ARID REGION
OF THE
UNITED STATES
Showing Areas Irrigated

Scale:
100 50 25 0 50 100 200 300 STAT. MILES.

Sackett & Wilhelms Litho.Co. N.Y.

AR-11
Part-2

ELEVENTH ANNUAL REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

Part II—IRRIGATION.

ARID REGION
OF THE
UNITED STATES
Showing Forest Areas

Scale:
100 50 25 0 50 100 200 300 STAT. MILES.

CONTENTS.

HYDROGRAPHY.

ENGINEERING.

THE ARID LANDS.

TOPOGRAPHY.

BIBLIOGRAPHY.

ILLUSTRATIONS

ARID REGION

OF THE

UNITED STATES

Showing Drainage Districts.

Scale:

100 50 25 0 50 100 200 300 STAT. MILES.

UNITED STATES IRRIGATION SURVEY.

ABSTRACT OF SECOND ANNUAL REPORT, 1889-1890.

The work of the United States Irrigation Survey during the second year has been carried on under the appropriation of $250,000 made March 2, 1889, by the force organized and equipped during the previous year. This is pursuant to the purposes outlined in the first annual report, which explains the origin, purpose, and plan of the Survey, publishes the instructions to the chiefs of the larger divisions, and gives the report of the topographic division to the end of the first fiscal year, and the reports of the hydrographic and engineering divisions during the greater part of the calendar year 1889.

This second annual report contains in condensed form the results of the work of the divisions of hydrography and engineering up to June 30, 1890. It is followed by the detailed statement before the Committee on Irrigation of the House of Representatives, which comprises a general discussion of the problems of irrigation in the arid lands of the United States, the work of the Irrigation Survey, and a résumé of the larger aspects of the problem, as well as other facts of general interest. This is followed by the report of the topographic branch of the Irrigation Survey and the abstract of disbursements, showing that $239,318.24 had been expended during the fiscal year.

In the developments of the work of this Survey no essential alteration has been made in previous plans, and the personnel of the field and office force has remained practically unchanged, the topographic work being under Prof. A. H. Thompson, and the hydrographic and engineering branches under Capt. C. E. Dutton. Work in all three divisions was rapidly pushed forward through the summer and fall of 1889 and the spring of 1890, being in full operation at the end of the fiscal year. The wisdom of thus apportioning the work of the Irrigation Survey has been demonstrated by the outcome, as investigations have been pushed forward more rapidly, and with larger results than could otherwise have been obtained.

The topographic survey has been carried on in a manner similar to that in which all such work has been conducted by the United States Geological Survey, so that the maps finally obtained are uniform in general character and appearance with those previously made, thus rendering them available for all the varied needs of scientific and engineering investigations, as well as for the irrigation examination proper. These maps not only show the lands of the arid region and the relative location of water supply and of tracts suitable for agriculture, but, by the well-known system of contours, they also exhibit the details of elevation and general slope of the ground. Thus with these maps it is possible to delineate with great exactness all of the facts essential to comprehensive irrigation schemes, and also to obtain with accuracy the area of catchment of every stream above any given point, as that of a reservoir site or a diverting dam. In short, these maps form a basis for the intelligent discussion of the whole problem of irrigation development.

As shown by the report of Prof. A. H. Thompson, the surveys for topographic maps have been made for publication on a scale of one inch to one mile in California, Colorado, Idaho, Montana, New Mexico, and Nevada, a total area of 20,850 square miles having been surveyed during the fiscal year. The contour interval of these maps has varied from 25 to 100 feet, depending upon the nature of the ground; that is to say, each increase in elevation of 25, 50, or 100 feet has been noted upon the maps in the conventional method by horizontal contours. In mountainous regions, where the slopes are abrupt and the land surface of little value except as it acts as a catchment area, the 100-foot interval is sufficient for all purposes, but on the lower and more level grounds a smaller distance is required.

