and unworthy of further regard. The subject was occasionally discussed from time to time, but it was not until 1867 that it was practically brought forward by Maj. Ryves. Maj. Ryves's proposals included an earth dam 162 feet high, with an escape crest 142 feet above the river bed, and the water was to be diverted into the Vigay Valley by a cutting having a maximum depth through the watershed of 52 feet. Other examinations were made, and finally a project was submitted by Mr. Smith, in 1872, which included a dam 171 feet in height, to be constructed by the silting process and having an escape 400 feet in length blasted out of the saddle at the right bank.

The final project, and that which has been adopted, was the outcome of further examinations made by Mr. Smith and Maj. Pennycuick, though to the latter are due most of the later details, and under him is being conducted the construction of the works. It was in this report that Maj. Pennycuick submitted the first proposal for the substitution of a masonry dam for one of earth. These final proposals were submitted in 1882, and included the construction of a dam (Fig. 258) located at the same point as that chosen by Mr. Smith, 7 miles below Maj. Ryves's site, the height to be 155 feet above the bed of the river, and the summit surmounted by a parapet 5 feet high and 4 feet thick. The dam proper is 12 feet thick at the top and 114¾ feet at the lowest part. It is constructed throughout of concrete composed of 25 parts of hydraulic lime, 30 of sand and 100 of broken stone. The front face is covered with a plaster composed of equal parts of lime and sand. A temporary dam 30 feet in maximum height was constructed above the main dam and a similar dam 10 feet high below the main site, in order to enable the latter to be completely cleared and the foundation trenches blasted out before the main dam was begun.

For the formation of waste-ways two saddles are utilized, one on each

bank (Pl. CXLI.) The one on the right bank has solid rock at a minimum level of 154 feet above the river bed, and will be cut down for a length of 420 feet to a level of 144 feet. On the left bank the solid rock is at a level of 104 feet, and the saddle will be built across with similar material to that of the main dam to the same level, 144 feet. The wall thus formed will have a length on its crest of 403 feet and a further length of 97 feet in excavation, making 500 feet in all.

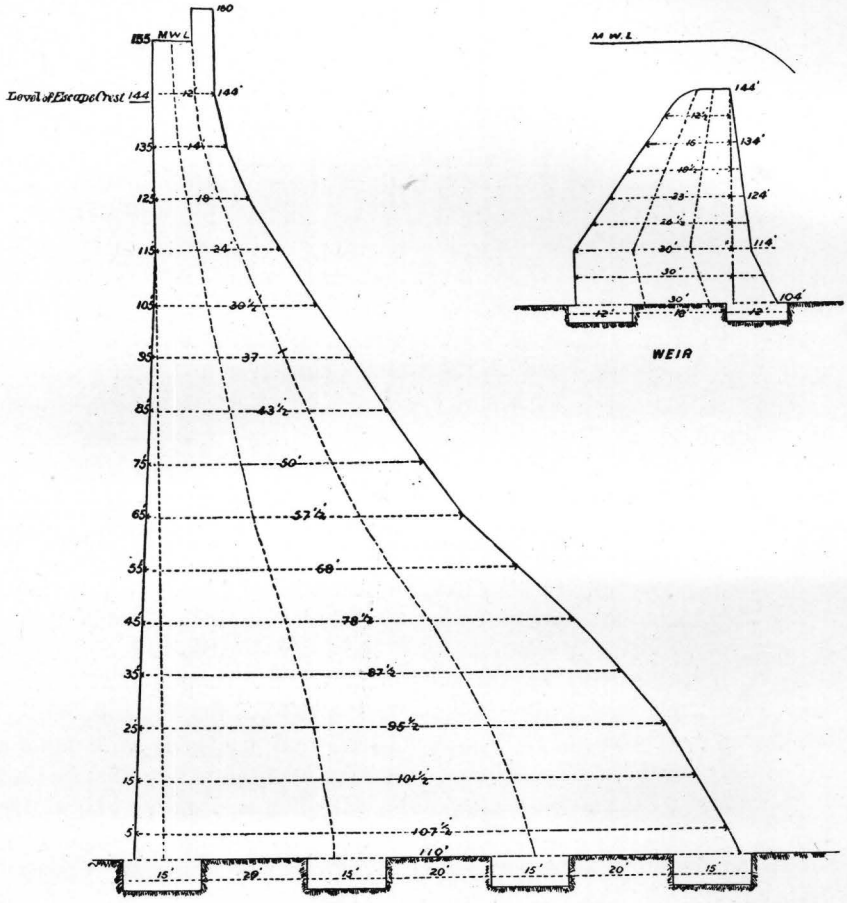
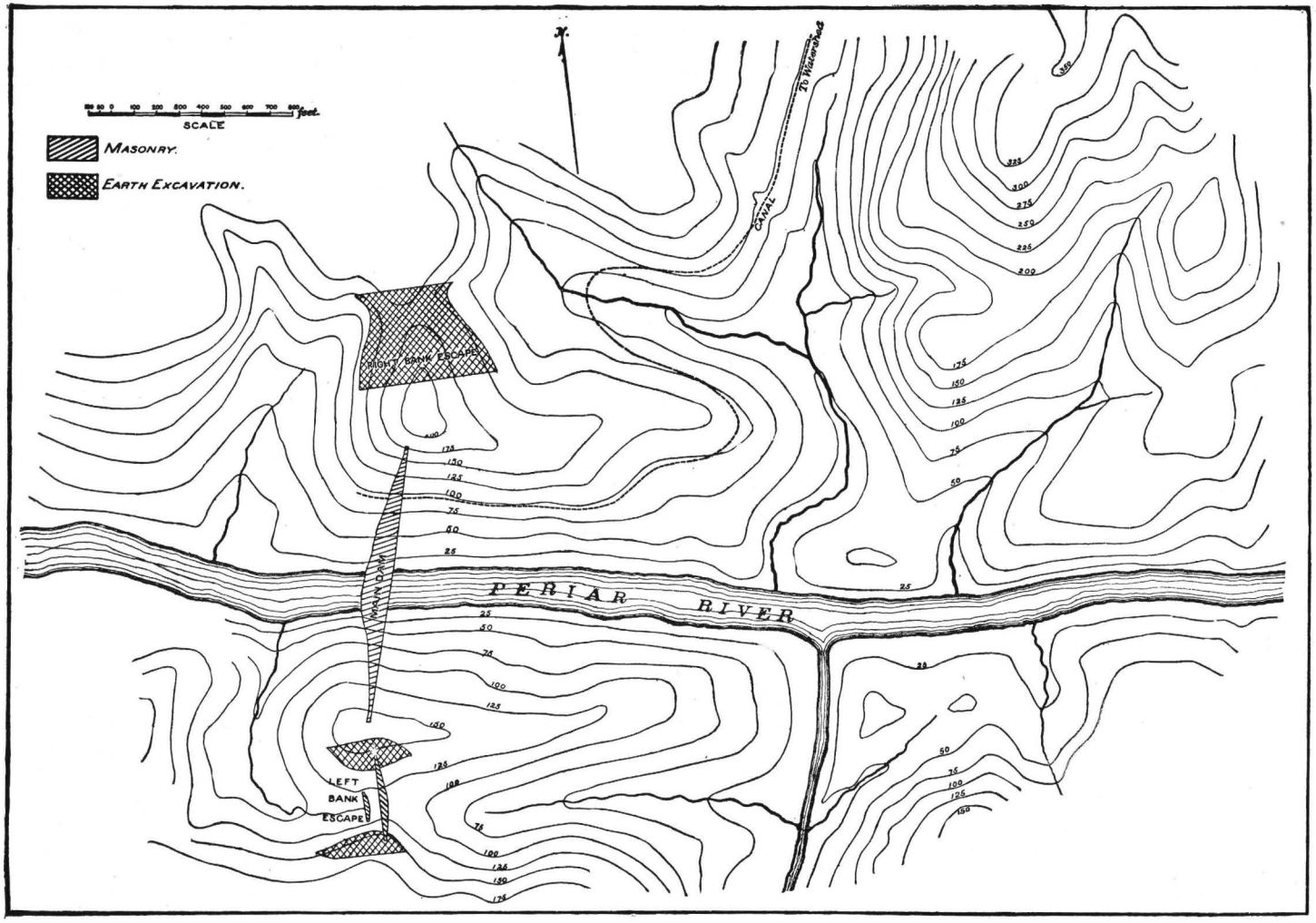


FIG. 258.—Cross-section dam and escape weir, Periar system.

The aggregate length of the two waste-ways is thus 920 feet. At a distance of 60 feet from the escape wall on the left bank will be built a subsidiary weir 10 feet in height, with its crest 30 feet below the upper wall, thus forming a water cushion. In the side of the valley tributary of the Periar, just above the dam, a cutting will be started at a height of 113 feet above the river bed running down toward the watershed, 21 feet wide at bottom, with a fall of 1 in 440. The depth of the cut-



PERIAR HEADWORKS. PLAN OF DAM AND ESCAPE.

ting in rock is 50 feet at a distance of 5,400 feet from the starting point, where it is replaced by a tunnel with an area of 80 square feet and a fall of 1 in 75. At its lower end the tunnel will communicate with the bed of a small stream by a cutting similar to that at the south end, 160 feet in length, the total length of the tunnel being 6,650 feet.

The rock in the river bed and on the watershed ridge is a hard syenite free from fissures and suitable both for a foundation for the dam and for material for its construction. Most modern dams of any magnitude have been built of uncoursed rubble masonry. Maj. Pennycuick argues that "concrete is nothing more than uncoursed rubble masonry reduced to its simplest form. As regards resistance to crushing or to percolation the value of the two materials is identical," he further says, "unless it be considered as a point in favor of concrete that it must be solid, while rubble may, if the supervision be defective, contain void spaces not filled with mortar. The selection depends entirely upon their relative cost, the quantities of materials in both being practically identical." At the site of the Periar works skilled labor is abnormally expensive and difficult to procure, while the facilities for the use of labor-saving machinery which can be largely used in the manufacture of concrete are unusually great. Accordingly, after full discussion, it was decided to adopt concrete as the material for the construction of the dam. Excellent sand is procurable from the bed of the river in numerous places above the dam.

The section of the escape dam (Fig. 258) on the left bank is designed so that the lines of pressure shall be within the middle third when a depth of 12 feet of water is passing over its crest, and so that the water shall have a clear fall to the surface of the water cushion below. As before stated, at a distance of 60 feet from the upper escape dam is constructed another dam 10 feet in height, with its crest 30 feet below that of the former. The depth of water passing over this dam will be about one and one-half that passing over the upper one, so that the fall from surface to surface will vary from 24 to 30 feet, and the depth of water cushion from 10 to 28 feet. The length of the right bank wasteway is fixed by the quantity of stone required for the dam. This quantity is 3,600,000 cubic feet, of which 1,400,000 are brought from the watershed cuttings, the cost of conveyance being less than that of quarrying at the dam site. The balance after the material has been supplied from other convenient sources is 1,600,000 cubic feet, to be obtained from the right bank waste way. It is contemplated that a great flood will raise the water to a level of 153·1 feet, while it would take several times this discharge to raise it to 155 feet. The maximum flood recorded occurred in 1869, and amounted to 65,500 second-feet; being 131,200 acre-feet in twenty-four hours, and 7,100 acre-feet in an hour.

From the mouth of the watershed tunnel the water of the Periar will pass by minor tributaries into the Soorooly River (Pl. CXL), and is controlled by numerous regulating works along the course of the various

tributaries of the Vigay. These works consist chiefly of sluices of simple form, their object being to pass the Periar water around the different weirs which have been constructed by the natives or Government in past times for the utilization of the water of the local drainage basin. None of these old works are provided with head sluices. Accordingly, the regulating sluiceways which are planned in connection with the Periar project, are designed to discharge the maximum amount of water which that project will furnish when the surface level of the stream above each weir is flush with the bed of the existing channel.

From the mouth of the tunnel to the junction of the Sooroolly with the Vigay is about 46 miles, and for a further distance of forty miles the water is conveyed by the latter river, no works being required in connection with it until it reaches the Peranny, at which point the distributive works begin. The Peranny weir is a substantial structure already existing and requiring but little improvement, the only alterations made being the closing of the undersluices, the leveling of the crest 5 feet above the floor of the latter, and some slight additions to the wing walls, apron, etc. Two main distributive canals have been planned, passing close under the foothills surrounding the plains about Madura. These and their branches all terminate in natural drainage channels. The quantity of water designed to be carried by the southern main canal is 1,500 second-feet at its head, where the depth is 6 feet, and it is designed to irrigate 75,000 acres of land. The existing or northern main canal is to have a head sluice of 20 vents, all of $5\frac{1}{2}$ feet span. The steepness of the Vigay Valley necessitates the construction of numerous drops or falls in both the main and branch channels. For the passage of cross drainage there are in all 26 inlets and 32 level escape outlets on the main canal, besides 2 aqueducts and 6 culverts, 3 inverted siphons and other works. The head and regulating works for the main canal and a secondary channel called the Vedacunay channel, are only 1,460 feet apart. It is necessary, however, that both works be built, for the ground between the two is unfavorable for an open channel.

The water supply is derived from the Periar, the drainage area of which is 300 square miles and is undoubtedly sufficient. The estimated rainfall in the Periar Valley varies between 65 and 200 inches per annum and averages 125 inches, while the depth of run-off from the catchment basin is 49 inches. The estimated discharge of the river available for storage is 760,000 acre-feet, while the loss by evaporation in Periar Lake and in the beds of the Sooroolly and Vigay Rivers is 70,000 acre-feet, leaving a balance available for irrigation of 680,000 acre-feet. The amount of water required for the irrigation of the lands in the Vigay Valley is 600,000 acre-feet. It is not estimated that over 7,500 acre-feet will be required to fill the beds of the rivers down which the waters of the Periar will be passed.

While the maximum storage capacity of the Periar reservoir is esti-

mated at 300,000 acre-feet, the total available storage capacity above the sills of the discharge sluices is but 160,000 acre-feet. It is estimated that the total cost of this work, including the latest additions to the project and interest charges, will amount to $3,220,000. The works are expected to be completed within 6 years from the time when they were commenced, and the irrigation to be fully developed within 10 years after their completion. The gross revenues are estimated to be $350,000 and the working expenses and collection charges $62,000. Therefore the net revenue will be $260,000; or, including the enhanced. value of the land revenue, $285,000, which is 9·3 per cent on the direct charges.

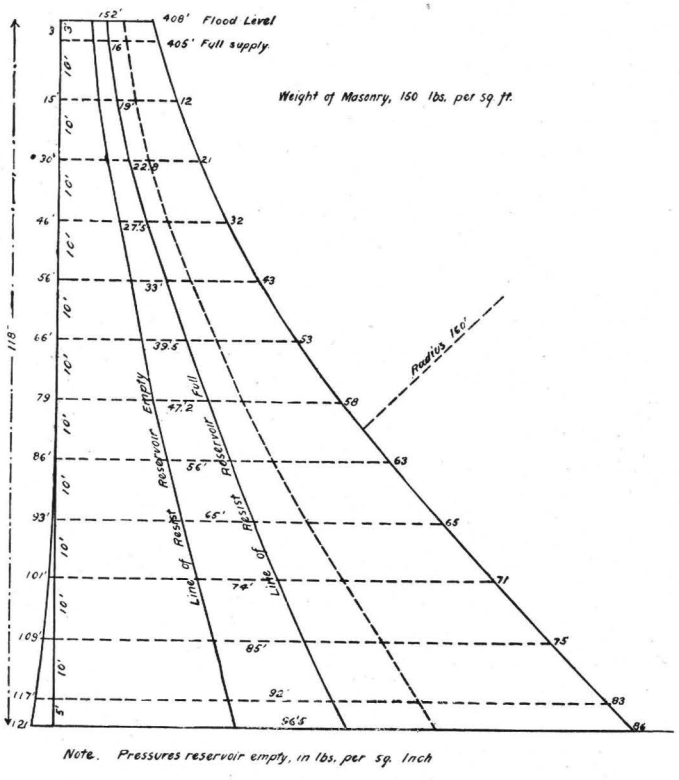


FIG. 259.—Tansa dam, Bombay.

TANSA RESERVOIR.

This reservoir is designed not for irrigation, but for supplying water to the city of Bombay for domestic uses. It is, however, constructed upon the general principles involved in water storage for purposes of irrigation, and the dam which forms it is of such great size and excellent workmanship and design that a description of it here will at least be instructive. The project for the construction of the great reservoir on the Tansa River for the storage of water for the supply of the city of Bombay was first brought prominently forward by Maj. Hector

Tullock, about 1870. The plans of the reservoir and dam as at present constructed were worked out and the construction undertaken by Mr. W. Clerke, chief engineer of the water supply of Bombay.

The Tansa River heads near the summit of the Western Ghauts where the rainfall is great, ranging from 150 to 200 inches per annum. The

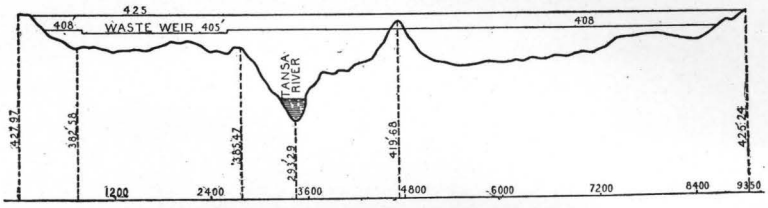


FIG. 260.—Tansa project, longitudinal section of dam.

area of the catchment basin above the dam site is but 52½ square miles, but the slopes are so steep and the precipitation so great in amount that the discharge is estimated to be about 8,000,000 cubic feet per day. The area of the reservoir is 8 square miles, and the maximum available

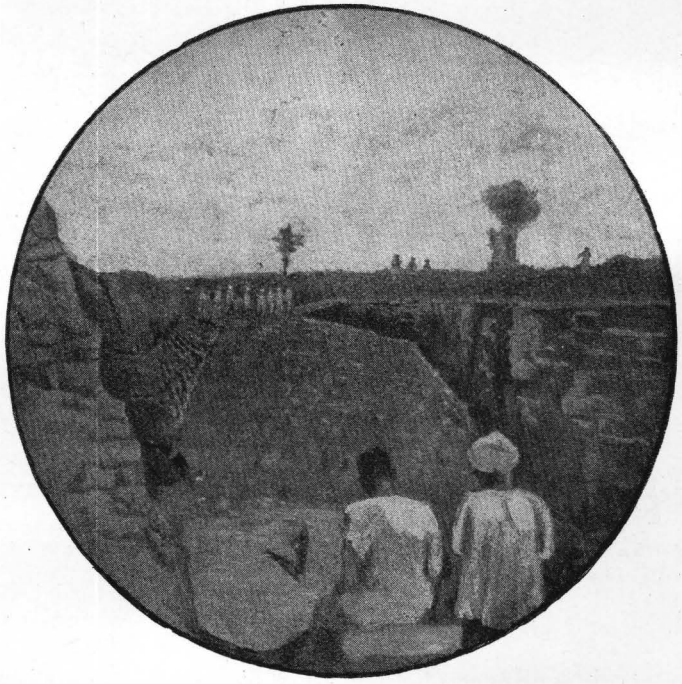
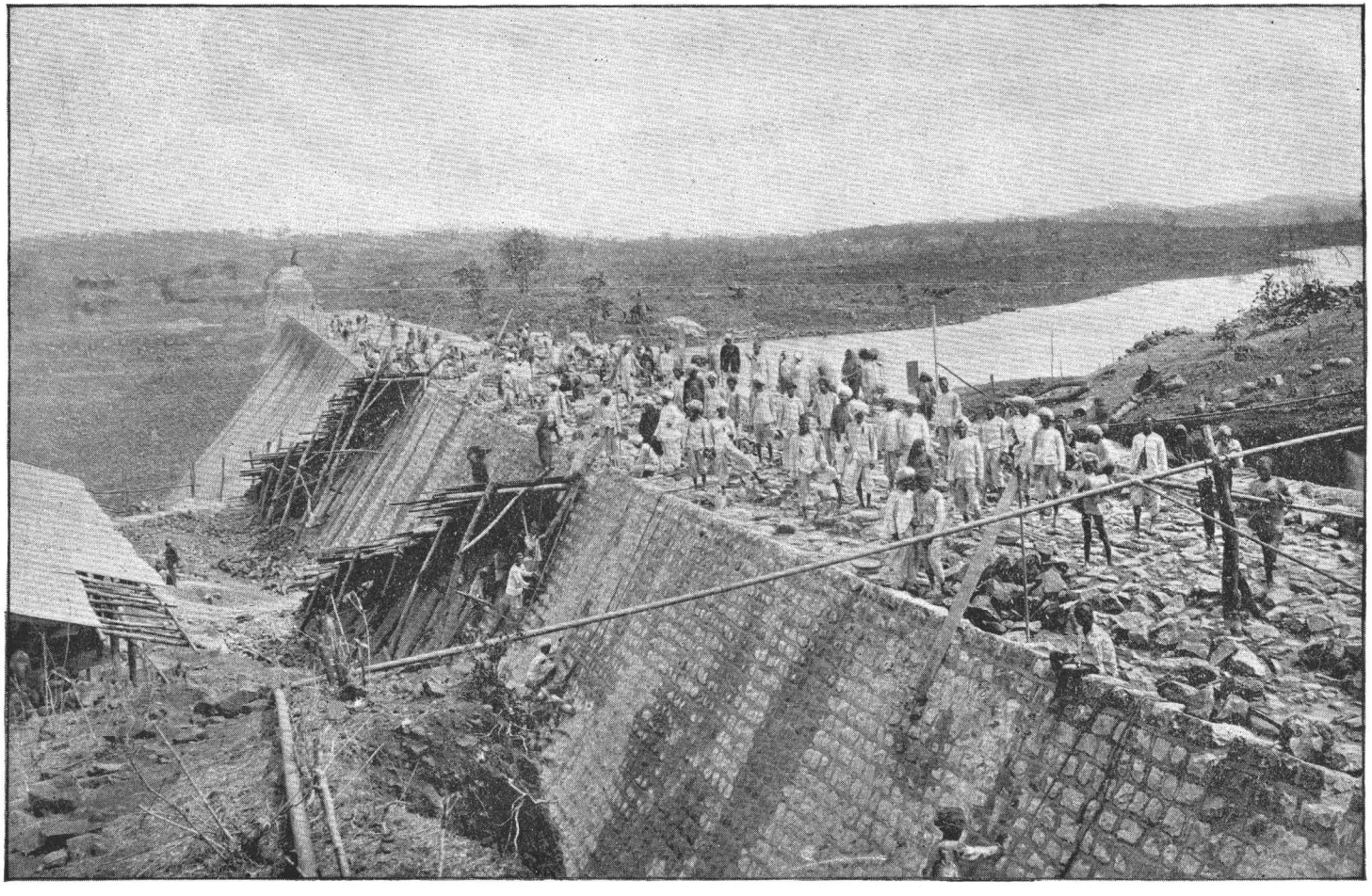


FIG. 261.—Foundation, Tansa dam.

depth of water above the sills of the discharge sluices is 20 feet. Its net available capacity is 52,670 acre-feet, less 36,800 acre-feet, which is equivalent to a loss of 6 feet in depth by evaporation and absorption. The gross storage capacity of this reservoir is far greater than the figures given above, and much more water could be utilized if it were



NATIVES BUILDING TANSA DAM, BOMBAY.

needed for purposes of irrigation by taking off the discharge sluices at a lower elevation.