The maps of the topographic branch show not only the absolute and relative altitude and slope of all surfaces and the position of streams, but also the correct location of towns, wagon roads, railroads, and the larger water ditches. They furnish thus the information demanded by the irrigation engineer at the very outset of his work in order to obtain a broad comprehension of the larger problems encountered by him. There is no intention, however, of making these general maps with the great elaboration required by the constructing engineer, since the cost and time required would be prohibitory, and the area in which the constructing engineer is particularly interested is almost insignificant in comparison with the amount covered by any one of the topographic sheets. For these purposes a survey of a far different character, covering a very small area or perhaps a long, narrow strip, is required, the work being done by other methods and with a different class of instruments.

During the progress of the topographic work, reports were made from time to time by the men in charge of parties, giving details concerning the forests within these areas, the reservoir sites, and the irrigable lands. The number of possible reservoir sites reported within the surveyed area was 188, these being within the drainage basins of the following rivers, viz: Walker, Carson, Truckee, Mokelumne, American, Yuba, South Platte, Grand, Arkansas and tributaries, Snake, Missouri, and Rio Grande. Some of these sites will doubtless prove of benefit in the development of irrigation, but an examination of the water supply of each locality will be necessary before the value of each site can be determined upon.

The hydrographic investigations of the Irrigation Survey have at the end of the second fiscal year begun to yield results of great value, exhibiting accurately the water resources of particular portions of the country and some of the fluctuations to which these are subject. The year 1889, however, was one of great drought, and the results of the measurements, therefore, indicate what may be expected during maximum aridity and show perhaps the extreme low-water conditions rather than the average conditions, a knowledge of which is so essential in plans of irrigation construction. It will be necessary to carry on work of this character for several years before the results of even one year can be fully appreciated.

Measurements and computations have been made showing the amount of water flowing in certain streams in the upper Missouri and Yellowstone basins in Montana, in the South Platte and Arkansas basins in Colorado, in the Rio Grande Basin in Colorado, New Mexico, and Texas, in the Gila Basin in Arizona, in the Truckee and Carson basins in California and Nevada, and in the Snake River Basin in Idaho and Oregon. The results of all this work are shown in condensed form in this report, together with necessary explanations and details essential to the utilization of the data. The measurements of flowing water were made by field parties especially equipped for this work, and moving from point to point on the various rivers as the necessities of the case demanded, the attempt being made to measure certain of the more important streams at various stages from low to high water. In addition to the main work of measuring the streams, investigations were conducted in order to determine the evaporation from water surfaces and the rainfall in certain areas, also the amount of sediment carried by running water, as well as certain other data required by engineers in preliminary estimates of irrigation systems.

The results obtained by the topographic and hydrographic divisions, besides being of general utility in the investigation of the extent to which the arid land can be redeemed by irrigation, have a direct practical application in the work of the third division of the Irrigation Survey, that of engineering proper. The officers of this division, knowing the character of the country as delineated by good topographic maps and possessing a general knowledge of the water supply, such as is being obtained by the hydrographic work, have made detailed examinations in certain chosen localities in order to determine the feasibility of certain large irrigation schemes, and to estimate the benefits to be derived by the construction of suitable works.

While the results of the work of the topographic and hydrographic divisions settle many questions of general detail, such as the extent and location of lands to be irrigated and their position and altitude relative to water, as well as the character of the supply available, yet there must always remain the momentous question whether the possible irrigation enterprises are practicable and profitable to the parties concerned. The general information obtained by these comprehensive investigations shows usually a larger area of land than can be irrigated by the available water supply, and also a number of possible reservoir sites and localities where canals can be diverted from streams; and it remains for an engineering survey to determine which one of the many possible localities and ways of diverting water is best, and whether, taking all facts into consideration, it can be made of sufficient benefit to induce capital or associated labor to construct the works.

Engineering surveys were carried on in Montana, principally along the Sun River; in Colorado on the head waters of the Arkansas, and in Kansas farther down the river; on the Rio Grande principally in the vicinity of El Paso; in California around Clear Lake and in the Sierra Nevadas; in Nevada on the Truckee and Carson rivers; in Utah around Utah Lake, and in Idaho on the lava plains adjoining the Snake River.

In Montana ten reservoirs were carefully surveyed, and also three canal lines leading from the Sun River to these reservoirs and to the lands to be irrigated; estimates have also been made showing that 235,600 acres could be reclaimed by such works at a cost varying with the method of construction, but at its maximum not prohibitory.

On the head waters of the Arkansas eight reservoir sites were surveyed and estimates of cost prepared. Especial attention was given to the Twin Lake site, and detailed plans were prepared for storage works necessary to impound 103,500 acre-feet of water. This amount could be increased to 121,800 acre-feet by lowering the outlet of the lakes. These lakes belong to the United States, and it has been shown that by a comparatively small expenditure this enormous volume of water can be held for use upon the lower lands. The preliminary survey of a canal line begun at a point about ten miles west of the Kansas-Colorado boundary demonstrated the possibility of irrigating land north and northeast of Syracuse, Kansas, whenever the necessary water can be obtained by the construction of such storage works.

The surveys in the Rio Grande division in the vicinity of El Paso, Texas, showed that a suitable dam could be constructed to hold within the reservoir thus created 537,000 acre-feet, of which at least 200,000 acre-feet per year could be utilized, the first cost being not over $5 per acre-foot of water available. Other reservoirs of less capacity were discovered and partially examined. These will hold at least 2,000,000 acre-feet of water even after rejecting those of doubtful value.

The survey of Clear Lake in California showed that the contents of the lake between a point 10 feet below mean low water and 10 feet above are 820,600 acre-feet, of which, however, nearly one-fourth is liable to be lost by evaporation, even if the full amount of water should be obtained. Other reservoir sites were surveyed upon the headwaters of the streams flowing from the Sierra Nevadas, seven surveys being completed, as well as four instrumental reconnaissances, and thirteen localities were examined and recommended for survey, together with thirty localities which were recommended for definite examination. These seven surveyed reservoirs have capacities respectively of from 2,000 to over 45,000 acre-feet, aggregating 173,280 acre-feet.

The work of the Survey in what was known as the Lahontan division, comprising mainly the streams flowing from California into Nevada, consisted of surveys of outlets of Lake Tahoe and of storage sites and irrigation canals along the Truckee and Carson rivers to irrigate the vast areas of desert land in the broad valleys of Nevada. The most notable of these is the Donner Lake site, whose storage capacity for a space of 20 feet above the present water surface is approximately 22,205 acre-feet. This can be increased to 42,827 acre-feet by placing a dam in such a position as to close the outlet of Donner and Cold Creek valleys. Independence Lake has been found to have a storage capacity of 23,707 acre-feet within the space between its present water surface and a plain 25 feet above it. Weber Lake can be made to hold 11,152 acre-feet more than its present capacity by a dam raising the water to a height of 20 feet. Other reservoir sites on the Truckee and also in Long Valley and Hope Valley on the Carson were examined, together with the necessary canal lines for delivering the water.

In the Snake River division surveys were made demonstrating the practicability of diverting the waters of Snake River upon the lava plains upon both sides of that stream, and reconnaissance showed that the amount of water available could be enormously increased by utilization of reservoir sites upon the head waters. The Swan Valley site, for example, is estimated to have a storage capacity of 1,500,000 acre-feet, and at Jackson's Lake 500,000 acre-feet could be held. The careful survey for a canal line leading from the Snake River in the vicinity of Eagle Rock or Idaho Falls showed that the canal if constructed would command 216,400 acres of arable land, all of it having an excellent soil. A line starting in the same locality and running out upon the lava fields to the north of the Snake River would cover at least 600,000 acres at small cost, depending upon the character of the work. Other surveys showed that canals lower down, while apparently possible, were in reality not practicable on account of the expense involved.

IRRIGATION SURVEY—SECOND ANNUAL REPORT.

By J. W. POWELL, DIRECTOR.

HYDROGRAPHY.

SCOPE OF WORK.