The dam (Figs. 259–260) is constructed of the best uncoursed rubble masonry, laid in hydraulic mortar which is made near the dam site. The total length of its crest is 9,350 feet, of which 1,800 feet are utilized as a waste way at the south end of the dam. It is constructed in two tangents in such a manner as to get the shortest line on a bed-rock foundation. These tangents meet near the center of the dam in a sharp rocky hillock, which projects a little above its crest. The top of the wasteway is 3 feet below the maximum flood height of the dam, and the volume of flood which will have to be wasted is estimated to be 25,000 second-feet.

The total cost of this work was about as follows:

Compensation for land, etc	$40,000
Excavations for foundations, 4,000,000 cubic feet, at 30 cents per cubic yard.	44,000
Rubble for masonry for the dam, 10,000,000 cubic feet, at $3 per cubic yard.	904,000
Total	988,000

MASONRY DAMS.

It may be generally said that all of the masonry dams constructed by Indian engineers in recent times have been designed according to the most approved modern formulæ and the material of which they have been constructed has been almost uniformly uncoursed rubble masonry. The Tansa dam (Pl. CXLII) is the most logical instance of the use of uncoursed rubble masonry throughout without any coursed work either in the facing or coping, thus giving an almost homogeneous wall. Mr. W. Clerke, chief engineer of this work, holds that the strains due to shrinkage and settlement in a dam thus constructed are uniform throughout its mass and have little or no effect to rupture it. Whereas in other dams, such as those at Betwa and Bhatgur, where a deep layer of coursed stones has been laid outside of the central core of uncoursed rubble or concrete, the homogeneity of the whole may be destroyed owing to unequal shrinkage or settling, thus diminishing the effective cross-section of the dam by the amount of the coursed facing.

The Periar dam is the most logical example of a dam constructed throughout of concrete without any facing or other material to destroy the homogeneous character of the material of which it is constructed. The great dam at Bhatgur is an example of a combined structure; all of the upper portion of this dam above the lines where the limit of pressure exceeds 60 pounds per square inch, is constructed of concrete faced with coursed rubble masonry. Below the point where the limit of pressure of 60 pounds per square inch is reached, the material used throughout is uncoursed rubble masonry, faced, however, as is the upper portion, with coursed stones. In building up this structure the coursed facing and the interior hearting of concrete were run up simultaneously in layers, and the various thicknesses of concrete were

bound together by the insertion in them of great irregular stone blocks which projected above each layer of concrete as laid. The upper 10 feet of this structure above the high-water line is composed entirely of a filling of spoil from the foundations and this is inclosed between the coursed facing.

The same general mode of construction, a combination of concrete and rubble, was used in the great diversion weir at Vir. The great weir dam at Betwa is constructed of uncoursed rubble masonry coursed on both faces; in addition to this the coping is of the best ashlar. The coursed facing is laid with headers not less than 2 feet long and

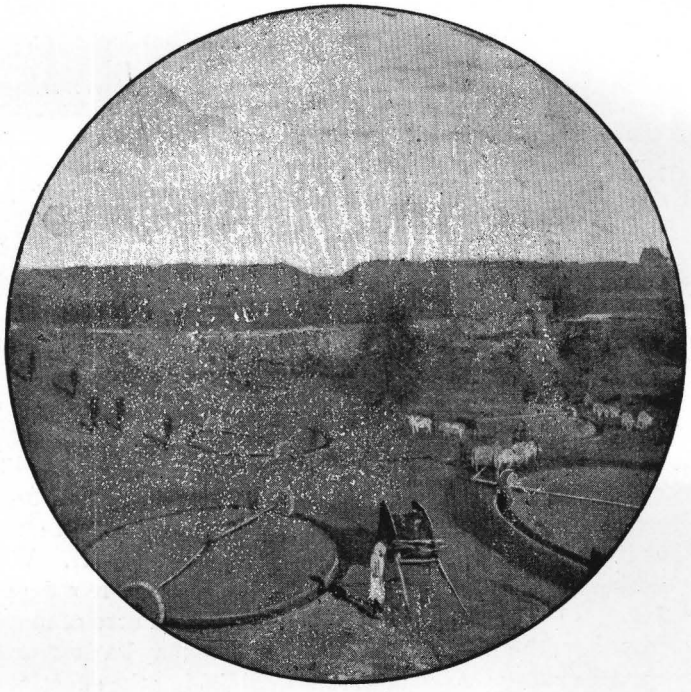


FIG. 262.—Mixing mortar with churus.

stretchers, two of which equal in height that of the headers. The material used in the rubblework is a kind of igneous granite, very hard and excellent for the purpose. The ashlar work, however, consists of hard sandstone. In a few cases brick has been used for the construction of low weirs. A notable instance of this is the great diversion weir at Narora, at the head of the Lower Ganges Canal, which is constructed almost throughout of brick. This material has proved entirely satisfactory, as the Narora weir is not very high and has to withstand but moderate pressures. The material used in the construction of the Tansa and Bhatgur reservoirs is a heavy trap or greenstone.

The cement used almost universally in the construction of works in India is of local manufacture, being made from dirty nodules of limestone

which are found in the clay soil distributed very generally throughout the country. These limestone nodules are called kunkar, and when burnt in a kiln produce an excellent hydraulic lime nearly equaling the best cement in hydraulic properties and resistance to pressure. Ordinarily these limestone nodules are comparatively small. The best hydraulic cement made from these is that produced near Vir, at the head of the Nira Canal. The nodules used for this are scarcely ever bigger than a man's fist. In other places they are much larger, notably in the Ganges Valley, where the material used in the construction of the Lower Ganges headworks was found in lumps and blocks weighing some hundred of pounds each. For the manufacture of hydraulic cement the limestone nodules are burnt in a common kiln with coke, charcoal, and cinders to hydraulic consistency. This hydraulic lime is then slaked and crushed, usually by means of the "churus," big stone wheels drawn by oxen (Fig. 262), though occasionally in modern mortar mixers, and is then mixed with the proper proportion of sand, either in the native mortar machine or more usually now in an iron mortar mixer.

The stones used in the construction of uncoursed rubble masonry are rarely larger than can be carried conveniently by two men, as almost all labor is manual, and rarely is carrying machinery used. The method of quarrying the stone and of transporting it by means of tramways is similar to that employed in America and Europe. The following are a few extracts from notes made by Mr. A. Hill, superintending engineer on the Bhatgur dam, on the masonry construction of that work:

In the facing the masonry is laid in courses, each of which does not exceed 9 inches in depth, as large stones are too troublesome to handle. The stones are wetted and the mortar and stones are well rammed. The stones for the rubble are as large as can be conveniently handled by two men, while the smaller stones are broken up for metal to be used in making concrete. In uncoursed rubble the stones touch along their whole sides, not at points or edges merely, and small chips are used to fill in spaces between the larger stones. All awkward projections are knocked off and the stones are well rammed into the bed of mortar in which they are laid, and which must be at least 1 inch in thickness. The average weight of these stones is perhaps 100 pounds.

The concrete is made of broken metal and river gravel, the former 3½-inch gauge, the latter one-eighth to 3 inches; the proportions used are, metal, 16 parts; gravel, 16; mortar, 12. The concrete is laid in two layers, each 4½ inches in thickness, and rammed for twenty minutes and one hour, respectively, and is kept constantly wetted for at least two weeks, that it may set properly. The concrete is mixed both by hand and machine, the hand mixing being done on a floor with a hoe; the machine mixing in iron barrels or mixers. The stone and gravel are wetted before being mixed. Briquettes of concrete used on this work, 15 by 10 by 10 inches in dimensions, after six months' setting ruptured under a crushing weight of from 400 to 800 pounds per square inch.

In making mortar only sharp, clear river sand is used. The lime, after being burnt to hydraulic consistency, is slaked for five hours, stirred and ground for three hours more, and then clean, wet sand is added in the proportion of 1 to 1 and stirred again for two more hours. For testing this is made into 2-inch cubes or briquettes, which are kept damp and are allowed to set for forty-eight hours, after which they are placed in water until tested.

The following are average tests of mortar made in this way at Bhatgur:

	Pounds.
Age 12 months, crushing weight per square inch	815
Age 9 months, crushing weight per square inch	600
Age 6 months, crushing weight per square inch	500
Age 3 months, crushing weight per square inch	300
Age 1 to 3 months, crushing weight per square inch	250

Some briquettes stood as high a crushing weight as 1,100 pounds per square inch when one year old. The hydraulic mortar used at Vir gives even better results. Several briquettes of mortar made there and mixed in proportion of 1 to 1 and from eight months to one year old required a crushing weight of 1,500 pounds per square inch to rupture them. Vir mortar mixed with two of sand to one of hydraulic lime breaks at 800 pounds pressure per square inch. The mortar used in the construction of the Tansa dam showed an average crushing strength of 800 pounds per square inch, though numerous specimens stood a test of from 1,500 to 1,800 pounds per square inch.

At the head of the Ganges Canal, in the Northwest provinces, the concrete blocks used for groynes in retaining works and for dams are of a peculiar composition, as hydraulic lime is scarce. They are composed of one part quicklime to three parts of broken stone (about 1-inch gauge) and two parts of brick dust. These blocks are not very strong nor hydraulic. At this place the blocks which are used under the water and subjected to the greatest pressure are composed of hydraulic lime, two parts; sand, one part; broken stone, three parts. The Periar dam, which, as before stated, is constructed throughout of concrete, is designed to withstand a limit of pressure of nine tons per square foot. The quantities of material have been estimated on the supposition that every cubic foot of concrete will require 60 cubic feet of solid stone, plus 10 per cent for wastage, to 25 cubic feet of unslaked hydraulic lime.

MATERIALS, LABOR AND COST.

It has generally been held that owing to the great relative cheapness of labor in India compared with that employed in the United States few lessons, especially of a financial character, could be drawn from a consideration of the results of Indian irrigation works. The reports on the returns derived from Indian works, the percentage of profit gained or loss incurred, are not of the most encouraging character. A thorough examination of this matter, both in the field and in the reports, has, however, allayed any doubts which the writer had on this subject, and leads him to believe that yet better results may be obtained in the United States, even in comparatively uninhabited regions.

As was shown in the earlier part of this report, the returns derived in India from works constructed with borrowed capital, on such works

as the perennial canals of the Northwest provinces, profits varying between 4 to 20 per cent per annum are realized. It was also shown, however, and this is the least promising phase of the investigation, that in scarcely any case had storage works been profitable. The loss in most cases on this class of works has been trifling, while in several cases a profit has been gained. Moreover, the older works of this class are rapidly becoming more popular. The value of irrigation is becoming better appreciated, even where a constant rainfall occurs, and such works are annually increasing in value.

It was soon seen that any attempt to ascertain the relative value, both cost and return, of works constructed in India by comparison of the rates of labor paid in that country and in America, was altogether futile. Nothwithstanding the remarkable cheapness of all classes of native labor, the relations of the laborer to the government, the character of the laborer, and the exhausting heat of the climate, all tend to make his day of labor a relatively short one, both in time and in work done. Few or no mechanical appliances are yet used in the construction of Indian works. It is claimed by some that the seeming cheapness of the labor seduces the engineer. This in most cases is not true. The average engineer appreciates the value of labor-saving machines, but has contended so long with the carelessness of the native laborer and his lack of interest in learning new ways that he has finally given up the struggle of trying to teach him to use modern appliances, feeling convinced that the native cooly achieves as good results in his own way as he could with better apparatus which he would misuse or fail entirely to avail himself of.

The long time required in the excavation of works, in filling, carrying, and emptying a little basket which holds perhaps a shovelful of dirt, tends decidedly to make the native labor expensive. The slow mode employed of carrying comparatively small stones for the construction of great dams, consisting of tying ropes around the stones, attaching them to poles, having them lifted onto men's shoulders with the aid of assistants, then making a slow, plodding journey from the stone pile to the top of the dam, all tend to increase the expense of the labor employed. (Fig. 263). In the construction of such works in the United States, machinery would dig the canals in great part, and a vigorous, skilled workman, using with intelligence labor-saving appliances, would in a day accomplish many times the amount of work that is done by the Indian cooly. In every individual operation is seen the slowness of native methods. If it be grinding mortar, oxen walk in a circle drawing a large stone wheel attached to a wooden beam, which laboriously and slowly grinds the mortar as the old Mexican arastra grinds the quartz (Fig. 262). Occasionally is a modern mortar mill seen operating beside the native churus and doing the work in a few minutes which the latter take hours to accomplish. In the blacksmith shop half a dozen men are needed to perform the work of one. The forge is

blown by a boy, who pumps air through a couple of leather bags beneath his arms, taking much more time to create the same degree of heat than a modern blacksmith's bellows would require.

The works constructed in India are invariably of the most substantial masonry and will last for centuries. Along the roads and railways the smallest bridges and culverts are constructed of stone and brick. On the canals, the least important regulator, aqueduct, or bridge is likewise constructed of the best masonry for all time. In our construction of such works, iron and timber would be extensively used for bridges and aqueducts, or, as we call them, flumes, and for many parts of the headworks and works along the canal lines, thus greatly reducing the cost.

FIG. 263.—Carrying stones to build Tansa dam.

Another great expense incurred on Indian works has been the effort to combine navigation with irrigation. This effort has been comparatively unsuccessful if viewed from the light of the modern requirements of a country possessing good railways and wagon roads. As before stated, in order to make the canals navigable their expense is greatly increased by the construction of locks throughout the whole length and of parallel canal channels; of bridges of greater headway, in order to admit boats to pass under them; and of expensive aqueducts or similar works, instead of the cheaper contrivances which might be used if navigation were not practiced. Above all, navigation entails great loss of water.

In the neighborhood of Poona labor is perhaps as cheap as anywhere in India. It is performed by all classes, ages, and sexes, the more skilled laborers, as masons, carpenters, and blacksmiths, usually being grown men. Most of the burdens, as gravel, sand, mortar and materials which have been excavated, are carried away on the heads of women and children. Common labor is paid about 8 cents per day. Masons and carpenters get from 16 to 20 cents a day, while a laborer with a team of bullocks gets 25 cents a day. On the Bhatgur dam donkeys and bullocks were frequently used as pack animals for carrying stones and earth. A donkey will carry a cubic foot of stone per trip and earns 6 cents a day. Common laborers were paid 8 cents, women and children 4 cents, and skilled laborers 20 cents per day. It was estimated that 8 skilled masons could lay and dress 3 cubic yards of masonry per day on this work. Owing to the slow mode in which the work was conducted it was necessary to employ a great number of laborers at one time, so many in fact, that a large portion of them were frequently idle through interference with each other. About 2,000 men, women and children were engaged on small portions of the dam at once and the daily rate of progress was about 5,000 cubic feet of rubble and concrete work and 1,000 cubic feet of course masonry facing.

At Tansa the work was done by contract, and the prices paid were a little higher than elsewhere. Rubble masonry cost $3 per cubic yard. On Lake Fife and Bhatgur the same class of good uncoursed rubble masonry cost but $2 per cubic yard. On the Tansa dam over 5,000 people were at work at one time. On the Betwa Canal earth excavation in deep cuts, not exceeding 40 feet in depth, cost but 6⅔ cents per cubic yard; surface excavation in earth with short haul cost 3 cents per cubic yard; uncoursed rubble masonry cost $2.30 per cubic yard; coursed rubble masonry, $6.25 per cubic yard, and dressed ashlar work $22.50 per cubic yard. On the Periar works the ordinary price of unskilled labor was 12 cents per day; for special work, such as feeding machinery, etc., the coolies were paid 20 cents per day; while head coolies, artisans, etc., were paid from 30 to 60 cents per day.

All kinds of material, other than those found in the country itself are most expensive in India. Coal is usually brought from England at a cost never below $20 per ton. Iron, steel, and machinery are relatively very expensive, as is Portland cement and wood of every kind. In fact, masonry work is generally cheaper than wood, and iron is always dearer than masonry. The great cheapness of masonry is owing to two causes: cheapness of labor, and cheapness of the hydraulic lime which is manufactured in the country almost invariably near the site of the work which is being constructed. On the Periar work drilling cost $10 per hundred running feet of drill hole, and the labor of quarrying, including plant, boring, dynamite, and all other expenses, amounted to about 85 cents per cubic yard, or as much as it would in the Western States of America. On the same work in tunneling, the

heading cost $6.50 per cubic yard, and for enlarging the tunnel $2.60 per cubic yard was paid; lime cost $1.30 per cubic yard, sand 40 cents per cubic yard, and concrete cost $1.70 per cubic yard laid in place. Of minor items, the removal of earth or cutting cost 6½ cents per cubic yard; steel, 15 cents per pound, and wrought iron 8 cents per pound. On the Sidhnai Canal, in the Punjab, concrete cost $1.80 per cubic yard; rubble masonry, $2.16 per cubic yard; and brick 95 cents per hundred laid in lime mortar. Earth excavation cost 4½ cents per cubic yard, and the best hydraulic lime cost $2.50 per cubic yard to manufacture.

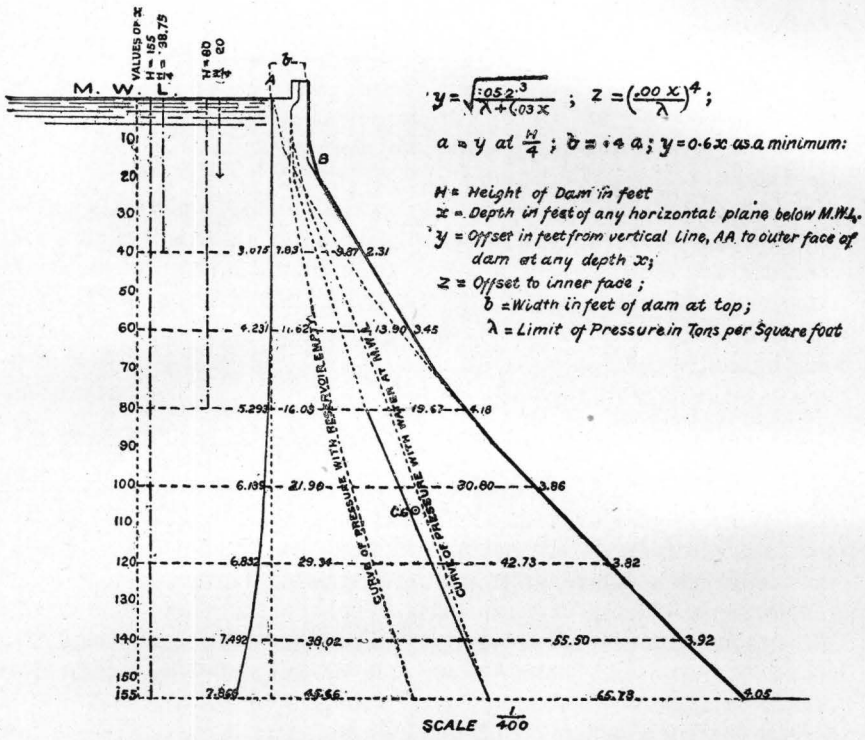


FIG. 264.—Profile of masonry dam, Molesworth's formula.

As stated in speaking of reservoirs and storage works, the Indian engineer designs the cross section of the dam on some theoretic profile which will be most stable and economical. All of these are similar to the profile which has recently been discussed and described by Mr. Edward Wegmann, in his treatise on the "Design and Construction of Masonry Dams." Modified formulas, based on Rankine, Delocre, Krantz, or Bouvier, are generally used. Little value has been given to methods sometimes adopted of constructing the dam on a plan curved horizontally. None of the high dams seen in India were sufficiently short to have been curved in this manner. A formula for the design of cross sections which is generally employed by Indian engineers is that

which was worked out by Mr. Guilford L. Moleworth, in 1883, and is as follows:[1]

$$Y=\sqrt{\frac{.05\,x^3}{\lambda+(.03\,x)}};\ Z=\left(\frac{.09\,x}{\lambda}\right)^4$$

A vertical line being drawn from the top front edge of the dam to the base, Y is the width from this line to the rear face and Z the corresponding width from the line to the front face at any distance from the surface of the water or from the top of the dam. Y is further equal to $0{\cdot}6x$ as a minimum; λ is the limit of pressure of the masonry in tons per square foot; H = top height of dam; a = Y at $\frac{H}{4}$ from the top; B = top width $=\frac{a}{2}$.

The accompanying diagram (Fig. 264) shows how this formula is applied. It is intended to secure the requisite stability at the front face when the reservoir is empty and at the rear face when it is full. This formula of Mr. Molesworth's, which has created considerable discussion among Indian engineers, is considered an excellent empirical formula for general use. Maj. Pennycuick, who designed the Periar dam, suggested a somewhat different formula,[2] and Gen. Mullins, in his Manual,[3] proposes a modification of Molesworth's formula, which may be generally stated as follows:

$$y=b+\sqrt{\frac{.05\,(x-b)^3}{\lambda+.05\,(x-12)}}$$

with $b=12$, or for smaller top widths.

$$y=b+(12-b)+\sqrt{\frac{.05\,(x-12)^3}{\lambda+.05\,(x-12)}}$$

and adjusting the part above $x=12$ to the top width selected.