Any discussion of the extent to which the lands of the arid region can be redeemed by irrigation, or of the engineering problems involved, requires a comprehensive knowledge of the distribution of water in each catchment basin and the amount available at various points in that basin. As this amount is never the same from day to day and varies greatly from year to year, it becomes necessary to continue investigations through a series of years, and from these obtain certain averages and extremes concerning flood and drought. The longer the measurements are continued the more valuable the results become—the more nearly do they represent the actual range of conditions, and hence the greater the reliance that can be placed upon them in making predictions for the future.

The water supply and the amount available at any one point are resultants of many and varied forces, most of which are beyond the control of man. In each drainage basin the relative effect of these differs in some greater or less degree, so that the results of investigations made in one locality apply only in a modified degree to any other place.

In the general subject of water control the great mass of information collected by other investigators relates mainly to localities far removed, both geographically and climatically, from the arid region, to lands where the object is oftener the disposal of excess of water than the conservation of a deficient supply. Thus it happens that in this broad inquiry a somewhat new path must be chosen, and, in a great degree, new methods of research devised.

In such an investigation it is not sufficient merely to measure the amount of water actually flowing at a certain point in a stream, and thus obtain long series of figures giving the amount which has been available; it is essential that beyond this a careful study be made of the effects of changing conditions, both natural and artificial, tending to modify the amount of available water; for a knowledge of the future supply must be based on estimates as to the degree in which these conditions may vary from year to year.

The facts of first importance to be ascertained, after the establishment of stream measurements, are the rainfall, the amount lost by evaporation, and the amount now diverted by artificial channels. Each of these subjects in turn embraces a wide field of research.

UNITS OF MEASUREMENT.

Broadly speaking, there have been in this country two classes of investigation of water supply and distribution; that made by the engineer officers of the Army under the river and harbor appropriations, for the purpose usually of improving navigation, and those made by many civil engineers at different times and places for municipal supply and water power. In point of quantities of water, this Survey stands intermediate between those two. The volumes measured and discussed are far less than those required for navigation, but are usually much greater than those used in city waterworks and in powers.

To illustrate: The discharge for the Missouri ranges from 25,000 to 400,000 second-feet; for the Ohio, from 60,000 to 1,200,000 second-feet; the Savannah River at Augusta, Ga., discharges in extreme low water 2,500 second-feet, at ordinary low water 5,000 second-feet, and in greatest freshets 300,000 second-feet[1] from a drainage area of about 7,500 square miles.

---

[1] Fifty-first Cong., 1st sess., House Ex. Doc., No. 213; survey of Savannah River above Augusta, Lieut. O. M. Carter, Washington, 1890, p. 31.

On the other hand, the Rio Grande in upper New Mexico, where largest, carries in low water from 300 to 400 second-feet, and in flood seldom exceeding 10,000; and the Bear River in Utah has about the same range. In short, in the case of a stream under investigation for irrigation purposes, we speak of hundreds or thousands of second-feet, while in estimates on rivers wholly or partially navigable, tens and hundreds of thousands are the units in use.

Again, in considering municipal water supply, the quantities discussed are so much smaller that they can be conveniently expressed in gallons. A hundred gallons a day per inhabitant is a common estimate of the water used in an American city. On this basis a stream of 5 second-feet would supply a town of over 30,000 inhabitants. This same stream, which could be conducted in a very small ditch, would irrigate, as water is used in Colorado and Utah, from 350 to 500 acres, and thus furnish support for from ten to fifteen families. Considering artesian wells, one which flows 2,000,000 gallons per day is worthy of remark, and is of great value for city purposes and often for power. This quantity of water equals 1·55 second-feet, a stream which would be entirely lost in an ordinary ditch before going many miles, and as usually employed would irrigate about 125 acres, or with greater care 250 acres.

There are two units in general use by this Survey: that for flowing water is the cubic foot per second, or "second-foot," as it is more commonly termed, and that for capacity, the acre-foot, which is the quantity of water covering an acre 1 foot in depth, or 43,560 cubic feet. There is a convenient connection between these two units: 1 second-foot flowing for 24 hours covers an acre 1·983 feet in depth, or in other words, with sufficient accuracy for general purposes, 1 second-foot per day equals 2 acre-feet.

The other units in common use in the West are the various *miner's inches*. The miner's inch is a quantity differently defined in the mining regions, being regulated largely by custom or agreement. In Colorado the miner's inch has been assumed in some instances to be 45 cubic inches per second, equivalent to 0·026 second-foot, or 1 second-foot equals 38·4 of these Colorado miner's inches.[1] In California the miner's inch is commonly quoted as 0·02 second-foot; 1 second-foot equals 50 miner's inches.[2] In the intermediate States and Territories these values and others are used, so that any measurement given in miner's inches is an uncertain factor.

In descriptions of town and city water supply quantities are usually given in gallons or millions of gallons for reservoir capacity, and in gallons per second or minute for flowing water. For hydrographic discussion or irrigation engineering the figures in this unit run up into unwieldy length.

For expressing the total discharge of a river the cubic mile per year has been found to be convenient, and is used largely by the Signal Service. It is especially convenient in ascertaining the relation of run-off to drainage areas, as these latter are estimated in square miles, and to obtain the average depth of run-off over a given area, it is only necessary to divide the yearly discharge in cubic miles by the area in square miles. Other units which have been used, such as the cubic yard or meter per minute or second, require no comment, as they do not seem to be very generally employed.

The following brief table gives these facts in convenient form. It should be remarked that a day in all these measurements means 24 hours.

1 second-foot equals 50 California miner's inches.
1 second-foot equals 38·4 Colorado miner's inches.
1 second-foot equals 7·48 United States gallons per second.
1 second-foot equals 6·23 British imperial gallons per second.
1 second-foot for one day equals 2 acre-feet.
1 second-foot for one day equals 646,272 United States gallons.
1 second-foot for one year equals ·000214 cubic mile.
1 second-foot for one year covers 1 square mile 1·131 feet deep.
1 cubic foot of water weighs 62·4 pounds.
100 California miner's inches equal 2 second-feet.
100 California miner's inches equal 15 United States gallons per second.
100 California miner's inches equal 77 Colorado miner's inches.
100 California miner's inches for one day equal 4 acre-feet.
100 Colorado miner's inches equal 2·60 second-feet.
100 Colorado miner's inches equal 19·5 United States gallons per second.
100 Colorado miner's inches equal 130 California miner's inches.

---

[1] Report of the State engineer to the governor of Colorado for 1883 and 1884, p. 60.
[2] Irrigation in California. Wm. Ham. Hall, 1888, p. 27.

100 Colorado miner's inches for one day equal 5·2 acre-feet.
100 United States gallons per minute equal 0·223 second-feet.
100 United States gallons per minute for one day equal 0·44 acre-feet.
1,000,000 United States gallons per day equal 1·55 second-feet.

STREAM MEASUREMENTS.

The methods of stream measurement by which the results shortly to be discussed have been obtained are described in the previous report[1] and in so many other publications relating to hydrography that it will be sufficient here to give some of the practical details and results of the experience of the last year, omitting general description.

Of the four general methods of measurement, the one used almost exclusively by this Survey is that by current meters. Floats have been used to a limited extent to obtain the approximate discharge at times or under circumstances when meters were disabled or not at hand. Weir measurements have been made in a few cases to obtain the discharge in ditches. In studying the duty of water it is necessary that the measurements of small quantities be made with a greater degree of exactness than is possible with a current meter. A small weir can usually be placed in an irrigating ditch, at slight expense, providing there is sufficient fall, and if correctly proportioned and the well known Francis formula[2] be used will give the flow with great precision. The use of the knife-edged weir is rapidly extending in the West, the accuracy of the measurements offsetting the inconvenience or care required.

Discharge results obtained by calculations based upon the slope, area of cross section, and depth of the stream have not met with favor or confidence. One great difficulty is in determining the exact slope, or, rather, for what length the slope shall be measured; and after all the measurements have been made with great accuracy the result depends largely upon an assumed factor of roughness of the bed, which factor is with many engineers a mere guess.