For weirs with water cushions the depth of the latter is sometimes determined from the formula $D=c\sqrt{h^3}\sqrt{d}$ in which D represents the depth of the cushion below the top of the retaining wall; c is a coefficient the value of which is dependent upon the description of the material used for the floor of the cushion, and varies between $0{\cdot}75$ for compact stone and $1{\cdot}25$ for moderately hard brick; h is the height of the fall, and d is the maximum depth of the water to pass over the weir crest. The width of the floor of the cushion will depend somewhat on the section of the weir, which need not exceed $8\sqrt{d}$, and should not be less than $6\sqrt{d}$. For works with a vertical drop and a horizontal apron on the same level as the retaining wall this masonry apron should be formed of fairly regular blocks of stone or of Portland cement concrete, the width varying as just given, and the thickness or depth of stone from $\frac{1}{5}$ to $\frac{1}{4}$ of $h+d$.

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[1] Roorkee Professional Papers, Roorkee, India, 1883.

[2] Periar project. Records of the Government of India, No. CCXV, Calcutta, 1886.

[3] Lieut.-Gen. J. Mullins, Irrigation Manual. E. F. N. Spon, London, 1890.

It is difficult to find any set rule for determining the depth of the water cushion by the height of the fall and the volume of water. At the Gairsoppa Falls, in the Western Ghauts, the Rajah Fall has a clear drop of 825 feet in height, and the pool into which it falls is 138 feet deep at low-water stage. The greatest depth of the hole formed by the waterfall in the new outlet of the Mudduk Masur tank is 24 feet. In ordinary states of the river the general depth of the water cushion is to the height of the fall as to 3 to 4 where the greatest action takes place and 1 to 2 in other places. An experimental fall on the Bari Doab canal had a height of 6·9 feet and depth of well of 9 feet, and 3·6 feet on crest, which gives the depth of the well to the height of the fall as 3 to 4. The water had no injurious effect on the bottom of the well. The subject of water cushions is one which is not very well understood, though these are very extensively used in India. To the author they appear to be a most effective and interesting addition to nearly every weir where they are placed, greatly increasing its stability and firmness.

TANKS.

Tanks were constructed in great numbers by the natives of India many centuries ago, and in some places, notably in central and southern India, in the Deccan, Madras, and Mysore, there are immense numbers of them. These old tanks were usually rude in construction, little care having been taken to economize in labor, and as a consequence the dams constructed were usually made much heavier in cross-section than was necessary. In recent years the British engineers have constructed several very large tanks, though many of the higher dams have masonry cores. The conditions controlling the location of a tank are similar to those before described for reservoirs. The water supply must be adequate to fill the tank, the location must be such that a suitable dam can be constructed at a reasonable cost, and an ample waste-way must be provided. In the location of the waste-way for a tank, even more care must be exercised than is necessary for a reservoir; for if the water be permitted to rise too high on the dam—or much worse, if it is allowed to discharge over it—it will speedily cause its destruction if it is built of earth.

It is desirable always to allow waste water to flow off by a side channel, which may be closed by a low rock or crib-work weir, or may consist only of an open rock cut; by such means there is no danger to the dam of having the shock of water falling over it. It may, however, be necessary to have a masonry waste-way constructed in the dam itself, but this is not advisable and is generally avoided. Such a waste-way is usually made by constructing a portion of the dam of masonry, the top of which is a few feet lower than the rest of the dam. When the catchment of the tank is small it is possible to provide for wasting flood-waters through an outlet or discharge channel in the dam itself. Such a discharge sluice is necessary in order to draw off the water for irriga-

tion, and must be of sufficient capacity to empty the tank in the shortest irrigating season. The level of the sill of this outlet sluice is generally that of the bed of the tank, but there are occasionally constructed one or more higher outlets to irrigate lands which lie above that level. These sluices are expensive works, and require a well constructed masonry or iron conduit to be carried through the dam, emptying into the canal at one end and receiving its water supply at the other end through a well or water-tower from which its admission can be controlled. It is usual to make the outlet tunnel of good masonry, and it must not be smaller than 2½ feet high by 2 feet wide, in order to permit a man to go through it to examine, clean, or repair it if required.

One cause of the frequent breaching of Indian tanks is, that great numbers are often constructed in one valley, the bed of one beginning where the cultivation of that of the next above it ends, so that the breaching of one often results in the destruction of a succession of those below it. Regarding the depth of tanks, if they be shallow a great loss of the stored water is sustained through evaporation. Shallow tanks are never intended to hold more than water enough for one crop. In India aquatic plants which grow from the bottom in shallow tanks are injurious; while those which spread on the surface, like the lotus, diminish the loss by evaporation. When water is not deeper than 7 or 8 feet the rays of the sun can penetrate to the soil, and growth of aquatic plants is the consequence. In the smaller tanks, intended to cultivate limited areas of land immediately below them, the most economical height for the dam on gently undulating ground where there is a natural and long slope to the rear has been found to be from 10 to 25 feet.

In the construction of modern tanks the same precautions are usually taken and the same detailed investigations made as for a reservoir project. The catchment basin, the discharge of the streams, the rainfall, and other physical phenomena are carefully studied; the lands to be irrigated are examined and their relative position to the location of the tank and catchment basin is surveyed and mapped. Careful surveys are made for the reservoir site to determine its capacity, and of the dam site in order to choose the best and most economical location and to ascertain the cost of the works.

The interior and exterior slopes of earth dams are usually considered as planes, forming together an angle of not less than 90°, and the figure should be so formed in order to increase its stability that lines of pressure passing from the interior faces at right angles may fall within its base. Upon the calculation that 1 cubic foot of rammed earth weighs 99 pounds and 1 cubic foot of water 62½ pounds, and supposing that the earth would stand at any slope, we find that the base of the prism resisting the lateral thrust of the body of water does not require to be more than two-thirds the depth of the column it supports, so that all quantities above that are due to the natural slopes, the stability of the dam and the prevention of percolation. Consequently, when large

works are projected it is a subject of close calculation which is the more economical, those exclusively of earth or those whose inner slopes have retaining walls of masonry.[1]

As constructed in India, the width of the top of the dam depends not so much on the pressure of water it has to sustain as on the prevention of percolation. The usual width now allowed is from 8 to 12 feet, thus giving room for a roadway. The top of the dam is made sufficiently high above the highest line of flood over the sill of the wasteway to prevent its being topped by waves. On a large spread of water a strong breeze forms waves sometimes 3 feet high, which on a long slope may be raised to 5 feet. The dam must be of such height that water can not pass over it, as the latter would quickly scour away the back slope until the thickness was sufficiently reduced to cause the dam to give way. Additional security against such an accident is obtained by raising a low masonry parapet on the outer edge of the slope, paving the top and giving it a slight dip inward to prevent the settlement of water.

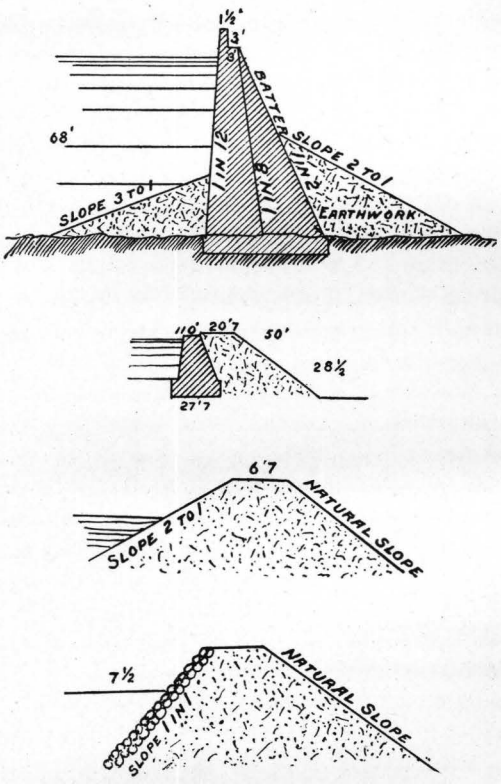


FIG. 265.—Cross-sections of earth and combined dams.

The number of disused tanks is remarkable. Many are not breached, but the discharge sluice is left open so that no water is collected. In many cases this is probably owing to the bed of the tank having been gradually raised by silting and thus converted into so productive a soil that it yields as much as or more than could be obtained by means of a diminished quantity of water applied to the comparatively barren soil below. An example of one of these old tanks thus abandoned, but capable of restoration, is the Mudduk Masur tank, believed to have been constructed about four centuries ago. It was formed by an embankment rising from the sides of a narrow gorge through which the Choardy River passed, and was supplemented by two dams in saddles

[1] H. Victor, Notes on Irrigation in the Bombay Presidency, Roorkee Professional Papers on Indian Engineering, Roorkee, India.

on a range of hills; that on the east bank 1,350 yards and that on the west 760 yards from the main dam, the length of the latter being 1,650 feet. The inside slope of 1 on 2½, in some parts 1 on 3, was revetted with large stones up to a cubic yard in bulk. This dam is from 945 to 1,100 feet wide at the base and is now from 91 to 108 feet high. There was a sluice under the dam at the east end above the level of the ground. The material of which the dam is constructed is a strong red earth with a considerable mixture of gravel, and was taken from the sides of a hill in the neighborhood. The east supplemental dam has its base 74 feet above the sluice in the main dam, and had also a sluice under it at the ground level. The west supplemental dam, the breaching of which destroyed the tank, was of similar construction to the others, and its base was 60 to 70 feet above the bed of the tank. There was no trace of any waste-weir, and it is probable that the want of this was the cause of the ruin of the tank. From the heights of the dams and the levels of the sluices it is probable that the depth of the tank was 90 to 95 feet, and at that level its area would have been 40 square miles and its contents about 870,000 acre-feet of water.

Another variety of tanks, constructed not on main drainage lines or streams but in depressions in a flat country, are usually closed by a different form of dam. There were many of these, and large numbers are breached or abandoned and their beds now cultivated. The embankments of these flat-country tanks are often of great length, not unusually 1 or 2 miles; that of the Veeranum tank is 12 miles long and the ruined bank of the Puniary tank in the Trichniopoly district is said to be 30 miles long. The height of these is generally inconsiderable, being in many hundreds of cases only sufficient to hold from 6 to 10 feet of water. A few of these works, however, are 20 or 40 or even 50 feet in depth. The inner slope is generally revetted with stone and has an inclination sometimes of 1 on 1, oftener of 1 on 2 or more. The height of the bank above the water level varies. For instance, the Nundyal tank has a dam at one place 18 feet high, 2 feet above the water level, 16 feet wide on top, with an inside slope of 1 on 1 and an outside slope of 1 on 2. The Kolevoy tank in the Nellore district has a bank 36 feet high, extending 9 feet above the water level, a top width of 12 feet, and equal slopes inside and outside of 1 on 1½.

As the accumulating alluvial deposit made year after year gradually raises the beds of tanks, these would become filled up were not some expedient adopted from time to time, such as adding to the height of the dam. This, however, generally involves an enlargement of the cross section as well as the raising of the waste weirs and the construction of new sluices at higher levels than the one occupied. One expedient frequently resorted to successfully is to have the mud stirred up by hand at the beginning of the rainy season, when the flood waters are permitted to carry it off through the discharge sluices.

This, however, is only partially effective, like the scouring of the undersluices in a reservoir.

In Central India there are many tanks; their history is rather modern and is very interesting. In 1820 the Mairs, a tribe occupying Marwar, Meywar, and Ajmere, were banditti living in the hills, constantly fighting and making raids on the Rajputs and other neighboring tribes. The Mairs lived chiefly by levying blackmail on isolated hamlets and on travelers. Col. H. Hill subjugated them, and by the establishment of a government, police, etc., caused them to live more peaceably and to commence the pursuit of agriculture. In 1835 Col. Dixon succeeded to the charge of the Mairs and arrived at the conclusion that the lack of water rendering agriculture impossible in a country whose rainfall was below 20 inches was the cause of their predatory life. Their history from this time was similar to that of the nomad and bandit tribes which occupied the country now irrigated by the Sirhind canal in the Punjab. Col. Dixon commenced by causing the construction of terraced irrigation lands by means of retaining dikes, and of tanks by means of earth or masonry dams.

Since being furnished with an abundant water supply for fertilizing the crops, the Mairs have, owing to this enlightened policy of Col. Dixon, now become peaceful and industrious cultivators. The small tanks furnish water for irrigation below them and water for wells near them, and when the water is drawn off their beds are cultivated and, being very fertile and moist from the deposition of sediment, produce excellent crops. These tanks now support a large population and produce considerable revenues.

The following table exhibits the principal dimensions of some of the Mairwara tank embankments and weirs:[1]

Name.	Length of embankment wall or weir.	Breadth—		Depth of foundation.	Height above foundation.	Spread of water.	Area irrigated, including cultivation in bed.	Cost.
		In foundation.	At upper surface.					
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	
Kabra	620	27	10	9	24	182	204	$3,125
Juwaja (escape weir added to ancient embankment.)	251½	28	.....	6	16	218	364	1,890
Roopana weir	522	10½	3½	0	18	25	36	1,100
Kalee Kuncur	3,369	42	6	0 to 10	28	182	437	8,275
Gohana	460	25	4¼	10	28	94	250	2,135
Burar weir, upper	240	30	7	8	36	72	109	2,000
lower	343	12½	6½	10	20	72	29	1,280
Loosanee	575	29	.....	20	24	218	273	810
Cheela Bura	954	5	3½	6	14	36	83	.....
Dewatan	1,333	21	.....	19	16	145	328	.....

[1] R. Baird Smith, Italian Irrigation, volume 1, page 420, William Blackwood & Sons, London, 1855.

The following table exhibits the results of some of the works detailed above, showing the increase in number of families, of wells, and of village tanks, etc., during eleven years preceding the preparation of Col. Dixon's report, 1835 to 1846:

Name of village.	Increase in number of—			Increase in revenue.
	Families.	Wells.	Village tanks.	
Kabra	38 to 133	3 to 46	0 to 31	$235 to $1,030
Juwaja	25 to 122	8 to 28	0 to 15	125 to 895
Kalee Kunkar	0 to 118	0 to 25	0 to 14	0 to 545
Burar	70 to 440	131 to 301	.....	1,925 to 4,425

The following table shows the whole number of tank enbankments constructed in Mairwara up to the date of the report:

Districts.	Number of embankments and weirs.	Spread of water in bed.	Area irrigated, including cultivation in bed.
		Acres.	*Acres.*
Ajmeer Mairwara	158	6,323	10,557
Mewar Mairwara	120	3,077	3,960
Marwar Mairwara	12	275	309
Total	290	9,675	14,826

From the above it will be seen that between the years 1835 to 1846 the increase in the number of wells was from 2,230 to 6,150, or 3,920. The increase in the number of tanks was from nothing to 2,065; the estimated population increased 60,000 (from 40,000 to 100,000) and the revenue increased from $48,000 to $105,000 or $57,000. The estimated sums expended under the sanction of the Government in all Mairwara during the same period of years was $125,000, while the aggregate increase in land revenue for the same period amounted to $320,000.

Lieut. Home, in 1868,[1] reported on six principal tanks in Mairwara the average capacity of which ranged from 920 to 2,400 acre-feet. The total outlay on these to the end of the year 1866 was $40,000. The net income to the end of the same year was $2,000, or a net gain varying between 1 and 12 per cent. The results of Lieut. Home's inspections showed that not only have Col. Dixon's works enormously benefited the country, but they have returned the Government 150 per cent on the expenditure incurred. The whole of the six tanks especially mentioned paid nearly 10 per cent on the capital invested.

In Mysore in southern India there are 37,000 tanks, of which Sir Robert Temple says:

> Wherever there is a depression in the land an embankment with a wasteweir and a sluice is thrown across it. The water is held up above it, and below it a few acres are sown with rice and sugar cane, and irrigated by means of sluices. A few yards

[1]Lieut. F. Home, R. E., Tank Irrigation in Ajmeer and Mairwara. Roorkee Professional Papers, No. 229, Roorkee, India.

lower down the depression comes another, and so on, increasing in size as they go on until a series of tanks may consist of more than one hundred all connected together, the overflow from the wasteweir of each being the chief feeder of the one below it and the stream that issues from the wasteweir of the bottom one being a river in magnitude. The tanks at the top of the series are mere ponds and those at the bottom are often good-sized lakes, and the area irrigated by these is frequently very large.

In Madras Presidency, including Mysore, there are said to be about 75,000 tanks. All of the smaller tanks are repaired either by the villages or by the landowner. The smaller tanks are used during the rainy season chiefly in order to keep up a constant supply of water for the fields during the intermission of the rainfalls. The larger tanks contain water supply sufficient often for one year and sometimes for several years. In Mysore early in 1866 Maj. Sankey [1] reported that the percentage of the whole area of Mysore under the tank system was 59·7, while the total area of the state is 27,300 square miles. Unless under exceptional circumstances, none of the drainage of 60 per cent of this area or 16,300 square miles is allowed to escape, or rather should, with proper attention, be allowed to escape, were all existing works in their normal condition. To such an extent has the principle of storage been followed that it would now require some ingenuity to discover a site within this great area suitable for a new tank. In 1854 Maj. Sankey said that "one-third of the tanks then existing in Mysore were large irrigating reservoirs." He found about one tank to the square mile and one village to the same area; the average quantity of cultivation was about 10 acres to a tank. In this area there are some great tanks, such as the Mudduck and Nuggar tanks mentioned elsewhere.

The ordinary Mysore tank is, however, a much smaller description of work, usually closed by a low and long dam; an average one being about 12 feet broad at top, 60 feet wide at bottom, and 18 feet high. In this description of tank the sluice is usually a large, substantial, and not infrequently expensive work. It consists of a square brick or stone cistern, 2 yards each way and 1 yard high, to keep off the sand at the entrance of the sluice, with one or more valves or plug holes in a stone at the bottom, from 6 inches to a foot in diameter each. The valve is attached to a long pole which is held in an upright position by 2 or 4 vertical stone pillars, to which horizontal projections are attached, one at top and another midway down, through a hole in the center of which the valve rod works. The pressure of the water upon the top of the valve keeps it sufficiently tight when lowered into the valve hole to prevent the escape of water. At the rear of the dam another cistern of about the same dimensions, and usually of brick in mortar, is built, three sides of which are furnished with square openings and shutters to permit of the water being turned off. The two cisterns are connected by a tunnel, the length of which depends upon the cross-section of the dam through which it is laid.

[1] Maj. R. H. Sankey, R. E., Irrigation in Mysore, Roorkee Professional Papers on Indian Engineering, Roorkee, India.

Most tanks receive their supply from the high ground in the neighborhood; but there are exceptions to this, as numerous tanks are partly supplied by channels, either from water courses or canals, which wind around remote hills and catch the rain flowing down their sides and convey it to the tanks. A single tank may possess several feeders of this kind. Many old tanks which had failed during the early native government have been restored by the British engineers; others which were decayed have been repaired, and a few which were tolerable have been put in perfect order. None of these irrigation works have deteriorated since the British took possession, and their condition on the whole has been greatly improved. Judging from various reports the works are probably now in a more effective condition than at any other time of which we have a record, and the increase in efficiency has apparently kept pace with the increased liberality in the expenditure, taking no account of the great rise in labor rates of late years.

In the Madras Presidency mainly, exclusive of Mysore, there were reported in 1882 to be 53,000 tanks, having about 30,000 miles of embankments and 300,000 separate masonry works, weirs, escapes, etc., yielding a revenue of $7,500,000 per annum, and having invested in them a capital of $75,000,000. In 1882 the area irrigated of first or wet weather crop amounted to 2,525,790 acres, and the area of autumn crop irrigated in the same year by tanks amounted to 675,400 acres. Some of these Madras tanks are, as before stated, of immense size. The Virainum tank, which is a very ancient work, has an area of 35 square miles and an embankment 12 miles long. It is still in full operation and returns an annual revenue of $57,000. The Chembrambaukam tank in Chingliput is so large that it resembles a great natural lake. Its embankment is more than 3 miles long, and its wasteways have a total length of 676 feet of escape. Its gross capacity is 63,780 acre-feet, its surface area is 8·95 square miles, or 5,730 acres, and it irrigates of wet weather crop 12,760 acres, and of autumn crop 3,200 acres. The dam which closes this reservoir ranges from 9 to 28 feet in thickness at the top, and from 16 to 28 feet in height, and is constructed of earth. It supplies irrigation to the fields by means of ten separate sluiceways. In 1882 the capital invested in this work had reached $312,000, and the revenue for that year amounted to $16,300.

Some of the most interesting tanks to be found in India, because they are the most modern, are several of the great tanks recently constructed in the Bombay Presidency, which are more truly reservoirs than tanks, as the latter term fails to convey a proper idea of their magnitude and importance. Of these the more important and interesting now in operation are the Ekruk tank near Sholapur, and the Ashti tank, also in the Sholapur district, and constructed on the Ashti River.