---

[1] Tenth Ann. Report, U. S. Geol. Surv., Part 2, Irrigation, p. 79.
[2] Lowell Hydraulic Experiments, by J. B. Francis.

CURRENT METERS.

For the diversified needs of this Survey, it has been found convenient to have two types of current meters; these are the direct recording, in which the number of revolutions is indicated on a series of small gear wheels driven directly by the cupped or vaned wheel of the meter, and the electric meter, in which the counting is done by means of a simple make-and-break circuit, the registering or "reporting" being made at any desired distance from the meter.

For shallow, quiet streams, where the gauger can work comfortably from bridge or boat, the direct recording meter is preferred, as it is very light, simple, and compact. It is mounted on a rod, and the gauger, holding it in the water at the desired points, allows it to register for a certain number of seconds, draws it up, and reads the result on the dials. The instrument can be quickly unpacked, there are no annoying electric wires, batteries, or connections, and it can be carried with ease.

In deep and torrential rivers, however, the current is usually too strong for a man to hold the meter or lower it to the bottom; much time is consumed in raising the instrument to read the dials, and there is uncertainty as to how the meter is behaving, especially in turbid waters. Moreover, in floods it is often impossible to go out upon the stream, and in these cases electric meters become a necessity.

The direct recording meters (see Fig. 121) are modifications of the Colorado meter, recommended by the State Engineer[1] as a result of his experience. The wheel revolves in a horizontal plane and consists of five vanes or cups, being similar in principle to the cup anemometer. This form of wheel is probably the invention of D. Farrand Henry and was used on the survey of the Detroit River about 1867 and later by Gen. Theodore G. Ellis on the survey of the Connecticut River.[2] A wheel of the

---

[1] Second Biennial Report of the State Engineer to the Governor of Colorado, 1884, p. 49.

[2] Flow of water in rivers and canals, by D. Farrand Henry, Detroit, 1873, p. 4; also Journal Franklin Institute, vol. 62.

Report on Survey and Examinations of the Connecticut River, Appendix B 14'. Ann. Report Chief Engineers U. S. Army, 1878, p. 60. Also, Buff & Berger's catalogue, Boston, 1889, p. 136.

same type is used on the Price electric meter.[1] Both the Ellis and Price meters, however, are used with an electric register, while in the Colorado type of meter the vertical axis of the cupped wheel engages directly with the gear dial wheels, which are placed above and in the rear of the center of the instrument. In the original form of the Colorado meter, the method