The following table gives some of the more important data connected with these tanks, and is derived from the Bombay revenue report for 1889:

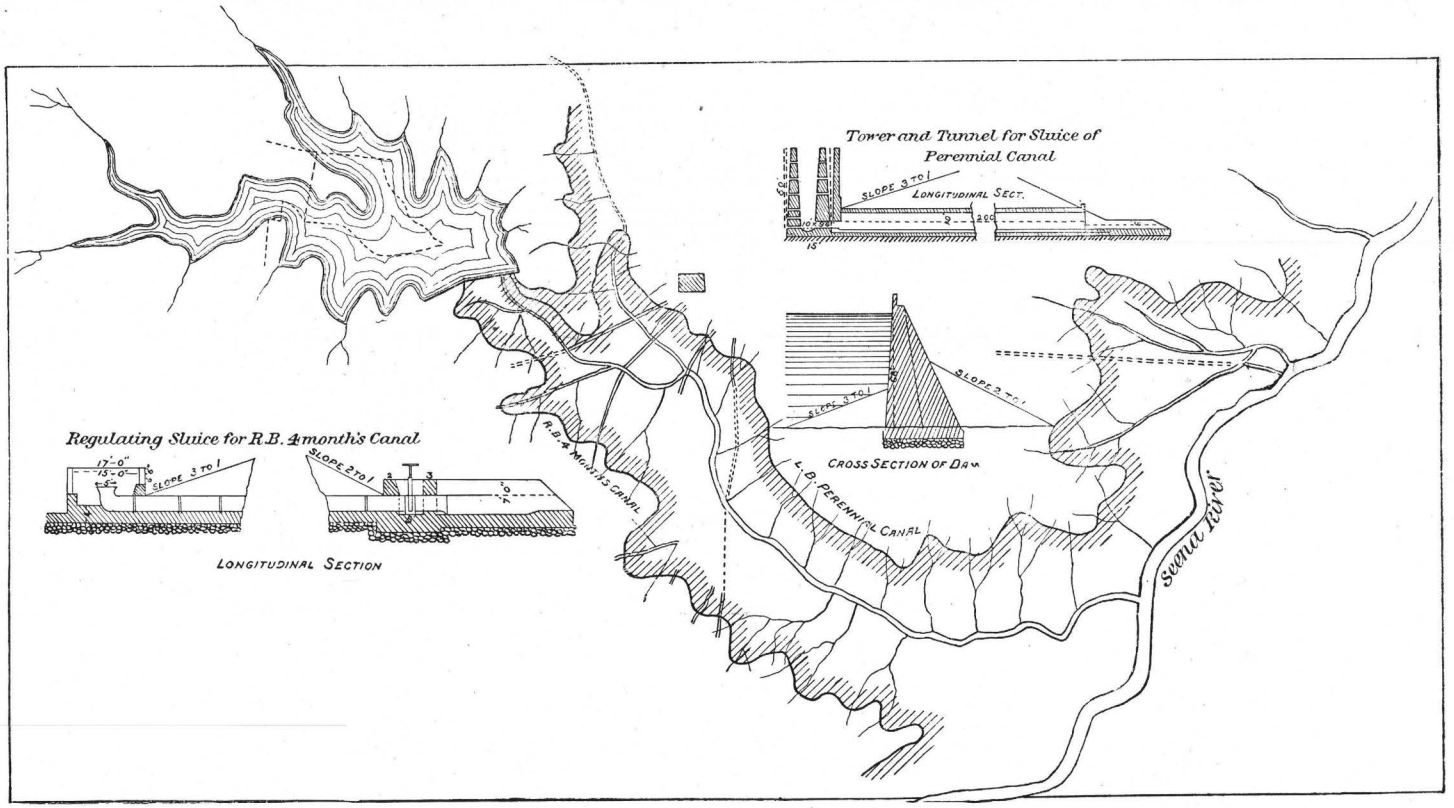
	Ekruk.	Ashti.
Area of catchment.....square miles..	159	92
Average annual rainfall.....inches..	31·5	29·2
Available contents.....acre feet..	76,130	32,660
Surface area.....acres..	4,640	2,677
Area commanded.....acres..	17,152	17,882
Area irrigated.....acres..	15,320	14,476
Main canal.....miles..	76	57·7
Distributaries.....miles..	48	6·5
Area irrigated:		
Autumn.....acres..	1,620	989
Summer.....acres..	1,355	1,440
Total.....acres..	2,975	2,420
Percentage double cropped	1·2	6·3
Discharge utilized.....second-feet..	33·3	9·2
Area of autumn crop irrigated per second-foot of discharge utilized.....acres..	40·8	155·8

EKRUK TANK.

The catchment area of the Ekruk tank is 159 square miles, on which the annual rainfall averages 24·7 inches and the run-off 41,400 acre-feet, or 4·87 inches per square mile. The rainfall on the irrigable lands served by this tank averages 22·8 inches per annum, the duty of the water supplied during the four months' autumn crop was 76 acres per second-foot, and the water rate charged on the land served during the year 1888 was 86 cents per acre irrigated or $73 per second-foot of discharge at the canal head. The crops raised were distributed about as follows:

Crop.	Acres.	Value.
Wheat	337	$3,100
Sugar	260	17,300
Millet	344	2,307
Beans	537	2,700
Total, including all others	2,976	38,000

This work was undertaken by the Indian government and is situated 5 miles northeast of the town of Sholapur. The scheme, drawn up in 1863 and sanctioned in 1866, comprises a tank formed by an earthen dam and supplying three canals for irrigation. It receives its water supply from the river Adhila, a tributary of the Lina, the fall of which is 7 feet per mile and its greatest flood discharge is 37,000 second-feet. The dam which forms the tank has a total length of 7,200 feet, including 2,730 feet of masonry, of which 1,400 feet is at the northern end and 1,330 feet at the southern end. The maximum height of the earthwork above the bed of the Adhila River is 72 feet, or 7 feet above the highest flood line. The height of the masonry portion is 3 feet above the highest flood, exclusive of 3 feet of parapet above that. When full the maximum depth of the tank is 60 feet and its contents 41,700 acre-feet



THE EKRUK TANK, BOMBAY—PLAN AND DETAILS.

of water, the surface area of which is 6⅓ square miles. The wasteway is at the northern end of the dam and consists of a channel 250 feet wide carried through a spur and discharging into a side drainage course. The calculated maximum velocity over the wasteway is 10 feet per second and its capacity of discharge is 250 by 5 by 10 = 12,500 second-feet. The depth of evaporation during eight months is 7 feet and the loss amounts to 17,250 acre-feet.

This tank has three discharge canals. The accompanying Pl. CXLIII gives some details of this work. The lowest or perennial canal is 28 miles long, and its sill is 20 feet above the level of the bottom of the tank. Its discharge amounts to 44 second-feet and it covers an irrigable area of 25 square miles. The next canal above this is intended to provide a four months' supply of water; it is 18 miles long, discharges 42 second-feet, and covers an irrigable area of 21 square miles of land. The highest canal is also calculated for a four months' supply, and is 4 miles long and discharges 21 second-feet of water. The discharge of one of these four-months canals is compensated for by the supply of rain received during the rainy season. The lower perennial canal is taken from the left bank, the second canal from the right bank, and the higher canal from the left bank. The discharge sluice at the head of the perennial canal consists of a masonry tunnel through the canal bank with a substantial masonry inlet tower on the water side. The diameter of the tunnel through the dam is 12 feet and its total length is 200 feet. The discharge sluices for the four-months canals consist of an iron pipe 145 feet in length and 5 feet in diameter through the dam, which is closed at the lower side by means of a valve worked by hand gear from above.

According to the revenue report for 1888–'89, the total outlay on the Ekruk tank to the end of that year amounted to $666,000, the total receipts from irrigation were $2,200, and the gross receipts from all sources amounted to $6,700; the total working expenses amounted to $6,800, showing a deficit of $100. As originally designed, this work was estimated to yield a net revenue of 9 per cent on the capital expended. Its failure to do this is largely due to the small demand for the water, owing to the natural rainfall on the district served being ordinarily sufficient to raise crops without irrigation.

ASHTI TANK.

The catchment area of this tank is 92 square miles, and the rainfall over this area averages 24·1 inches per annum; the run-off amounts to 8,000 acre-feet per annum, or 1·62 inches per square mile. The rainfall on the irrigable lands served by the tank averages 19·8 inches per annum. The project comprises a tank on the Ashti River, formed by an earthen dam 12,709 feet long and 58 feet in maximum height, having a total storage capacity of 34,500 acre-feet of water. There are two discharge canals, one on each side of the Ashti River, which extend

to its junction with the Bhima River and command 25,270 acres of irrigable land.

This work is situated in the Sholapur district, about 16 miles southwest of the town of Madha. The project was originally prepared by Capt. C. B. Penny, R. E., in 1869. In 1876, when the great famine was imminent and the prosecution of relief works was urgently called for, this was one of the first works undertaken for that purpose. The project (Fig. 266) was then thoroughly revised and complete plans and estimates prepared by Mr. Charles T. Burke[1] under the orders of Col. C.

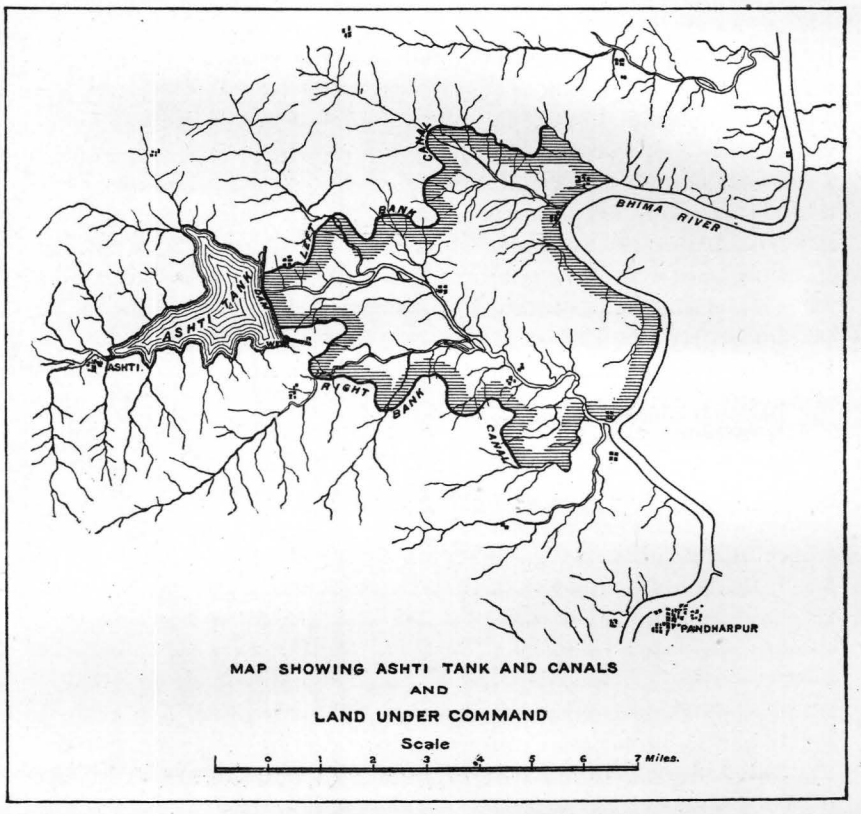


FIG. 266.—The Ashti tank and canals.

J. Merriman, R. E., chief engineer. The available capacity of the tank is 30,000 acre feet, and to furnish this quantity a run-off of 6·3 inches per annum would be required from the catchment basin. The run-off during an average season is but 6 inches or 4·87 per cent. of the available capacity of the tank. The features of the ground, however, do not admit of the capacity of the tank being reduced, as the level of full supply was regulated by the only saddle available for the wasteway.

[1] Charles T. Burke, The Ashti tank, Proceedings of the Institution of Civil Engineers, vol. 76, Part 2, 1883, London.

Had that been lowered the quantity of rock excavation necessary would have cost more than the earthwork required to raise the dam, besides which there is manifestly an advantage in making the reservoir of large capacity if it can be done without increased expense.

The loss by evaporation, absorption, etc., was estimated at 4 feet in depth on half the area at full-supply level. From actual experiment after the completion of the work it was found that the loss from evaporation in 1880 during the six winter months of dry weather was 3·8 feet; deducting this quantity, the net supply of water available for irrigation is 25,300 acre-feet.

The total length of the dam is 12,709 feet. Its top breadth is 6 feet, its breadth at full-supply level is 42 feet; the side slopes above this point are 1 on 1½ below it, the inner slope is 1 on 3, and the outer slope 1 on 2. Previous to its construction the site of the dam throughout was cleared of vegetable and loose material, and the sand and silt were removed from the entire area forming the site of the dam in the river bed. Thus the dam throughout rested upon a sound and firm foundation. There is no puddle wall, but a puddle trench, the filling of which rises 1 foot above the groundsurface, extends throughout the whole length of the dam and is 10 feet in width, and has been excavated down to a compact im-

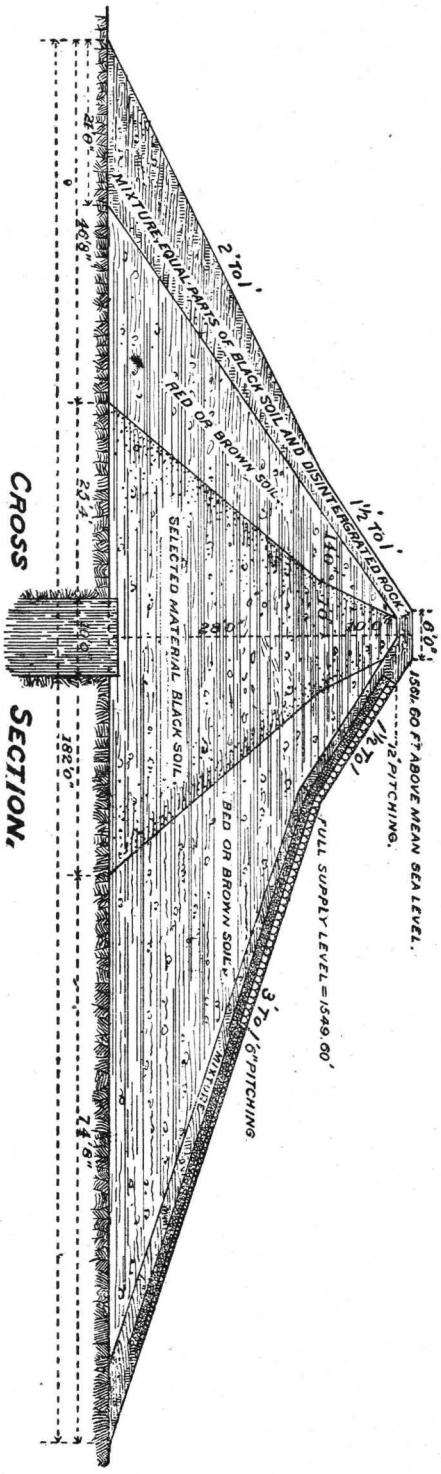


Fig. 267.—Ashti tank dam.

pervious bed. Its composition is 2 parts sand and 3 parts of black soil. The central third of the dam is built up of selected material of black soil, extending, as shown in the accompanying illustration (Fig. 267), in a triangular section, from the dam crest, where it is 6 feet wide, to the base, where it is 60 feet wide. Outside of this are two triangular sections composed of the brown soil of the country, and this is faced outside with from 1 to 15 feet of puddle of sand and black soil, while a similar puddle on the inner slope is paved with 6 inches of large stone pitching to enable it to resist wave action. Across the river bed a trench 5 feet in width was excavated along the entire length of the dam down to the rock and extending 100 feet into the banks of the river. On each side, this was was filled with concrete and was connected with the puddle trench. The puddle trench was curved around the concrete wall and continued across the river at a distance of 20 feet from the concrete wall on the up-stream side.

The following procedure was adopted in completing the foundation of the dam in the river bed. The puddle trench and concrete wall having been finished during the dry season, measures were taken to utilize the floods of the ensuing rainy season to assist in clearing away the sand, silt, etc., from the site in the river bed. Piers of loose rubble-stone were disposed in rows upon the upstream side of the site; these were about 5 feet in diameter and were placed about 40 feet apart. During breaks in the wet weather the sand to be removed was plowed and thus more readily acted upon by the scouring action of the floods, which flowed with a high velocity through the contracted water area between the piers and caused the removal of a large quantity of sand from the site at a small expenditure. A low dam of dry rubble work was then constructed across the river about 100 feet above the site to prevent it from again being silted up, and during the dry season the work was carried up in the ordinary manner.

The pitching given to the inner slope of the dam was calculated as follows:

The thickness of the pitching depends upon the greatest height of the waves to which the dam is exposed, and the maximum height of the waves depends upon the "fetch" or distance from the shore where their formation commences and was determined by Stevenson's formula

$$x = 1.5\ \sqrt{F} + (2.5 - \sqrt[4]{F})$$

where x = the height of wave in feet, F = the fetch in nautical miles. Again, Rankin states that where an embankment of loose stone is exposed to the action of waves it must be faced with blocks set by hand, the least dimension of any block in the facing being not less than two-thirds of the greatest wave height. From these two considerations the thickness of the pitching was deduced.

The cross section of the Ashti dam is considered to be amply strong

in every way, yet Mr. Burke deems it well to consider whether in works of such magnitude the adoption of a more liberal cross-section would not be advisable. He says that the Ekruk tank dam has a top breadth unnecessarily great and not uniform, as it is diminished in proportion to the height. This does not improve the appearance of the dam, is unnecessary under any circumstances, and involves an increased outlay. The top breadth of the Ashti dam is too narrow, for, although sufficient in strength, Mr. Burke considers it objectionable for various reasons. A dam of this kind would warrant, if but for appearance alone, as well as for the convenience afforded by a roadway, a small outlay to increase its top breadth sufficiently. In preparing the plans of the Pangoan tank which was subsequently designed by Mr. Burke, the top breadth was increased to 8 feet, and even this appears insufficient for a dam 77 feet in height. Mr. Burke recommends the following as a minimum top width for works of this nature in India: For earthen dams 50 feet in height and over, top breadth to be 10 feet; under 50 feet in height, 8 feet. In the course of time settling may occur in dams constructed wholly of earth, rendering repairs and renewals necessary. In the first ten years after the completion of the Ekruk dam, $2\frac{1}{2}$ feet in depth of new material was added to its top, and this could not have been properly rolled solid if the roadway had not been sufficiently wide for compression by a heavy roller.

The change of inclination from 1 on 2 to 1 on $1\frac{1}{2}$ of the outer slope of the Ashti dam is undesirable. As regards the inner slope, the inclination of 1 on 3 up to the level of the estimated maximum flood appears to be good. This should then change in tanks to 1 on $1\frac{1}{2}$ to the top of the dam. It is a matter for consideration whether the upper part should not be 1 on 1 rather than 1 on $1\frac{1}{2}$. It would probably be an advantage, Mr. Burke thinks, that waves should be reflected rather than broken on the slope, and on the authority of Mr. Scott Russell it appears that a slope of 1 on 1 will reflect waves, while on flatter slopes they are broken. The cross section recommended by Mr. Burke for general adoption in India is as follows: The height of the dam above the full-supply level, or the crest of the weir, is $h=d+x+c$; in which $d=$ the depth of water in the tank above the weir-crest level when a maximum flood is flowing over the weir; $x=$ the height of the top of pitching above the surface of the maximum flood in the tank, found by the formula previously given; and $c=$a constant of the value of 2 or 3 feet according to circumstances, that is, the vertical height of the top of the dam above the top of the pitching.

The wasteway of the Ashti dam consists of a channel having a clear width of 800 feet excavated through a saddle in the high ridge constituting the western boundary of the tank. The bed of this channel which is excavated in rock is level for a mean length of about 600 feet and then falls away, with a slope of 1 in 100, toward the Rapla torrent, into which the flood waters are discharged, and thus pass into

another valley distinct from that draining the tank. The discharge capacity of this wasteway is 48,000 second-feet, which will cause the water to rise 7 feet above its sill or within 5 feet of the top of the dam. The discharge capacity of the wasteway was calculated as follows:

L = width of channel = 800 feet.

d_2 = the depth of water in the channel = 3.5 feet.

The surface slope of the channel being 1 in 100, the mean velocity is as follows:

$$v = 92.26 \sqrt{\frac{h}{e} \times d_2} = 17.25 \text{ feet per second}$$

and the corresponding discharge is 48,300 second-feet. The head of water in the tank necessary to cause a discharge of this volume was determined by the formula

$$D = C_d L d_2 \sqrt{2gd} + \tfrac{2}{3} C_d L d \sqrt{2gd}$$

where d_2 is the depth of the channel and the constant $C = 75$.

The Ashti tank was designed as a minor productive work, the total outlay on which to the end of 1889 amounted to $270,000. The revenues from irrigation in that year amounted to $800 and the gross revenues $900. The working expenses during the same time amounted to $2,600, leaving a deficit of $1,700.

TANK DAMS.

Gen. Mullins in his Manual of Irrigation[1] lays down some different rules for the top width and various dimensions of an earthen dam from those above quoted from Mr. Burke. He says that the top width of an earth dam should not be less than 4½ feet anywhere, and, while that width will suffice for the ends of dams of comparatively shallow tanks, the width at the deeper part of these should be increased to 6 feet. From 9 to 12 feet will be a proper top width for larger dams, and for very large ones one-fourth of the depth of the water is the prescribed minimum for the deeper parts and 8 feet at the ends. The top of the dam, the upstream slope of which is revetted, should always slope toward the rear edge, so that the rainfall may flow off down the rear slope and not on the revetment, with the risk of washing out the back of the latter; 1 on 16 for earth and 1 on 24 for gravel will be suitable grades for this top slope. The grade of the interior or front slope will depend upon the description of protection against wash to be provided, revetted slopes ranging from one-third to 1⅓ on 1; for shingle, slopes of 1 on 2 or 2½ are suitable. The gradient for the exterior or rear slope will vary according to the nature of the soil from 1 on 1½, which is the steepest allowable, to 1 on 3.

In southern India at or near the center of the dam is considered the best position for a puddle wall. It is of primary importance that the wall should not crack during the considerable periods of each year

[1] Lieut. Gen. J. Mullins, Irrigation Manual, E. & F. N. Spon, London and New York, 1890.

that the tanks are either dry or the water in them is at a low level. The material most used for puddle walls in Madras is clay of the description used for tile-making. It is well tempered and a puddle made not too wet. Any excess of moisture beyond that needed to allow of the entire wall being worked into a homogeneous mass increases the risks arising from settlement. The top width given to puddle walls, whatever their height, is about 2 feet, and the top level is made from 1 to 2 feet below the level of the top of the dam. Batters of from 6 on 1 to 8 on 1 are given to the faces of the puddle wall. The thickness of the wall at the base, that is, at the ground level, is usually found by the formula $2+\frac{2h}{b}$ in which h is the height from the ground to the top of the wall and b is the batter. The foundation of the wall is frequently of concrete down to an adequate depth below the ground surface, viz: to 1 foot at least in clay or impervious soil and to 4 feet in more or less pervious soils. The cross section of the foundation trench is made as wide at top as the base of the puddle wall and somewhat narrower at the bottom, being cut with side slopes of 3 or 4 on 1. In revetting water slopes of dams a suitable backing of small stone and gravel is always placed beneath the revetment of uncemented stone.

In designing the surplus weirs or wasteways the quantity of water to be gotten rid of must first be ascertained. The length of weir required is usually ascertained in Madras either from tables or by calculation with the formula for weirs:

$$D=L\times\tfrac{2}{3}\,cd\,\sqrt{2gd}=$$
$$=L\times\tfrac{2}{3}c\times 8{\cdot}02\,\sqrt{d^3}$$

which, with $c=\cdot 6075$ (a value applicable to very many tank works) becomes $D=3{\cdot}25\ L\ \sqrt{d^3}$, in which D is equal to the discharge in second-feet; c is a coefficient, the value of which varies with the form of the weir, but seldom exceeds 0·65; d is the maximum depth in feet of water to be allowed to pass over the weir, and $2g$ is a consonant representing the force of gravity.

As of interest, showing how even earthen dams which are constructed in a most substantial manner may slip or subside from some unexpected cause, the following is a description of the slips which occurred in the Ekruk and Ashti dams. The full-supply level of the Ekruk dam has a thickness of 91 feet, and at the maximum calculated flood level its thickness is 41 feet. From the date of its completion in 1869 until September, 1872, the dam was perfectly sound and in good order, but in that month excessive rain fell all over that part of the country in which the dam is situated. From 9 to 14 inches of rain were gauged at different places in the catchment area between the 19th and 23d. The water on this occasion rose to 6 feet over the crest of the waste weir and at the same time three slips occurred in the rear slope of the dam. Col. Fife, the chief engineer, at once visited the tank and reported that the slope of the embankment where the earth had slipped or been washed

down was not vertical, but was about 45°, and this for about 10 feet only, after which it became flatter. No leakage whatever was observed through the dam. Prior to this accident dry stone drains had been constructed at an angle down the rear slope to carry off the rains and prevent scouring of the embankments; it was thought that these drains at the site of the slips had become choked or had sunk owing to the saturated condition of the soil and had thus allowed the water to accumulate and escape, washing away the earth below. These drains on the slope were accordingly done away with, the dam was carefully made up to its original section, berms were constructed to weight the toe of the dam at the sites of the slips, and surface drains were cut to carry off the slight leakage under the dam.

No further accident occurred to this dam until the summer of 1883, when another slip took place, coincident with heavy rain on the catchment basin. The position of this slip was directly in continuation of one of the slips of 1872, the rear half of the dam having for an average length of 188 feet subsided vertically about 8 feet. This portion of the embankment was founded principally on black soil which had become saturated, resembling a pulpy mass, and had been forced upward by the pressure of the dam. To remedy this a dry stone retaining and draining wall was constructed at the toe of the dam at the side of the slope. This wall was sunk 8 feet into the ground and was 10 feet wide at the bed; cross drains were also cut to drain this in the direction of the creek below the bank, and a counterfort or berm 45 feet wide and 10 feet in height was raised on the toe of the embankment to counteract, by its weight, the tendency to bulge upward.

Early in November, 1883, owing to excessive rains, the water in the Ashti tank rose 1 foot over the crest of the waste weir; shortly after, a small horizontal crack about 40 feet in length was observed in the pitching on the front slope, and it was immediately repaired by removing the stones, tamping the bank, and relaying the pitching. About a week later a crack 3 inches wide and 4 inches deep was found in the rear of the slope. This crack had a horizontal length of about 60 feet and ran down the slope to a level of about 10 feet below full-supply mark. It was at once repaired, but on the following day it reopened, when a settlement at the top of the dam was observed. From this time for several days the top continued to subside and the ground at the toe of the dam to bulge upward. Equilibrium was not established until a week later. The total settlement of the top of the dam amounted to 16 feet, bringing it 4 feet below the full-supply level of the tank; the pitched slope, however, remained intact up to about 4 feet above this level.

The causes of the slips resemble in a measure those of the slips at the Ekruk tank. A considerable length of the dam is founded on a clay soil, with nodules of dirty lime in it, and generally contains a quantity of of alkali which causes it to become semifluid when soaked with water.

It is probable that at the site of the slope the excavation for the puddle trench had not been made quite deep enough to prevent leakage of water under it. The length of the slipped portion at the top was 155 feet. The dam at this point is 44·3 feet in height and at the time of the accident the water was standing 31·7 feet deep at this point.

The permanent corrective measures adopted after the cessation of the movement were the digging of a trench at the toe of the rear slope which was filled with bowlders and broken stone (Fig. 268), as was done for the Ekruk dam, heaping the excavated material and other earth on to the bulged-up ground to counterbalance the lifting action, remaking the dam to its original section, and adding earth and broken stone to give additional weight to the rear slope. The drainage trench has been extended along the slope wherever the foundation was thought to be treacherous and this has been supplemented by additional drains, similar in character and running parallel to it, and two counterforts or berms have been added to the slope all along the rear portion of the dam, about 700 or 800 feet in length, to weight the toe.

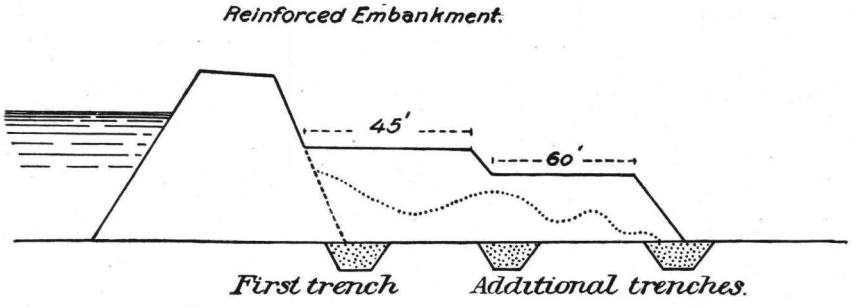


FIG 268.—Ashti dam slips.

COMBINED STORAGE AND CANAL SYSTEMS.

Several combined storage and canal systems have already been described in their proper places. The Nira project, the Betwa system, the Periar system and the larger tanks just described are all combined systems of storage works and irrigating canals. There are two other combined systems which differ from these in their general characteristics and should be described as of peculiar interest. One is the Palar anicut system in Madras whereby the water from the Palar River is furnished to a number of tanks by means of main and branch supply channels and is stored in these tanks until wanted for purposes of irrigation. The other is the Zhara Karez irrigation scheme in Beluchistan by which a number of small detached tanks situated in the bottom lands adjacent to the Machka torrent are filled by a tunnel intercepting the subsurface flow and by channels taken from the torrent to the tanks during portions of the year when there is running water in the stream.

PALAR ANICUT SYSTEM.

The Palar anicut or weir was originally designed to give an improved supply to old channels which fed a series of old native tanks. It is situated on the Palar River 4 miles below the town of Arcot and has a catchment basin above it of 3,974 square miles, the maximum flood dis-

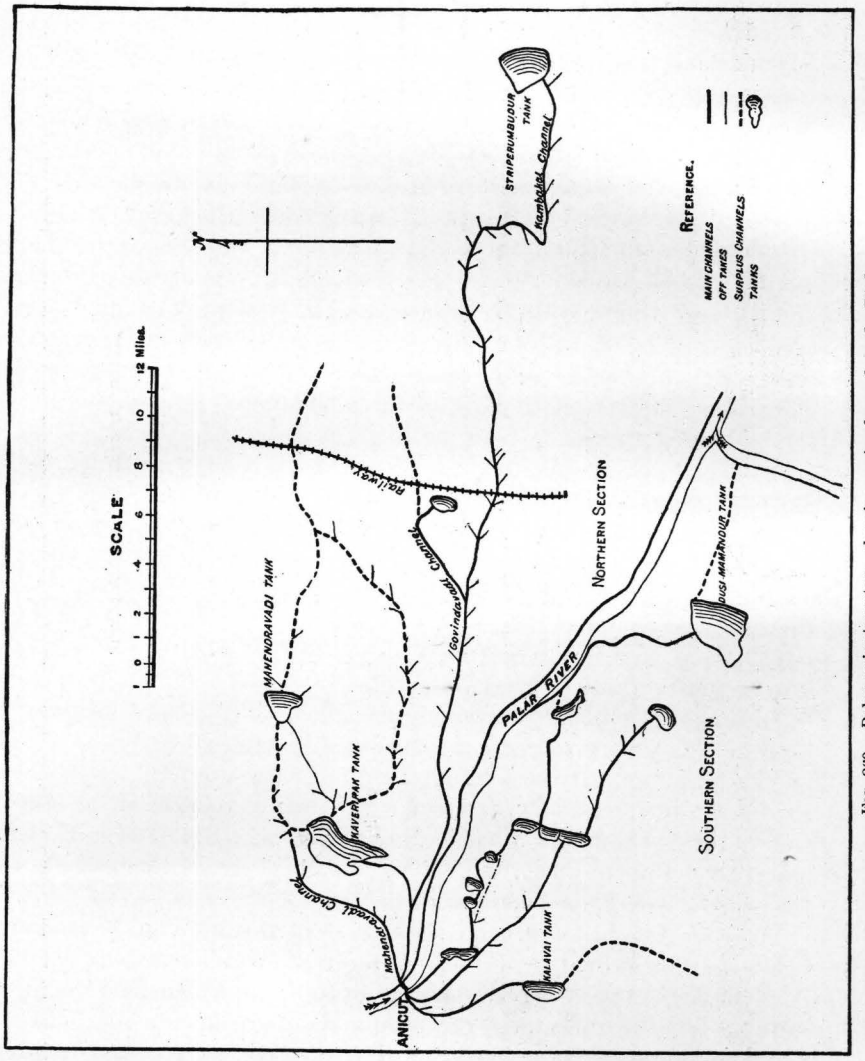
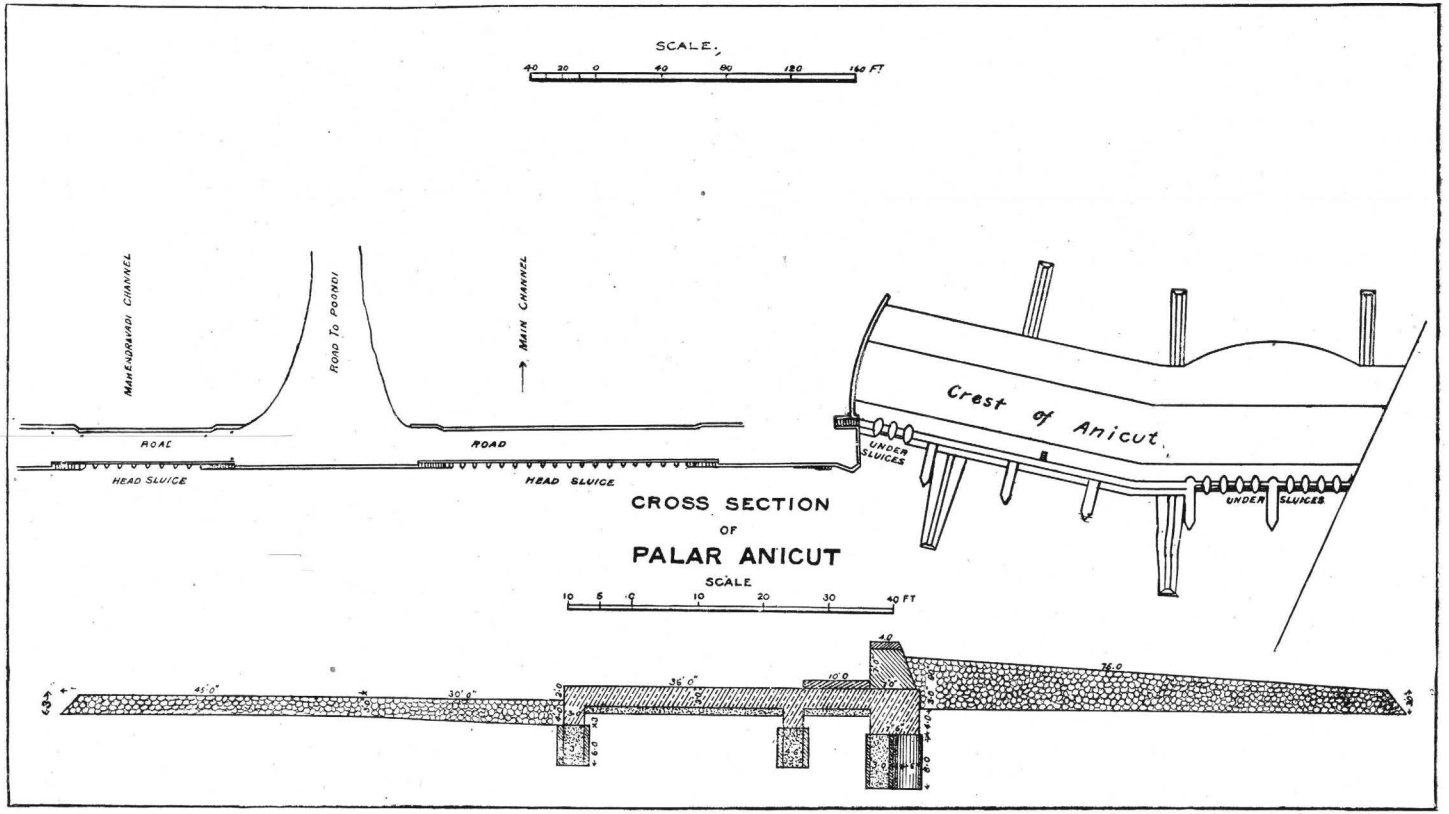


FIG. 269.—Palar anicut system, showing main channels and off-takes.

charge from which is 25,000 second-feet. Anicut is a Tamil word which means literally weir, and the Palar anicut is a simple diversion weir constructed across the Palar River whereby water is diverted on both banks of the river into the supply canals which head above the weir.

The irrigation which commenced in 1853 with an area of 9,000 acres



PALAR ANICUT SYSTEM.

of wet-weather irrigation and 700 acres of dry-weather irrigation extended until 1882, when there was an area of 66,700 acres of wet-weather and of 20,600 acres of dry-weather irrigation. The net revenue derived from the system previous to the end of 1882, including the enhanced land revenue, was $290,000 or 36·5 per cent on the amount of direct charges. The amount of interest charged to the same date, however, was $670,000.

The weir itself (Pl. CXLIV) is 2,634 feet in length between wing walls and 7 feet high with a vertical fall and is founded on a suitable row of circular wells. There are three aprons, the first of cut stone in mortar 36 feet wide, and the third of dry rubblestone 30 feet wide. The undersluices on the north side of the river consist of 22 vents of 5 by 5 feet each, those on the south side of 10 vents of the same dimensions. The weir was breached for a length of 1,015 feet by the floods of October, 1874, previous to its final reconstruction. The channels on the north are the Mahendravadi channel supplying the tank of the same name, and the main channel which branches into two supply channels, one at 3 miles from the head and the other at 21 miles from the weir. From this last channel other branches are taken off which terminate in various tanks. On the south side are three channels. The project has not realized the anticipations originally formed because the supply in the river bed was overestimated, besides which there were considerable defects in the channels themselves as originally laid out.

The water records show that on an average there are 273·7 days yearly on which no water is registered. The northern channels receive a full supply when there is 5½ feet on the sill of the weir undersluices, and the southern channels not until there is 7 feet on that side.

The Palar River rises on the Mysore plateau and runs into the ocean after a course of about 220 miles. There is extensive irrigation from it by means of river channels which are chiefly provided with masonry heads. The weir supplying the system here described is built at the one hundred and fifty-second mile, and is situated about 4 miles below the famous town and fort of Arcot. The drainage basin of the river to this point is about 3,974 square miles, the maximum flood discharge about 25,000 second-feet, and the maximum depth of flow passing over the weir 6·75 feet, as before stated.

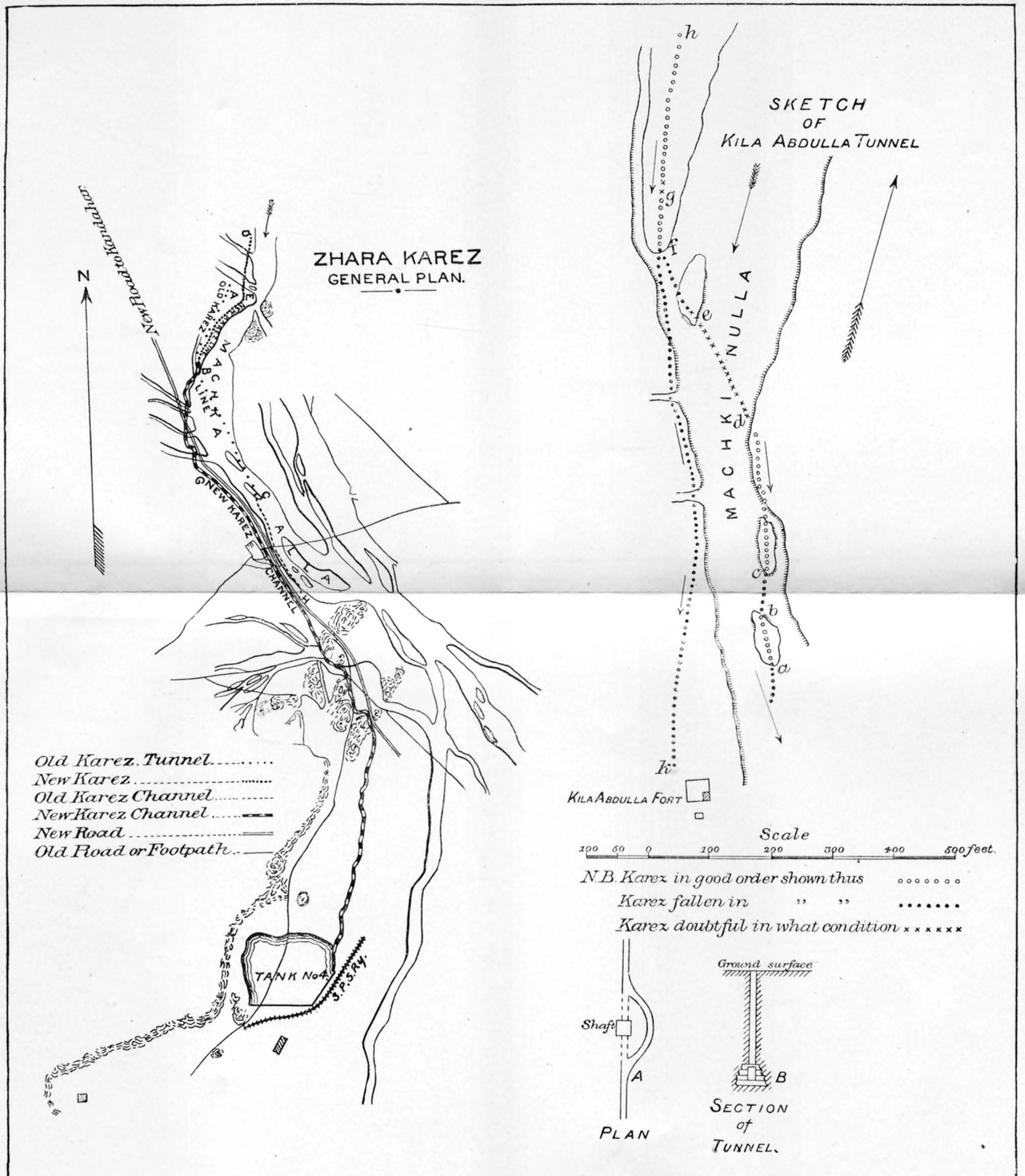
There is little or no direct irrigation from the main or branch channels. In almost every case the water is first let into the tanks in which it is stored. These are frequently of large size, as the Kaveripak tank on the northern and the Dusi Mamandur on the southern side, which irrigate 5,870 and 3,050 acres respectively. As at present constructed the system contains on the northern side 127 tanks irrigating 38,260 acres, or about 300 acres per tank, and 74 tanks irrigating 14,750 acres, or nearly 200 acres per tank on the southern side. Only a portion of these however are filled by river water, many of them receiving large supplies from the local drainage, which is conveyed to them by various channels.

The Palar River is an extremely objectionable one for the supply of a large irrigation system. The northern head-sluices receive a full supply only during an average of 22·6 days in each year, as the latter are 1½ feet above the sills of the northern sluices. The carrying capacity of the northern main canal is not more than 3,140 second-feet. It is 215 feet wide, carries 4 feet in depth of water, and has a fall of 3 feet per mile. The southern main canal is 113 feet wide, carries 4 feet in depth of water, and has a fall of 6 feet per mile with a discharge of 2,300 second-feet. Combining these results with the number of days during which the water supply is available it will be seen that the northern channel carries 140,000 acre-feet during the period of full supply and the southern channel 65,000 acre-feet. These are assumed as the volumes which determine the area capable of being irrigated.

ZHARA KAREZ IRRIGATION PROJECT.

This scheme proposes to store in detached small tanks the water supply which runs in the Machka torrent for a month or so in spring. The site of the scheme and the catchment basin of the torrent are in Beluchistan in the neighborhood of Khojak Pass. In the winter a good snow generally falls on the hills and after melting filtrates through the shale and runs off in springs lower down. The bed of the torrent has a slope seldom less than 1 in 70 where it leaves the hills; a short distance lower down its bed deepens until it is about 30 feet below the surface of the plain. There is no possible site for a large reservoir and accordingly five small sites for tanks were selected. About six of the last twenty years there has been no winter supply in the stream. In summer there are occasional heavy showers, but the floods last but a few hours and little or none of their water can be stored. The tanks are to be filled by small water courses leading from the stream (Pl. CXLV) and the water will then be utilized about the 1st of May in giving a final watering to rain-sown wheat crops, as the spring rains are generally sufficient up to that time. When empty, the beds of the tanks will be utilized for small crops without irrigation. There are no distributing canals, as in no case is anything larger than a large private water channel necessary.

The tanks are all on a comparatively small scale, the maximum depth having been fixed at 12 or 14 feet. As no clay was available for making puddle, the top of the bank is 3 feet above the full supply level, and the inside slopes are either pitched with bowlders or planted with willows. The outlet sluice is a simple concrete wall with numerous holes 0·8 of a foot in diameter placed at various depths and closed by wooden plugs, which can be opened by hand from a movable ladder resting on top of the well. From the bottom of the well a culvert leads under the embankment with stop walls on the outside. There is scarcely any local drainage to any of the tanks, and hence no large escapes are necessary. As a precaution the top of the well is only carried up to the full supply level.



ZHARA KHAREZ IRRIGATION PROJECT, BELUCHISTAN.