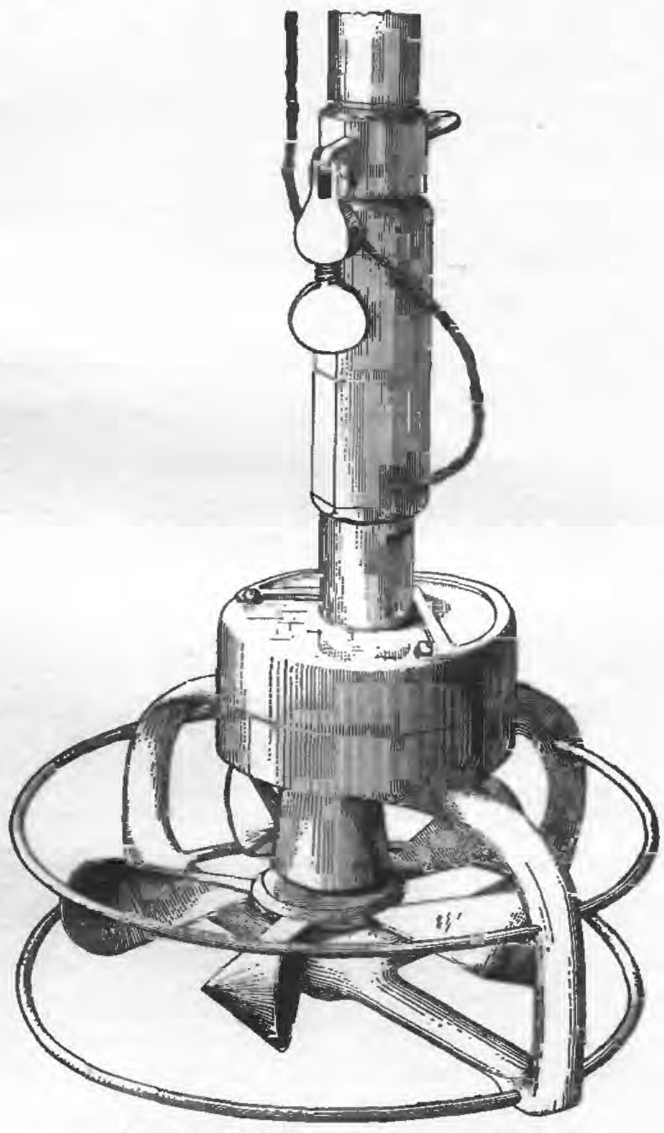


Fig. 121.—The Colorado current meter.

of stopping and starting the registering wheels is by throwing the cupped wheel in and out of gear, the wheel being tilted forward or backward through a very small angle, moving on the lower bearing as pivot. A small spring holds the wheel out of gear. In the modified form of later make, on the contrary,

[1] Theory and Practice of Surveying, Johnson, 1889, p. 299, or Gurley's catalogue, Troy, N. Y., p. 235.

the registering is started and stopped by having the dial wheels move as a whole, forward and backward, to engage with the pinion of the cupped wheel, whose axis remains vertical.

The meter when in use is screwed to the end of a metal rod, which for convenience is made in sections of 3 feet each. A wire or cord is connected to the lever which throws the dial wheels in or out of gear. On being placed in the water, the dials being read previously, the wheel is allowed to revolve freely for a few moments in order to acquire the velocity of the water, and at the desired instant the operator jerks the cord, bringing the registering wheels into gear. At the end of the given number of seconds, the cord is released with quick motion and the dials cease to revolve. The mèter is then taken out of the water and the new reading is noted, together with the number of seconds during which the revolutions were made.

This form of wheel is very convenient, as it can be used in shallow channels, close to the bottom, and is self-clearing of grass and leaves. In swift water it is very difficult to hold the rod so that it will be perfectly vertical, the force of the water tending to pull the meter down stream, and unless the operator is constantly on the alert his wheel will at times be inclined to the horizontal

Mr. E. E. Haskell, of the Coast and Geodetic Survey, has pointed out that when the cupped wheel is inclined it moves faster than when held perfectly horizontal. He gives the following data as typical of the results of a large number of experiments.

Angle of inclination of meter	Time in seconds going 300 feet	Number of revolutions in 300 feet	Increase
Degrees			
0	128	68	
12	126	79	11
0	76	70	
17	76	84	14
0	111	68	
17	111	82	14

A competent man will of course never allow his meter to drift backward 12° or 17°, but as a matter of fact it is very difficult for the ordinary operator, especially when tired and working in deep, swift water, to keep his rod plumb; quite often it is inclined at an angle of 5° or even more. It is sometimes very convenient in such swift waters to thrust an iron bar firmly into the bed of the stream, and stay the meter from this by means of a short piece of wire and an iron ring running freely up and down on the bar.

The electric meters used by this Survey (see Fig. 122) are nearly all modifications of the Haskell[1] direction current meter, the central body containing the compass needle being omitted

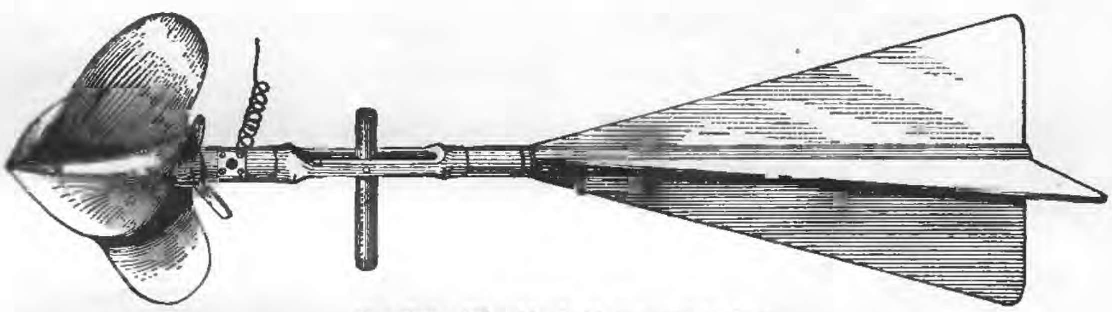


Fig. 122.—The Haskell current meter.