The total amount of water available in the tanks for purposes of irrigation, after deducting losses by absorption, will be 1,550 acre-feet, and this is estimated to be sufficient to irrigate 2,570 acres; from which deduct about 30 per cent for the bad years, when there will scarcely be any rainfall, the average acreage irrigable during the dry season will be about 1,800. To this may be added 200 acres of wet-weather crop sown in the tank bed. The total cost of constructing this system of tanks is estimated as being $2,800, and the total revenue is estimated to be 75 cents per acre, from which it will be seen that the scheme as a whole is estimated to pay 4 per cent.

In 1887 the construction of tank No. 4 was authorized, in addition to which a tunnel 5,800 feet in length was authorized to be constructed under the stream channel with shafts at every 50 feet, and curved passages around each shaft with a short piece of open excavation 900 feet in length. From the last shaft to the surface of the ground is an open channel 2,500 feet in length to connect the tunnel with tank No. 4. The object of this tunnel is to intercept the subsurface drainage and thus insure a supply to the tank which will immensely increase its utility as an irrigating reservoir.

For many generations there has been an old tunnel at this site which frequently fell into decay and disuse until again cleaned out. Its alignment is shown in the accompanying illustration (Pl. CXLV). About the year 1883 a portion came to grief through a flood finding its way down some of the shafts, and since then it was not used until its repair was proposed in 1887. By the latter part of 1887, 40 shafts and a half mile of the tunnel had been completed. The water-bearing stratum had been reached and a discharge of half a second-foot obtained. The old tunnel worked with a constant discharge of 9 second-feet for 40 years. As the new channel is better located and in better soil, it is estimated to give at least as good results as the old one did. The slope of the tunnel is 3 in 1,000; the sections 3 by 1·7 feet, or say 5 square feet, which with a mean velocity of 1·8 feet per second will give a maximum discharge of 9 second-feet.

The estimated cost of this work is nearly $4,000. The rates paid were 10 cents per lineal foot in depth of shaft and 20 cents per lineal foot of horizontal tunnel, the excavation being entirely in earth. The returns estimated are as follows: Discharge, 9 second-feet; area irrigable by one second-foot or duty, 150 acres; rate per acre, $1.50; gross revenue, about $1,600. The maintenance charges will amount to practically nothing.

RIVER CONSERVANCY.

In connection with all irrigation works maintained on the great plains and deltaic rivers of India, river training and improvement works must be constructed in order to maintain the stream in the channel which will cause it to do least injury to the various irrigation works. During seasons of flood the branches of these great rivers change, as does

the Missouri River, tearing into enormous tracts of the surrounding country, and they would if not properly guided destroy great portions of the canal and remove hundreds of acres of valuable irrigable land. In addition to this destruction of property, they cause severe inundations during times of flood, which destroy valuable crops and property.

These inundations, when of small magnitude and confined within reasonable limits, do little harm and even much good may result from them. They do not tend to increase the healthiness of the neighborhood, but the silt deposited by the water tends to fertilize the land, thus enabling richer crops to be produced with much less trouble. Autumn crops which lie along the edge of inundations of this minor class are usually defended by earth embankments, which often extend for miles in length. These embankments are of no great height or solidity, and are merely built in comparatively shallow water to save the crops, but inundations of greater magnitude, where the waters attain great force and extend through the heart of a large district, destroying houses, bridges, and canals, and washing away land, are of another kind. In providing a remedy for this class of inundation the engineer must possess great skill and patience.

The planting of Nanel grass, which is a long, coarse variety of water grass, when the plantations are properly arranged and progressively made, gives one of the best means of reclaiming parts of the river which are beyond the proper boundaries of the water way. This grass thrives in the streams of India, the cost is much less than that of any other treatment, and the reclamation is performed by the action of the river itself, by the deposition of silt due to the reduction of the current, so that water highly charged with silt at the upper end of a plantation is often found to issue from the lower end with little or no discoloration.

Above and below the head works of the Lower Ganges canal at Narora the river flows through a low bottom land which is limited at some distance back from its banks by a bluff about 60 feet in height. It was immediately found necessary to construct training works to prevent the stream from cutting into this bottom land, thus turning the end of the weir from above, or perhaps cutting into the bank and destroying the canal itself below the weir. These training works extend for 4 miles above the head of the canal and about 15 miles below it (Fig 270). The works consist on the upstream side of the weir of a long earthen embankment from which other embankments of earth jut out at right angles to the course of the stream, thus forcing the current over to the other side. At first these embankments, or, as they are called, "groynes," were constructed so as to point downstream, making an angle of perhaps 45 degrees with the course of the current, but it was found that they did not work well. They have since been re-aligned so that they project at right angles to the stream, and are placed exactly one-half mile apart, and they are found to perform their work excellently. As yet none have failed.

These groynes are often very long, some as much as 2½ miles in length. They are simply straight embankments of earth 10 feet wide on top with slopes of 1 on 2. The last 150 feet at the end of the groyne, or the nose, as it is called, is paved with heavy stones to a depth of 2

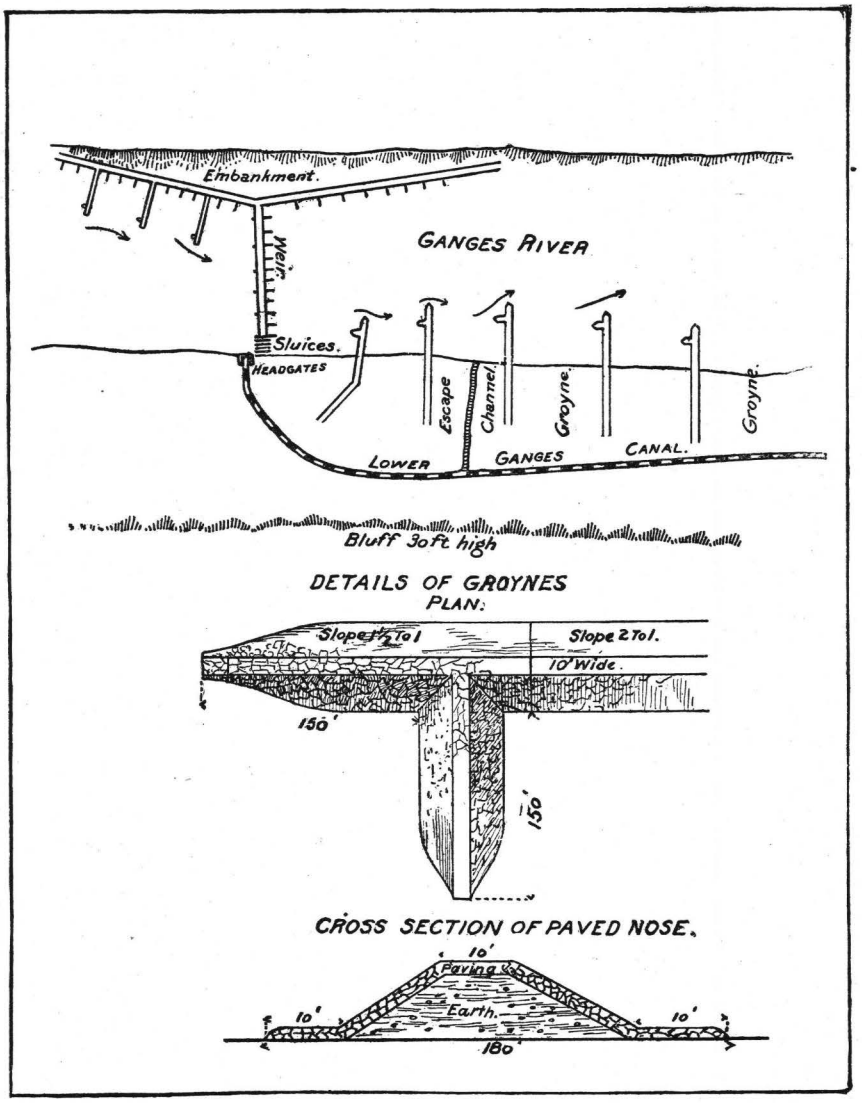


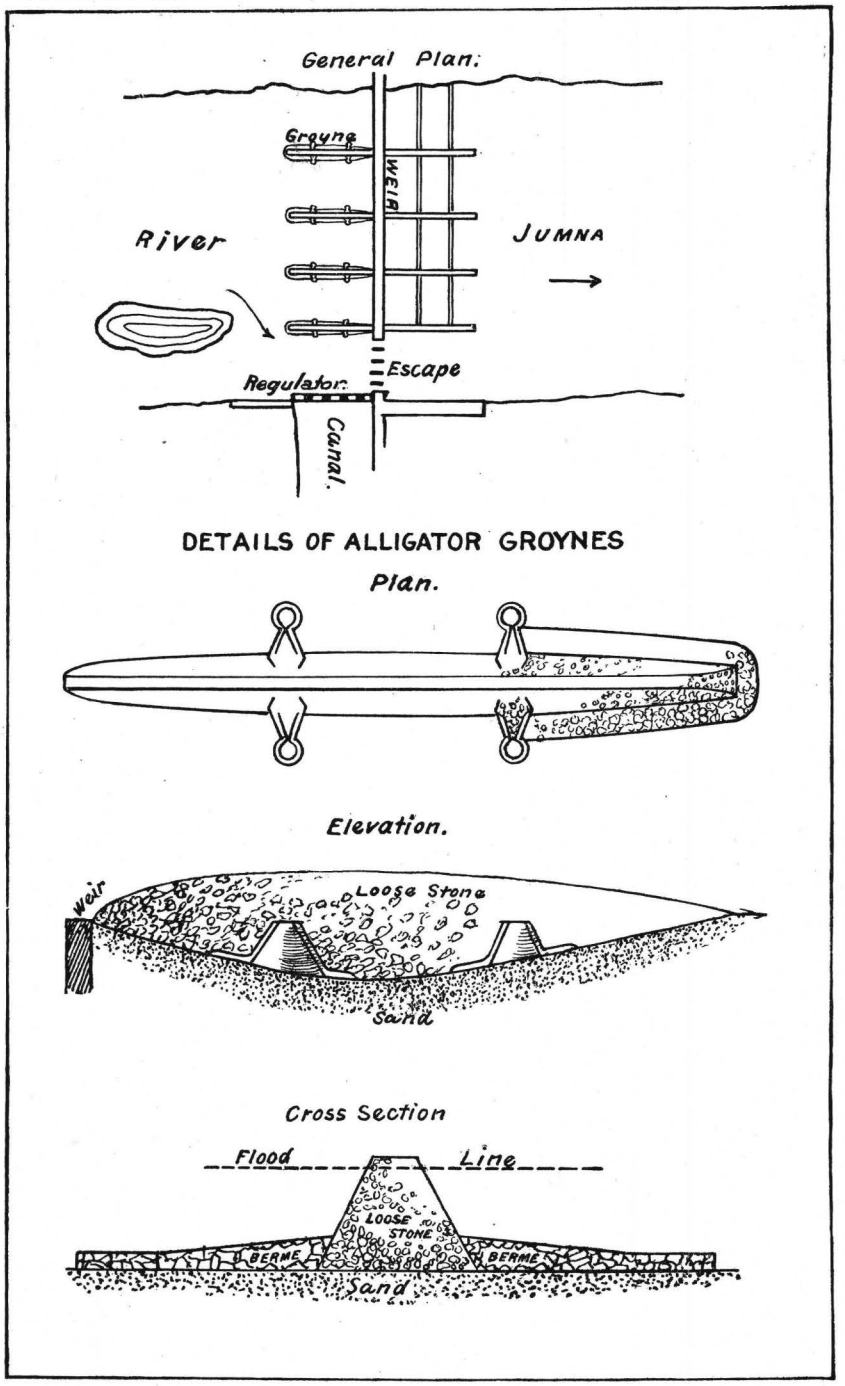
FIG. 270.—Training works, Lower Ganges Canal, Narora.

to 3 feet, and at 50 feet from the end a spur 50 feet in length similarly paved is run at right angles to the line of the bank pointing upstream.

At Hardwar, the head of the Ganges Canal, the river runs between high steep gravel and rock banks, on which it is able to make no im-

pression by erosion, and training works are therefore unnecessary below the weir. Above it, however, the bed of the stream is so broad and is divided into so many channels during the dry season that it is necessary to construct extensive training works to keep open a permanent channel known as the Hardwar channel, which passes in front of the head of the canal and supplies it with water. The fall of the river above the head works is 8 feet per mile, and at low-water stage it has a velocity of 6 feet per second. This velocity is many times greater in periods of flood. As shown in the plan of the head works at Hardwar (Pl. CXVII) the training works consist of bars sunken into the river channels to prevent the retrogression of grades and the consequent destruction of the dams; of weirs to turn the water into the Hardwar channel; of rectangular groynes projecting into the river similarly to those on the Lower Ganges Canal, in order to keep the water in the Hardwar channel; and, lastly, of embankments of bowlders to protect the weaker portions of the river banks. Great difficulty has been encountered in maintaining the integrity of the noses of the groynes as the heavy floods undercut these and cause them to fall into the river. Great concrete blocks 3 by 5 by 2 feet in dimensions, weighing 2 tons each, are first dropped into the river as a foundation for the groynes. When these reach the water surface the end of the groyne is built up of loose concrete blocks in a regular manner and the remainder of the groynes, constructed of bowlders, is run back from this end. As the floods wash away the foundation blocks, the built-up portion of the groyne falls in and replaces them, furnishing a new foundation, and this in turn is itself replaced, thus in the course of a few years the bed of the river becomes filled to such a depth with these blocks that further destruction ceases to take place and the groynes will then stand for many years.

At the head of the Agra canal at Okhla the weir which diverts the water into the canal head is, as before described, constructed of loose hand-placed rocks and to preserve its integrity, and at the same time to train the course of the Jumna River toward its right bank and against the head of the canal, groynes of a peculiar form of construction are run out at right angles to the line of the weir (Pl. CXLVI) and parallel to the course of the river. These works are known as "alligator groynes" from their peculiar form which somewhat resembles that of an alligator. They are constructed of loose stones dumped into the river without any foundation on which to rest, the tops and sides of the groynes being carefully hand laid so as to give them shape and integrity. The floods annually wash away portions of these groynes at first and during low season they have to be repaired, but, like those on the Ganges Canal, in the course of a few years the mass of rock underlying the groyne becomes so great that repairs rapidly diminish in amount or entirely cease to be necessary. The tendency of the water in the river is to flow in a direction nearly parallel to the line of the weir and



TRAINING WORKS, AGRA CANAL, OKHLA.

toward the undersluices, thus destroying the weir. These groynes cause portions of the water to flow over the weir at right angles to it, thus doing it no injury. At the same time other portions of the stream are forced over against an island indicated in the accompanying plate, and tend to remove it at the same time furnishing a supply for the canal head.

Spoon-bills or legs are run out from the groynes at right angles, and a berm 10 feet in width is built around the end of the groyne and the spoon-bill. The portion annually destroyed is the berm. This falls into the river, leaving the main body of the groyne intact. The top of the groyne is built at an elevation of 1 foot above highest flood level, and the top of the spoon-bill is 7 feet below flood level.

LAND RECLAMATION.

A good deal has been done in some of the more swampy portions of India toward the reclamation of swamps and their conversion into valuable agricultural properties. This reclamation has been most extensively practiced in what are known as "duns," especially because it increases the healthfulness of these regions by substituting for marshes dry land under cultivation. Swamp reclamation has been practiced in various parts of the United States and the methods are essentially the same in character as those employed for the same purpose in India.

In reclaiming marsh lands, such as those in the "duns," it has been considered usually essential, first to make a complete survey of the region in order to discover the slope of the lands in the direction of which cuttings for the purpose of drainage can best be made. The lines on which the drainage cuts shall be made having been laid down it remains simply to so design these cuts that they shall command the gross area of the swamp in the most economical manner, and shall completely remove the water from it. Some of these drainage works have added thousands of acres of valuable land to the agricultural regions, and have changed fever-stricken neighborhoods to healthy cultivated fields where fevers are scarcely known. The financial returns from some of these works have been even greater and more satisfactory than those from irrigation works proper, and reclamation works of this character are now prosecuted in India with as much zest as is the construction of canals or storage works.

FINANCIAL STATEMENT.

Amount appropriated for and expended by the United States Geological Survey (Irrigation Branch) for the fiscal year ending June 30, 1891.

Amount appropriated under joint resolution of June 30, 1890, and subsequent dates, for irrigation surveys			$41,095.89
Amounts expended, classified as follows:			
A. Services		$20,310.99	
B. Traveling expenses		963.54	
C. Transportation of property		267.40	
D. Field subsistence		2,898.51	
E. Field supplies and expenses		4,783.70	
F. Field material		2,621.92	
G. Instruments		3,362.00	
K. Books and maps		16.00	
L. Stationery and drawing material		265.46	
N. Office rents		435.93	
O. Office furniture		127.00	
P. Office supplies and repairs		92.31	
Q. Storage		125.61	
R. Correspondence		4.39	
T. Bonded railroad accounts:			
Transportation of assistants	$173.10		
Freight	2.75		
		175.85	
Total expenditure			36,450.61
Balance unexpended June 30, 1891			4,645.28

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the first, second, and third quarters of 1891. (Irrigation appropriation.)

Date of payment	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
July 31	43	C. C. Willard	Rent of office, July, 1890	$266.66
31	61	Pay roll of employés	Services July, 1890	1,027.60
Aug. 29	52	Fred A. Schmidt	Irrigation supplies	10.80
30	69	Pay roll of employés	Services August, 1890	904.02
Sept. 4	6	Z. D. Gilman	Supplies	18.00
8	12	United States Express Co	Freight charges July, 1890	137.70
10	13	John C. Parker	Supplies	4.00
10	15	Charles G. Stott & Co	ditto	12.48
Oct. 10	12	Pennsylvania R. R. Co	Transportation of assistants	46.15
17	32	S. J. Haislett	Irrigation supplies	84.00
22	36	United States Express Co	Freight charges	13.25
29	46	Atchison, Topeka & Santa Fé R. R.	Transportation of assistant	63.76
29	48	Adams Express Co	Freight charges	50.25
Nov. 18	18	Columbia Phonograph Co	Phonographic services	20.83
Dec. 10	18	Pennsylvania Company	Transportation of assistant	37.05
1891.				
Jan. 13	1	J. U. Burket & Co	Irrigation supplies	2.25
		Total		2,698.80

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during month of July, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
July 30	1	E. S. Ritchie & Sons	Repairs to instruments	$20.00
30	2	William P. Trowbridge, jr	Traveling expenses	4.65
30	3	do	Field expenses	41.42
30	4	J. B. Williams	do	18.95
30	5	Frank P. Thwaites	do	6.00
30	6	T. M. Smith	do	30.00
30	7	J. B. Williams	Traveling expenses	68.10
31	8	W. B. Lane	Field expenses	61.60
31	9	J. B. Williams	Services July 1890	100.00
31	10	William Ham Hall	do	337.00
31	11	Frank P. Thwaites	do	75.00
31	12	L. C. Fraser	Rent of office	50.00
31	13	Albert de Rutg	Services July 9–15, 1890	13.54
31	14	William B. Lane	Services July, 1890	60.00
31	15	Pay roll	do	327.20
31	16	do	do	623.97
31	17	Sumner H. Bodfish	do	202.20
31	18	A. D. Foote	do	252.70
31	19	Pay roll	do	178.06
31	20	do	do	115.00
31	21	do	do	255.00
31	22	Robert Robertson	do	100.00
31	23	R. P. Irving	do	50.00
31	24	E. C. Hawkins	do	125.00
31	25	Lewis C. Goldsborough	Rent of office	35.00
31	26	Denver Transit and Warehouse Co.	Rent of storeroom	20.00
31	27	Robert Robertson	Field expenses	113.84
31	28	do	Traveling expenses	73.05
31	29	G. F. Wakefield	Field expenses	31.50
31	30	W. W. Follett	Traveling expenses	63.15
31	31	do	Services July, 1890	200.00
		Total		3,651.93

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during July, 1890.

1890.				
July 22	1	Willard D. Johnson	Traveling expenses	$63.90
22	2	S. C. Gallup	Supplies and material	174.29
22	3	J. W. Simons	Labor	25.30
22	4	J. A. Reeves	Storage	7.50
22	5	J. W. Simons	Repairs	412.35
24	6	R. W. Parry	Field expenses	15.50
24	7	Arcade Hotel	do	23.00
24	8	E. M. Douglas	do	27.05
25	9	do	do	38.55
26	10	W. T. Griswold	do	45.07
28	11	M. J. Kiely	do	39.05
28	12	E. M. Douglas	do	32.08
28	13	H. C. Daugberg	Pasturage	47.80
28	14	W. S. Bailey	Subsistence	7.35
28	15	W. O. H. Martin	Supplies	70.72
29	16	Willard D. Johnson	Field expenses	369.40
29	17	H. E. Clermont Feusier	do	60.98
31	18	Employés	Pay roll, services July, 1890	967.50
31	19	do	do	610.26
31	20	do	do	1,128.60
31	21	do	do	97.72
31	22	do	do	613.78
31	23	A. F. Dunnington	Services July, 1890	151.60
31	24	P. V. S. Bartlett	do	75.80
31	25	E. M. Douglas	do	168.50
31	26	A. F. Mack	do	20.95
31	27	Redick H. McKee	do	134.80
31	28	R. H. Chapman	do	117.90
31	29	C. H. Fitch	do	151.60
31	30	Amos Scott	do	60.00
31	31	H. C. Rizer	do	185.30
		Total		5,944.20

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the month of August, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 6	32	J. B. Williams	Traveling expenses	$55.25
6	33	....do	Field expenses	60.75
6	34	H. P. Croft	....do	22.00
7	35	Rene Wilson	Services July 1–31, 1890	5.00
7	36	F. M. Smith	Field expenses	86.35
8	37	Wm. B. Lane	Traveling expenses	38.21
9	38	F. J. Mills	Services July, 1890	125.00
9	39	W. L. Paddock	....do	75.00
9	40	John Beltz	....do	50.00
9	41	Oscar E. Harper	....do	50.00
9	42	Pay roll	....do	165.00
9	43	F. M. Smith	Field expenses	45.09
12	44	E. S. Nettleton	Services August 1–12, 1890	130.43
14	45	Wm. P. Trowbridge, jr	Field expenses	63.52
14	46	Russell Chase	....do	27.48
16	47	Curt W. Miller	Services July, 1890	20.00
16	48	E. S. Nettleton	Traveling expenses	19.70
16	49	W. A. Farish	Field expenses	104.35
16	50	F. H. Newell	....do	5.00
18	51	J. J. Lallie	Repairs to instruments	8.75
18	52	Lewis C. Goldsborough	Rent of office	17.50
18	53	E. C. Hawkins	Services Aug. 1–14, 1890	56.45
18	54	....do	Field expenses	8.00
18	55	J. B. Williams	Traveling expenses	30.35
21	56	Robert Robertson	Field expenses	167.77
22	57	G. T. Wakefield	....do	73.24
25	58	T. M. Brannon	Services July, 1890	75.00
27	59	F. M. Smith	Field expenses	74.35
29	60	Pay roll	Services Aug. 1–29, 1890	1,093.36
29	61	....do	....do	140.31
29	62	....do	....do	189.33
29	63	....do	....do	142.74
29	64	....do	....do	107.58
29	65	A. D. Foote	....do	230.41
29	66	H. P. Croft	Services July, 1890	60.00
29	67	T. M. Brannon	Services Aug. 1–29, 1890	70.16
29	68	Wm. B. Lane	....do	56.13
29	69	Wm. Ham Hall	....do	315.22
29	70	Frank P. Thwaites	....do	70.16
29	71	J. B. Williams	....do	93.54
29	72	Curt W. Miller	....do	18.71
29	73	Wm. B. Lane	Field expenses	71.20
29	74	Howard Sebree Co	Field supplies	93.93
29	75	Pay roll	Services Aug. 1–29, 1890	449.01
29	76	Wm. P. Trowbridge, jr	Field expenses	53.61
29	77	Russell Chase	....do	34.15
29	78	F. M. Smith	....do	84.50
29	79	Anderson Bros	....do	108.67
29	80	R. U. Parry	Forage of stock	50.40
		Total		5,196.86

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during August, 1890.

Aug. 6	1	Fred J. Knight	Services July, 1890	$151.60
6	2	A. F. Dunnington	Field expenses	49.50
6	3	Employés	Pay roll services, July, 1890	180.00
7	4	Fred A. Schmidt	Supplies	15.60
7	5	Willard D. Johnson	Field expenses	382.11
8	6	J. M. Dikeman	Services July 21–31, 1890	21.28
8	7	Frank R. Coffin & Brother	Material	37.10
8	8	....do	....do	41.52
8	9	Charlie Tong	Services July 23–31, 1890	13.05
8	10	W. T. Griswold	Field expenses	273.01
8	11	E. T. Perkins, Jr	....do	24.10
8	12	Charles Himrod	Subsistence	107.69
9	13	J. B. Block	Forage	10.86
9	14	J. W. Miller	....do	3.40
12	15	R. H. Chapman	Field expenses	17.00
12	16	H. E. Clermont Feusier	....do	39.75
15	17	C. D. Chinn	Forage	30.00
15	18	W. & L. E. Gurley	Material	30.00
15	19	W. J. Lloyd	Traveling expenses	39.50

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during August, 1890—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 15	20	Pat Young	Pasturage	$24.10
15	21	John Hill	Repairs	29.00
15	22	Willard D. Johnson	Field expenses	68.55
15	23	Spratlen & Anderson	Subsistence	71.34
15	24	....do	....do	106.40
15	25	....do	Supplies	6.70
15	26	J. B. Lippincott	Field expenses	23.40
16	27	R. H. Chapman	....do	33.10
16	28	F. Kline	Material	72.50
16	29	A. P. Davis	Field expenses	39.55
18	30	John Lee	Forage	72.00
18	31	E. M. Douglas	Traveling expenses	14.40
18	32	Nichols & Yager	Labor	20.00
18	33	Ione Coal and Iron Co	Pasturage	17.95
18	34	W. O. H. Martin	Subsistence	149.40
18	35	A. F. Dunnington	Field expenses	58.60
18	36	H. E. Clermont Feusier	....do	48.65
19	37	W. J. Luke	Repairs	32.25
19	38	W. O. H. Martin	Material and supplies	17.10
19	39	Samuel Myers	Supplies	8.00
19	40	Alex. C. Barclay	Field expenses	28.45
19	41	Reeves & Co	Forage	38.50
19	42	Fred. Laurence	Traveling expenses	56.85
19	43	W. & L. E. Gurley	Material	26.50
21	44	Gross, Blackwell & Co	Subsistence	31.28
21	45	C. C. Bassett	Field expenses	52.45
21	46	J. B. Lippincott	....do	6.24
21	47	Robert A. Farmer	....do	43.53
22	48	E. M. Douglas	....do	82.70
22	49	R. H. Chapman	....do	42.91
22	50	P. V. S. Bartlett	....do	18.25
22	51	A. C. Schmidt	Labor and supplies	86.45
22	52	Paul Holman	Services July, 1890	70.80
25	53	H. E. Clermont Feusier	Field expenses	78.20
28	54	J. W. Simons	Supplies	48.01
28	55	Spratlen & Anderson	Subsistence	87.12
28	56	....do	....do	87.12
28	57	S. C. Gallup	Material and supplies	160.99
28	58	Fred A. Schmidt	Drawing material	10.80
28	59	E. M. Douglas	Field expenses	187.75
28	60	Frank Frates	Subsistence	141.03
28	61	M. J. Kiely	Field expenses	26.00
29	62	Oppenlander & Rehm	Subsistence	55.36
29	63	Stuart P. Johnson	Traveling expenses	16.00
29	64	Thomas W. Hayward	Subsistence	14.56
29	65	O. L. Houghton	Material and supplies	19.35
29	66	William Malboeuf	....do	68.75
29	67	Gross, Blackwell & Co	Subsistence and material	233.39
29	68	A. F. Dunnington	Field expenses	54.05
29	69	P. V. S. Bartlett	....do	44.00
29	70	W. T. Griswold	....do	20.55
29	71	E. T. Perkins, jr	....do	9.65
29	72	....do	....do	40.91
29	73	Dave Chandler	Services July, 1890	50.00
29	74	J. B. L. McGuire	Services July 1–18, 1890	29.03
29	75	Employés	Pay roll Aug. 1–29, 1890	1,173.15
29	76	....do	....do	996.15
29	77	....do	....do	692.74
29	78	....do	....do	934.12
29	79	....do	....do	592.34
29	80	....do	....do	148.33
29	81	....do	....do	90.74
29	82	H. E. Clermont Feusier	Services July 1–Aug. 29, 1890	163.00
29	83	C. H. Fitch	Services Aug. 1–29, 1890	141.85
29	84	H. C. Rizer	....do	173.37
29	85	John H. Jackson	Services Aug. 7–21, 1890	14.52
29	86	J. R. Shaw	Forage	51.00
29	87	Alex. C. Barclay	Field expenses	17.44
		Total		9,636.34

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the first quarter of 1891, month of September, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 8	81	J. B. Williams	Traveling expenses	$10.85
8	82	do	Field expenses	58.25
8	83	Howard Sebree Co	Field supplies	80.19
9	84	F. M. Smith	Traveling expenses	24.25
9	85	J. B. Williams	do	101.20
9	86	do	Field expenses	53.92
10	87	Perkins Bros	Forage of stock	27.09
10	88	R. W. Parry	Storage	4.84
10	89	Frank P. Thwaites	Field expenses	5.61
10	90	Semple & Rose	Storage	5.80
10	91	Overland Freight Transfer Co	do	9.67
10	92	L. C. Fraser	Rent of office	46.77
11	93	W. A. Farish	Field expenses	154.23
11	94	F. M. Smith	do	99.79
12	95	Robert Robertson	Traveling expenses	192.04
15	96	Frank P. Thwaites	Field expenses	4.00
15	97	John A. Roebling's Sons Co	Field material	5.30
15	98	Edward Denny & Co	Office supplies	10.05
15	99	Wm. P. Trowbridge, jr	Field expenses	26.16
16	100	H. P. Croft	do	23.38
16	101	do	Services Aug. 1–29, 1890	56.13
17	102	T. M. Bannon	Field expenses	124.10
17	103	do	Traveling expenses	14.60
17	104	do	Field expenses	88.25
20	105	G. F. Wakefield	do	59.13
20	106	John S. Halsey	Storage	9.67
22	107	F. J. Mills	Field expenses	160.35
26	108	Denver Transit and Warehouse Co.	Storage	18.71
30	109	F. H. Newell	Field expenses	5.00
30	110	C. C. Everhart	Services Aug. 1–29, 1890	46.77
30	111	Dave Chandler	Services Aug. 1–24, 1890	38.70
30	112	H. E. Clermont Feusier	Field expenses	7.75
30	113	R. H. Chapman	do	14.75
30	114	W. & L. E. Gurley	Instruments	348.00
30	115	Willard D. Johnson	Field expenses	13.54
30	116	E. M. Douglas	do	29.12
30	117	Ione Coal and Iron Co	Forage of stock	39.00
30	118	do	do	14.30
30	119	Barney Gilmore	Services July 1–Aug. 29, 1890	20.00
30	120	W. J. Luke	Repairs	19.00
30	121	E. M. Douglas	Traveling expenses	12.13
		Total		2,082.39

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during September, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 6	1	Jno. W. Hays	Services Aug. 1–29, 1890	$110.33
6	2	Paul Holman	do	66.20
6	3	Pay roll	do	113.00
6	4	C. C. Bassett	Field expenses	34.70
6	5	Gross, Blackwell & Co	Supplies	26.70
8	6	Fauth & Co	Material	930.00
8	7	Wm. H. Hyde	Supplies	9.00
8	8	S. A. Newman	Pasturage	73.10
13	9	Robert A. Farmer	Field expenses	16.30
9	10	Willard D. Johnson	do	100.00
9	11	Andrew McClelland	Forage	290.72
9	12	Jno. M. Killin & Co	Material	209.65
9	13	Oppenlander & Rehm	Subsistence	63.68
10	14	A. P. Davis	Field expenses	60.18
10	15	P. E. Harroun	Services Aug. 2–16, 1890	24.19
10	16	Pablo Eusinos	Services July 28 to Aug. 27, 1890	25.00
10	17	Brown & Manzanares Co	Material	75.00
11	18	H. E. Clermont Feusier	Field expenses	45.86
12	19	Gross, Blackwell & Co	Subsistence	101.98
12	20	Wm. Malboeuf	Material	68.00
12	21	Nelson Morgan	Services Aug. 6–29, 1890	38.70
12	22	C. D. Chinn	Forage	30.00
12	23	Frank Bradbury	Services Aug. 1–15, 1890	19.35
12	24	Idaho Saddlery Co	Repairs	22.00
12	25	Iseli & Milne	Labor	44.25
12	26	W. T. Griswold	Field expenses	75.05
13	27	A. C. Schmidt	Supplies	41.25
13	28	Robert A. Farmer	Field expenses	14.00
13	29	R. H. Chapman	do	40.15
15	30	W. C. Skeels	Services Aug. 8–29, 1890	35.48
15	31	D. F. Alleus	Pasturage	20.00
15	32	C. C. Bassett	Field expenses	94.08
16	33	W. T. Griswold	do	9.05
16	34	Robert A. Farmer	Traveling	6.95
16	35	J. B. Block	Supplies	44.95
16	36	J. W. Miller	do	9.45
18	37	Amos Scott	Services Aug. 1–29, 1890	56.10
18	38	J. B. Lippincott	Field expenses	33.69
19	39	E. T. Perkins, jr.	do	9.00
19	40	A. F. Dunnington	do	24.65
19	41	Willard D. Johnson	do	82.13
22	42	E. M. Douglas	do	35.98
22	43	Fauth & Co	Supplies and material	531.50
22	44	do	do	525.00
23	45	R. W. Parry	Feed	15.60
23	46	Spratlen & Anderson	Supplies	85.41
24	47	Robert A. Farmer	Field expenses	13.86
30	48	W. J. Luke	Repairs	44.00
		Total		4,405.22

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during November and December, 1890.

1890.				
Nov. 3	1	Chinn Bros	Field material	$32.00
3	2	Frank R. Coffin & Bro	do	70.00
Dec. 29	3	E. M. Douglas	Field expenses	105.14
29	4	William P. Trowbridge, jr	do	21.50
29	5	Albert de Ruiz	Traveling expenses	3.25
29	6	George Ryneal, jr	Instruments	61.01
29	7	George A. Newton	Field material	47.68
		Total		$340.58

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during February and March, 1891.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1891.				
Feb. 11	1	Gross, Blackwell & Co	Material and forage	$99.69
11	2	Sparks Bros	Stock	590.00
14	3	Fred A. Schmidt	Instruments	150.00
24	4	John C. Parker	Irrigation supplies	30.75
Mar. 4	5	Lewis S. Hayden	Maps	15.00
16	6	Fauth & Co	Instruments	680.00
20	7	Wycoff, Seamans & Benedict	Irrigation supplies	125.00
31	8	Sparks Bros	Stock	460.00
		Total		2,150.44

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during May, 1891.

1891.				
May 6	1	W. & L. E. Gurley	Instruments	$168.00

Amount expended as per foregoing statement	$36,274.76
Amount of bonded railroad accounts for freight, $2.75, and passenger transportation, $173.10, settled through the Treasury Department	175.85
Balance on hand	4,645.28
Total	41,095.89

INDEX.

A.

Page.

Absorption from irrigation canals, India 430–435
Aden tanks, Arabia 387
Administration of irrigation works, India 407
Adobe Creek, Colorado, reservoir sites near 109–113
Agra Canal, India, described 386, 445–447
weir on 464
falls on 483
drainage reservoir on 488
Agricultural and financial results of irrigation in India 417
Agua Fria Creek, New Mexico, reservoir site on 198, 199
Agua Fria district, description of 315
Agua Negra Chiquita Creek, New Mexico, water supply 284
Agua Negra Creek, New Mexico, water supply 284
Albuquerque district, New Mexico, description of 270–273
irrigation practice in 272, 273
Alignment of canals, India 458
Alkali lands, India, effect of irrigation on 420–422
American Fork, Utah, flow of 335
Apishapa River, Colorado, reservoir sites on 94–95, 100–101
Arapaho Creek, Colorado, reservoir site on 91–92
Area cultivated and irrigated, India 396
Arid regions, extent and position of 219–220
Arkansas River, Colorado, reservoir sites on 79–81, 119–120
Arkansas River basin, discharges of rivers in 240, 349
Arlington, Colorado, reservoir site near 111–113
Arroyo Hondo, New Mexico, irrigation on 252
Ashti tank, India 545–550
Authors consulted in preparation of paper on irrigation in India, list 371–373
Automatic sluices, India 469
Automatic weir gate, Reinolds, India 509

B.

Baca location, No. 1, New Mexico, reservoir sites on 177–180
Bari Doab canal, India 450–451
falls on 482, 483
Battle Creek, Idaho, gauging station 333
Beale, H., aid by 377
Bear Lake 327–329

Page.

Bear River, upper 325–327
gauging on 327, 329
lower 329
tables of discharge 352
Beaver Creek, Colorado, reservoir sites on 66–67, 74–76
Beaver Head River, Montana, reservoir site on 148–150
Bells Meadow reservoir site, California 26–27
Berenda River, New Mexico, water supply 285
Beresford, J. S., cited on diminished efficiency of irrigating canals due to absorption and evaporation 430, 432, 433
Betwa canal system, India 383, 515–520
Betwa reservoir, India 383
Bhatgur dam, India 377, 507, 529
Bhatgur reservoir, Nira project 377
Big Hole River, Montana, reservoir site on 142–146
Big Horn River, Wyoming, discharge of 238
Big Meadow reservoir site, California ... 34–35
Blacktail Deer Creek, Montana, reservoir site on 147–148
Block foundations for masonry, India ... 477
Blue Water Creek, New Mexico, reservoir sites on 194–197
water supply 276
Boca Station, California, reservoir site at 42–43
Bombay Presidency, India, tanks in 543–544
Bonham, B. F., aid by 380
Boulder Lake, New Mexico, reservoir site on 166–167
Box Elder Creek, Montana, reservoir site on 156–157
Brazos Creek, New Mexico, water supply 265–266
Buckley, R. B., aid by 380
Buena Vista, N. Mex., reservoir site at 184–185
Burke, Chas. T., on dimensions of earthen dams 549
Buxar Canal aqueduct, India 485

C.

Cache la Poudre Creek, discharge of 239, 348
Cache Valley, description of 330–333
water storage in 332
canal system of 333
Caird, James, cited on value of irrigation works in India 394
California, reservoir sites in 10–54
work in 316–318

Page.

Canal acts, India 410
Canal and storage systems combined, India 553
Canals, India (inundation) 425–427
(deltaic and perennial) 428, 435–439
cross sections 455
alignment of 458
regulating gates in 473–477
Canal system, Rio Grande Basin 280
Upper Gila 303
San Pedro 304
Middle Gila 306
Lower Salt 312
Lower Gila 314
Upper Bear River 326
Bear Lake 329
Lower Bear River 333
Cangilon Creek, New Mexico, water supply 264, 266
Canyones Creek (Lower), New Mexico, water supply 264, 266
Canyones Creek, New Mexico, water supply 265, 266
Carpenter, Prof. L. G., on fluctuations of the Cache la Poudre Creek 239
Carson River, Nevada, description of 325
tables of discharge of 351
Catchment basins, discharge from 500
Cautley, P. T., cited on Ganges Canal project 439
cited on employment of escapes in irrigation canals, India 479, 480–481
Cauveri River, India, table showing discharge of, etc 402
Cavour Canal, Italy 388
Cawnpur branch, Ganges Canal 442
Cebolla Creek, New Mexico, water supply 264, 266
Cement used in dam construction, India 528–529
Chama district, New Mexico, description of 261–269
water supply of 262–266
irrigable lands of 267
irrigation practice in 268
Cherry Valley Lake, New Mexico, reservoir site on 186–188
Cherry Valley reservoir site, California 31–33
Chicken Creek, Utah, water supply 342
Chuki torrent diversion work, India 484
Churus or mot, a form of irrigation well in India 423–424
Circulation of irrigation water in soil, India 497
Clarkston Creek, Utah, water supply 332
Clasoil station, Montana, reservoir site near 141–142
Clear Creek, Utah, water supply 341
Clerke, W., aid by 375, 378
Coffins Hollow reservoir site, California 27–28
Collinston, Utah, gauging station 333
Colorado Creek, New Mexico, irrigation on 251
Colorado district of the Rio Grande, area, topography and hydrography of 245–250
irrigation practice in 248–251

Page.

Colorado reservoir sites 55–127
Colorado River, description of 290–292
gaugings of 291–292
Concrete and cement used in irrigation works, India 529
Condilo, N. Mex., reservoir site at 183
Conduitt, H. W., aid by 382
Confederate Gulch, Mont., reservoir site near 140–141
Corbin, E. C., on effect of irrigation on alkali lands 421
Cost of construction of irrigation works in India 530–536
Cost of labor and materials for irrigation works, India 392
Cotton crop in India 396
Cottonwood Creek, Colorado, reservoir site on 105–106
Cottonwood Creek, Idaho, water supply 330
Crofton, J., cited on financial returns from investment in irrigating works in India 393
cited on current velocity in irrigation canals 457
Crops, divisions by seasons, India 369, 398
extent and varieties of, India 396–397
Cross section, slope and alignment of canals in India 455–458
Cross sections of dams, India 538
Cucharas River, Colorado, reservoir site on 89–91
Cultivated area, India 396
Cunningham, H. S., cited on value of irrigation works in India 394

D.

Daileys Pinnacle, Montana, reservoir site at 148–150
Dailey's Ranch, Montana, reservoir site at 147–148
Daisy Dean Creek, Montana, reservoir sites on 129–132
Dams, India, cross sections of 455
design of 535
(earth) India 548
Dauphin Rapids, Montana, gauging at 237
Davidson, Geo., cited on dam construction 459
Davidson, S. A., discharge measurements of Salt River, Arizona, by 312
Dearborn River, Montana, gauging on 237
Deccan, rivers of the 401
Deep Creek, Montana, gauging on 237
Deer Creek, California, reservoir site on 17
Deficiency of water for irrigation in arid regions 221–223
Dehree headworks, Soane canals 381
Deltaic and perennial canals, India 428
Deltaic canals, India 435–438
Deseret, Utah, irrigation around 343
Dickens, C. H., cited on expenditures for irrigation works in India 393
Discharge gaugings, India 435–495
tables, North Platte River 240
tributaries of the Chama River 266

Page.
Discharge tables, Gila River 306
Verde River 310
Salt River, in canyon 311
Salt River, Arizona dam 313
Discharge tables, rivers of arid region ..345–361
Distributing canals for irrigation in India 490–495
Drainage basins classified 232–234
Drainage basins, India 400
Drainage works, India 484–490
Dry Lake reservoir, Montana 155–156
Dumont's Meadow reservoir site, California 21–23
Duns, India, canals in 400, 446
Duty of water 223, 224
San Luis Valley 250
Gila Basin 296–298
India 428
Dyar, H. M., work of 241

E.

Earth dams, India, stone pitching of 548
cross section of, India 549
dimensions of, India 550
East Fork of Arkansas River, Colorado, reservoir site on 115–116
Eight Mile Creek, Colorado, reservoir site on 73–74
Ekruk tank, India 544
El Rito Creek, New Mexico, reservoir site on 169–170
water supply 263–266
Embudo gauging station, New Mexico, work at 257–258
Engineer Corps, United States, Army, gaugings of Missouri River by .. 237
Errarar Meadow reservoir site, California 35–36
Escapes from irrigation canals, India ..479–481
Espanola Valley, New Mexico, irrigation in 258–261
Espiritu Santo grant, New Mexico, reservoir site on 180–181
Etawah branch, Ganges canal 442
Evaporation observations, Utah, Texas, Arizona 234–235, 308, 337, 338
Evaporation, from canals, India 430–435

F.

Falls and rapids in irrigation canals, India 481–484
Falls River, Idaho, flow of 344
table of discharge of 356
Famines in India and America 391
Ferdinand Creek, New Mexico, irrigation from 254
Ferrel, William, on cause of diversity of climate 220
Financial and agricultural results, India 394–417
Floods, relative amount of 227–228
time of 228–229
intensity of 227–228, 230
Follett, W. W., work of 241, 280
Forestry, India 404, 405
Forrest, James, aid by 375
Foundation wells or blocks, India 477
Frijoles Creek, New Mexico, water supply 264, 266

G.

Gallinas Creek, New Mexico, water supply 264, 266
Gallinas Springs, water supply of 287
Gallisteo Creek, New Mexico, water supply 270, 273, 277
Galton, Douglass, on effect of irrigation on health in India 420
Ganges Canal, India, description 385, 439–443
(Lower) description 443–444
Hardwar weir 465
Myapur dam 467
regulating gates for 474
escapes on 480
falls on 481
Solani aqueduct on 485
superpassages on 487
Ganges River, table showing discharge of, etc 402
Gannett, Henry, gaugings by 239, 327, 329
Gaugings of river discharges, India 435
Gentile Valley, Idaho, description of ...329–330
Geology of India 402
Ghauts (The) in India 401, 403
Gila district, middle 305, 306
lower 314
Gila River basin, irrigation in 292, 295–298
description of 292–316
topography of 292–294
area of 295
agricultural lands in 295
duty of water in 296–297
storage of water in 298, 308
rainfall in 299–301, 307
upper Gila district 302
San Pedro district 303, 304
middle Gila district 305–306
evaporation in 308
Verde district 309
upper Salt district 310
lower Salt district 311–313
lower Gila district 314
Glen Station, Mont., reservoir site near ..142–146
Godaveri River, India, table showing discharge of, etc 402
canal system, India 436
Graneros Creek, Colorado, reservoir on .. 87–88
Granite Lake reservoir site, California .. 30–31
Grape Creek, Colorado, reservoir site on .. 56–58
Grass Lake reservoir site, California 46–47
Great Basin, general description 324
Truckee River 324
Carson River 324
Salt Lake Basin 325–338
Sevier River 339–344
Groynes, Lower Ganges Canal, India 558
Agra Canal, India 560
Gusana, N. Mex., reservoir site at 190
Gypsum Plains district, description of .. 281

H.

Page.

Hall, Wm. Ham, work of 316, 317
Hardwar weir, Ganges Canal 465
Harvey's Meadow reservoir, California .. 51-52
Hassayampa district, description of 315
Hayden, F. V., reports of 239, 327, 329
Headwater districts, defined 232, 233
Headworks of canals in India 458-460
  Nira Canal, India 510
Heenan Lake reservoir, California 17
Henry Fork, Idaho, flow of 344
  table of discharge of 355
Hermit Valley reservoir site, California . 23-24
Hetchy Hetchy Valley, California, reservoir site in 36-38
Hill A., cited on effect of scouring sluices . 508
  cited on masonry construction of Bhatgur dam, India 529
Himalayas 399
History of irrigation, India 406
Hondo River, New Mexico, water supply of 285, 286
Hope Valley reservoir site, California ... 47-50
Hopson, L. D., work of 241
Horse Lake reservoir, New Mexico 165-166
Hot Springs Indian Reservation, reservoir site on 202-203
Huerfano River, Colorado, reservoir site on 88-89
Hughes, W. C., aid by 375
Hulls Meadow reservoir site, California . 28-30
Humidity and irrigation 234
Hydrographic data, sources of 221
Hydrographic work, nature of 219

I.

India, paper by H. M. Wilson on irrigation in 363-561
  rainfall in 369, 403, 404
  financial returns from irrigation in . 390-396
  nature of crops in 396
  areas cultivated and irrigated in 396
  geology of 402-403
  meteorology of 403-404
  forestry in 404-405
  history of irrigation in 406-414
  administration of irrigation works in 407-414
  wells and inundation canals in 415-427
  extent of irrigation in 416-417
  financial and agricultural results of irrigation in 417-419
  objections to irrigation in 419-422
  cost of irrigation works in 530-536
  tanks in 536-550
  (Northern) compared to western United States in matter of irrigation . 390-392
Indian Pool reservoir site, California 17
Inundation canals for irrigation, India 415, 425-427
Irrigated area, India 396
Irrigation in India, paper by H. M. Wilson on 363-561
  financial returns from 390-396
  classes of 390-415
Irrigation in India, extent of 392-417
  financial and agricultural results ... 417-419
  objections made to 419-422
  method of applying water to crops .. 495-497

J.

Jemez River, New Mexico, hydrography of 274, 275, 277
  agriculture on 275
Jordan River, Utah, flow of 335
Joseph City, Utah, irrigation around 342
Judith River, Montana, reservoir site on . 160

K.

Kali Nadi aqueduct 486
Kao Nulla siphon aqueduct, Soane Canal, India 490
Kaweah River, water supply 320
Kern River, water supply 319
Kilburn, Colo., reservoir site near 109-111
King, M., aid by 385
King, W., aid by 380
Kings River, water supply 320
Kirkwood Creek, California, reservoir site on 52, 53
Kistna River, India, table showing discharge of, etc 402
Kistna River canal system, India 436
Kurra aqueduct, Nira Canal, India 513, 514
Kushuk Fall, Agra Canal 483

L.

Labor in India on irrigation works, cost of 530-536
Laguna Pueblo, N. Mex., reservoir site on 192-193
Lake Alice, Wyoming, description of 327
Lake Fife reservoir, India 376, 504-505
Lake Vernon reservoir site, California .. 33-34
Land reclamation, India 561
Land value increased by irrigation, India . 393
Laramie River, Wyoming, discharge of . 239
Las Animas, Colo., reservoir site near .. 111-113
Las Animas River, Colorado, reservoir site on 125-127
Leamington, Utah, gauging station 344
Lebo Lake reservoir, Montana 163-164
Legislation in India concerning irrigation 407
Le Quesne, W. H., aid by 378
Lima, Mont., reservoir site near 150-151
Lincoln's Ranch, Mont., reservoir site near 134-137
Little Chama River, New Mexico, water supply 265-266
Little Truckee River, California, reservoir site on 38-40, 42-43
Lost river districts 232, 233, 234, 315
Lower Ganges Canal, headworks of 383-384
  description 443-444
  Narora weir 463
  regulating gate for 476
Lower Gila district 311
Lower Salt district 311-312
Lower San Joaquin River water supply . 323, 224

Page.
Lower Truckee reservoir site No. 1, Nevada 209–210
Lower Truckee reservoir site No. 2, Nevada 210–212
Lucero Creek, New Mexico, irrigation from 254

M.

Madison River, Montana, discharge of 236, 346
Madras Presidency, India, tanks in 542–543
Madura Plains, India, irrigation in 524
Mahaunddy, automatic sluices 469
Mairwara tanks, embankments, and weirs, India 540–541
Malarial results of irrigation, India 419
Marr, G. A., gaugings of Missouri River, by 237
Martinsdale, Montana, reservoir sites near 127–129, 164–165
Masonry dams, India 527
Material, labor, and cost, irrigation works, India 530–536
Maxwell land grant, Colorado, reservoir sites on 96–99
Merced River, water supply 322
Mesilla Valley, New Mexico, description of 279–280
Meteorology, India 403–404
Midnapore canals, Bengal 437
Mink Creek, Idaho, water supply 330
Missouri River, Montana, discharge of 236–237, 347
Mitchell Creek, Montana, reservoir sites on 141–142
Mohammedan canals, India 406
Mokelumne River, California, reservoir site on 24–25
water supply 323
Molesworth's formula for dam construction 535
Moncrieff, Scott, aid by 387
Monkman's Ranch, Montana, reservoir site near 155–156
Montana reservoir sites 127–165
Monument Peak, California, reservoir site at 43–44
Mora River, reservoir sites on 183–185
Mot or churus, a form of irrigation well in India 423–424
Mount Bullion, California, reservoir site at 16
Mudduk Masur tank, India 538–539
Musselshell River (north fork), Montana, reservoir sites on 128–129, 132–133
Musselshell River (south fork), Montana, reservoir sites on 133–134
Mutha Canals, India 376–377
Mutha Canal scheme 504–506
Myapur dam, Ganges canal 467
Mysore, India, tanks in 541–542

N.

Nadrai acqueduct, India 486
Narora weir, Lower Ganges, India 463
Needles, Sidhnai weir 472
Nevada reservoir sites 209–212
New Mexico reservoir sites 165–209
Newton reservoir, Utah 332
Nira canals, India 377, 506–515
Northern plain, India 400
North Platte River, discharge of 239–240
North Utica Lake reservoir, Montana 161
Nutrias Creek, New Mexico, water supply 264–265, 266
Nutritas Creek, New Mexico, water supply 265–266

O.

Oak Grove Creek, Colorado, reservoir site on 120–121
Oasis, Utah, irrigation around 343
O'Brien, E., on effect of irrigation on alkali lands 420
Ogden River, Utah, water supply 334
table of discharge of 353
Ogee falls, Ganges canal 481
Oil Creek, Colorado, reservoir sites on 62–64, 67–68
Ojo Caliente, New Mexico, reservoir site on 202–203
Ojo Caliente Creek, New Mexico water supply 263–266
Oreste, Canavotte, aid by 388
Orissa canals 437
Oso Creek, New Mexico, water supply 263–266
Otter Creek, Montana, reservoir site on west fork of 158
Otter Creek, Utah, water supply 340
Owyhee River, Oregon, flow of 344
table of discharge of 357

P.

Pacific Valley reservoir site, California 25–26
Paecottah, a form of Indian well-sweep, etc 423, 424
Palar anicut combined storage and canal system, India 554–556
Palmer, C. G., aid by 386
Palmer, E. C., cited on time required for saturation of fields 434
Panguitch Hayfield, Utah, description of 340
Panguitch Lake, Utah, water supply 341
Pecos River, New Mexico, reservoir sites on 189–190
canal system of 289
Pecos River district, description of 282–290
climate and water supply of 283–284
irrigation and agriculture in 287–290
Peile, J. P., cited on value of irrigation works in India 394
Penasco Creek, New Mexico, water supply of 286
Percolation and evaporation 430–435
Perennial canals, India 438–439
Periar Canal project, India 520–525
Periar dam, India 522, 527
Persian wheel, a machine used for irrigation from wells in India 424, 425
Picuris Creek, New Mexico, reservoir site, on 174

Page.
Picuris Indian Reservation, reservoir sites on 174–175
Pine Creek, Colorado, reservoir sites on 58–59, 116–119
Plateau Valley, Utah, description of 340
Platte River Basin, discharges in 238–240
Pleasant Valley, California, reservoir site in 14–15
Pojuaque Creek, New Mexico, irrigation from 260
Political divisions, India 408
Porter, A. G., aid by 388
Precipitation. (*See* Rainfall.)
Profiles of masonry dams in India 534–536
Provo River, Utah, flow of 338
table of discharge of 354
Public works department, India 409
Pueblo Creek, New Mexico, irrigation from 253
Puerco, N. Mex., water supply 275–277
irrigation on 276, 277
Purgatoire River, Colorado, reservoir sites on 96–99
Puertocito, N. Mex., reservoir site at 188–189
Pullers Springs, Montana, reservoir sites near 152–155
Punjab, India, canals in 447
Puthri torrent crossing, Ganges Canal 441–442, 487

Q.

Quinby, G. T., work of 241

R.

Railway carriages, India 379
Rainfall, Gila basin 299–301, 307
India 359, 404
Rio Grande Basin 243–245
not increased by irrigation 234
relation to river flow 226, 230–231
Ranipur torrent crossing, Ganges Canal 441, 487
Rebsch S., aid by 376
Reclamation of land, India 561
Red Lake Reservoir, California 13–14
Red Rock Creek, Montana, discharge of 236
Red Rock River, reservoir site on 150–151
Regulating gates for canals in India 473–477
Regulator, Nira Canal, India 512
Reh Commission, India 421
Reservoir sites located and surveyed during fiscal year 1890–'91 1–212
platted and their reservation from entry or settlement requested 9
Reservoir sites, India 499
Reservoirs and tanks, India, discriminated 498
India, statistics 503–504
Rice crop in India 397
Rice, irrigation of 496
Rio Caliente, New Mexico, reservoir site on 171–172
Rio Colorado, New Mexico, reservoir sites on 173–174, 199–200
Rio Felix, New Mexico, water supply of 286
Rio Grande, New Mexico, reservoir sites on 175–176, 191–192, 203–209

Page.
Rio Grande Basin, area, topography, and detailed hydrography of 240–290
rainfall in 243–245
Colorado district 245–250
discharge of 246, 257, 280, 349–350
Taos district 251–256
Tres Piedras mesa 256
work at Embudo gauging station in 257
Española Valley 258–261
Chama district 261–269
Santa Fé district 269
Albuquerque district 270–273
Santa Fé River and adjacent streams 273, 274
Jemez River 274
Puerco River 275–277
résumé of water supply in 277
mesas along 278–279
canal system in 280
Mesilla Valley 279–280
Gypsum Plains district 281–282
Pecos River and tributaries 282–290
Rio Grande de Taos, New Mexico, irrigation from 254
Rio Hondo, New Mexico, reservoir site on 173
Rio Jemez, New Mexico, reservoir sites on 178–179, 181–182
Rio Mora, New Mexico, reservoir sites on 183–185
Rio Pecos, reservoir site on 189–190
Rio Salado, New Mexico, reservoir sites on 200–201
Rio San Antonio, New Mexico, reservoir site on 180
Rio San José, New Mexico, reservoir site on 192–193
River conservancy, India 557–561
River discharge and rainfall 226, 230–231
River discharge gauging, India 435
River systems, India 402
River trunk districts, defined 232, 233
Roberts, Thomas P., gaugings on Missouri River 236–237
Rock Creek, Colorado, reservoir site on 121–123
Rocky Ford, Colorado, reservoir site near 107–109
Rocky Gap reservoir, Montana 137–138
Roswell, N. Mex., irrigation around 289
Ruby River, Montana, reservoir site on 152–153
Rule Creek, Colorado, reservoir site on 103–105
Run-off tables 358–361
Rush Creek, Colorado, reservoir site on 83–84
Rutmoo torrent level crossing, Ganges Canal 442, 448–490

S.

Sacramento Basin, general description 316–318
Sage Creek, Montana, reservoir site near 159
Saint Charles River, Colorado, reservoir sites on 84–87
Salado Creek, New Mexico, water supply of 277
Salt Lake Basin, description of 325–338
Upper Bear River 325–327
Bear Lake 327–329
Lower Bear River 329
Cache Valley 330–333
Ogden and Weber rivers 334
Utah Lake drainage 334–339

Page.
Salt River district (upper), description of 310
(lower), description of 311–313
San Antonio Creek, New Mexico, reservoir site on 177–178
San Cristobal Creek, New Mexico, irrigation on 252
Sand Creek, Colorado, reservoir site on. 70–71
San Felipe, N. Mex., reservoir site near. 191–192
San Ildefonso Creek, New Mexico, water supply of 277
San Luis Valley, area and topography of 247–250
administration of irrigation service in 249–250
water duty in 250
San Mateo Creek, New Mexico, reservoir site on 193
Sanpitch River, Utah, water supply 342
Santa Ana Pueblo, N. Mex., reservoir site near 181–182
Santa Clara Creek, New Mexico, water supply of 277
Santa Clara River, Colorado, reservoir site on 92–94
Santa Cruz Creek, New Mexico, water supply 260, 277
Santa Cruz district, description of 315
Santa Fé Creek, New Mexico, reservoir site on 182–183
water supply of 273
Santa Fè district, description of 269–270
San Joaquin Basin, general description. 316–318
Kern River 319
Tule River 319
Kaweah River 330
Kings River 320
Upper 321
Merced River 322
Tuolumne River 322
Mokeulmne River 323
Lower 323
San José Creek, New Mexico, water supply 276
San Luis Valley, irrigation in 247
San Pedro district, Arizona, description of 303–305
Sapello, N. Mex., reservoir site at 185–186
Sasoon superpassage, Sirhind Canal, India 488
Schuyler, Eugene, aid by 387
Scouring sluices in weirs, India 467–473, 508
Sediment measurements at Embudo, N. Mex 258
Seven Mile Creek, Colorado, reservoir site on 55–56
Seven Rivers, New Mexico, water supply of 286
Sevier River Basin, description of 339–344
water storage in 340, 341, 342, 343
East Fork 340
West Fork 341
Joseph City 342
Leamington 343
Deseret 343
table of discharge 355

Page.
Sidhnai Canal, India 451–552
Sidhnai Canal weir, India 465, 466, 472–473
Silver King Valley, California, reservoir site in 19–20
Sind, inundation canals of 427
Siphon aqueduct, Soane Canal, India 490
Siphon superpassage, Nira Canal, India. 514
Sirhind Canal, India 447–450
Six Mile Creek, Colo., reservoir site on .. 72–73
Sixteen Mile Creek, Mont., reservoir site on 134–137
Skipworth, G. T., aid by 385
Slate Creek, Colo., reservoir site on 59–61
Slips, earth dams, India 551
Slope and velocity of canals, India 456
Sluices in weirs, India 467–508
Smith, R. Baird, cited on value of immigration in India 392
cited on financial returns from investments in irrigation works in India 394
on effect of irrigation on navigation of rivers 422
Smith Canyon Creek, Colo., reservoir site on 101–103
Smith Fork, Wyo., water supply 327
Smith, J. Fewson, gauging by 335
Smith River, Montana, reservoir sites on south fork of 137–140
Snake River Basin, description of 344
tables of discharge 355–358
Soane canals, India 380–382, 452–455
weir on 464, 465
automatic sluices on 470
regulating gates for 476
falls on 482
Soda Springs, California, reservoir site at 10–11
Solani aqueduct, Ganges Canal 442, 485
Sospizio, Carlo, aid by 388
South Utica Lake, Montana, reservoir site 162
Spanish Fork, Utah, flow of 335
table of discharge 354
Spring Rivers, New Mexico, water supply 285
Squaw Valley, California, reservoir site in 12–13
Stampede Valley, California, reservoir site on 39–40
Stinking Lake, New Mexico, reservoir site on 168
Stone pitching, earth dams 548
Stonewall Valley, Colorado, reservoir sites in 97–99
Storage of water, for municipal supply and for irrigation 224–226
Gila Basin 298, 308
India, cost of 502–503
Storage works for irrigation in India 498–561
Storage works and canal systems combined, India 553
Strachey, R., cited on financial returns from investments in irrigation works in India 394
Stream measurements 235
Subsidiary weir, Betwa, India 519
Sugar cane, irrigation of 496

Page.
Sullivan, H. E., cited on value of irrigation works in India 394
Summit Valley reservoir site, California 10–11
Sun River, Montana, discharge of 236–347
Superpassages, India 487

T.

Tanks in India 536–550
Tank dams, India 550–553
Taos Creek, New Mexico, irrigation from 252–253
Taos district of the Rio Grande 251–256
irrigation practice and administration in 255
irrigable and irrigated lands in 256
Tansa dam, India 378–379, 527
Tansa reservoir, India 378, 525–527
Tarr, R. S., work of 241, 281, 282
Temperature, India 404
Tennessee Fork of Arkansas River, Colorado, reservoir site on west branch of 113–115
Tenures, land, India 413
Tesuque Creek, New Mexico, water supply 261
Teton River, Idaho, flow of 344
table of discharge of 356
Thomas Fork, Wyoming, water supply .. 327
Thompson, A. H., report of 1–212
Thuillier, R. H., aid by 380
Tierra Amarilla Grant, New Mexico, reservoir sites on 165–166
Timpas Creek, Colorado, reservoir site on 124–125
Topography of India and America compared 369
Topography, India 399
Training works, India 557
Tres Piedras Mesa, New Mexico, description of 256
Truckee River, Nevada, reservoir, sites on 209–212
description of 324
table of discharge of 351
Tule River, water supply 319–320
Tuolumne River, California, reservoir, site on 36–38
water supply 322–323
Turkey Creek, Colorado, reservoir, sites on 76–79
Two Butte Creek, Colorado, reservoir, site on 106–107
Twin Lake reservoir, California 53–54
Twin Valley reservoir, California 40–41

U.

Undersluices, India 508
Upper Gila district 302, 303
Upper Little Truckee reservoir, California 38, 39
Utah Lake, Utah, description of basin .334–339
water supply of 335
fluctuations of 336
evaporation at 338
discharge of Provo River into 338
Upper Salt district 310–311
Utica, Mont., reservoir sites near 161–162

V.

Page.
Vallecitos Creek, New Mexico, reservoir sites on 169, 170–171
Valle Grande, New Mexico, reservoir site in 177
Valle San Antonio, New Mexico, reservoir sites in 179, 180
Van Auken, A. M., gaugings of North Platte River by 239
Velocity of canals, India 456
Velocity of current in irrigation canals . 457
Verde district, description of 309–310
Vir headworks, Nira project 377
Vir weir, India 378
Vonder Horst, W. P., aid by 383

W.

Warm Creek, Idaho, water supply 330
Waste ways to dams, India 550, 551
Water, methods of applying 495
Water duty, definition of 223–224
San Luis Valley 250
Gila basin 296–298
India 428–430
Water storage, cost of 224–22
Cache Valley 332
Utah Lake 336, 337, 339
Sevier River Basin 340–343
India, cost of 502–503
Water storage and canal systems, India .553–557
Weber River, Utah, water storage 334
table of discharge of 353
Weirs, India 460–467
Weir gate, Reinolds's automatic, India . 509
Weiser River, Idaho, flow of 344
table of discharge of 358
Well foundations for masonry, India ... 477–479
Wells for irrigation, India 415, 423–425
Wells, Nadrai aqueduct 478
West Beaver Creek, Colorado, reservoir site on 64–66
West Gallatin River, Montana, discharge of 236, 237, 346
West Oil Creek, Colorado, reservoir site on 61–62
Western Jumna Canal, India 450–451
Wheat crop in India 397
Willow Creek, New Mexico, water supply 265–266
Wilson Creek, Colorado, reservoir site on 69–70
Wilson, Herbert M., paper on irrigation in India by 363–561
Wilson, W. J., aid by 385
Wolf Creek reservoir, California 20–21

Y.

Yellowstone River, discharge of 237, 238, 347
Yeso Creek, New Mexico, water supply .. 285
Young's Crossing, Cal., reservoir site at 45
Yuba River, California, reservoir site on 10–11

Z.

Zhara Karez irrigation project, India .. 556–557

O