and the velocity wheel and tail screwed into a convenient swivel or rod support. The wheel is of the propeller type, conical in longitudinal projection, thus cleaning itself from leaves and grass. The flukes are given a strong pitch, and are so proportioned as to cause the wheel to revolve at ordinary velocities once for about a foot linear movement of current.

There is no question that this is the best type of wheel yet presented for a current meter. It projects forward so that back action of water on the main metal body is reduced to a minimum. The bearings are simple, the number of parts few, the instrument is strong, can be used in the most violent torrents, and yet is sensitive to low velocities. Beyond the inconvenience of wires and batteries common to all electric meters, the Haskell is superior to any form yet tried.

[1] Theory and Practice of Surveying, Johnson, 1889, p. 315.

For work in the turbulent streams of the West there is grave objection to the helicoidal, flat-faced velocity wheels, such as are used in the various forms of Woltman tachometer,[1] as floating objects are apt to rest against the wheel or become entangled in it, destroying the observation. The same objection also applies to the Fteley[2] meter, in which the velocity wheel, instead of being driven in advance of the body of the meter, is set in a heavy metal frame. Attempts have been made to protect this wheel by wire guards, but these only increase the mischief by furnishing new resting places for leaves or twigs.

The Haskell wheel is supported on a long, stout, steel pivot, in size a little larger than a lead pencil, which extends into the wheel almost to the extreme point. When in the water and in motion the bearing is wholly on this steel point. A considerable space is left around this long pin to be filled with oil, so that there is little if any friction on the rear of the wheel. The electric connections are in the brass stem, the "make and break" being done by a small pin pressing forward against the rear of the wheel, and as the latter revolves, alternately pushing against brass and vulcanite sections.

An electric meter, very similar in general principle to the above, has been devised by Mr William Ham Hall, for the State Engineering Department of California. Several instruments of this type were loaned to the U S. Geological Survey for use in Colorado and Nevada. Like the Haskell meter, the wheel projects forward, but instead of four flukes it has two, one on each side of the central axis. The "make and break" is made by pressure of a pin against the side of the longitudinal shaft, which, instead of being rigidly fastened, as in the Haskell meter, is attached to the wheel and revolves with it. This pin alternately presses against the steel shaft and a bit of agate which is let into one side of the shaft. These meters have done good service, although they are not strong, and are more easily disabled than the Haskell meter, and the method of interrupting the electric current is open to more objections.

---

[1] Survey of Conn River, Ann. Rep Chief Eng. U. S A , 1878, Appendix B, pt. 1, p 307.

[2] Best figured in Buff & Berger's Catalogue, Boston, 1884, p. 1837.

RATING THE METER[1]

Each meter, before results can be obtained, must be rated, that is, the relation which exists between the speed of the wheel and the velocity of the water must be ascertained; in other words, the number of times the wheel turns for a given speed of the stream must be known. In the use of a current meter the operations consist merely of observations of the number of revolutions of the velocity wheel in a given time in various parts of a stream, and it is only when the meter rating is known that the amount of movement in these different places can be calculated.

The rating is usually done by drawing the meter through quiet water over a course of given length, and noting the time. For instance, a meter was run through still water very slowly, going 100 feet in 4 minutes or 240 seconds; and the dials showed 20 revolutions. Then the meter was run more rapidly, covering the same distance in 100 seconds. The dials did not show 20 revolutions, however, but an increase to 24, and again at still higher speed—100 feet in 12 seconds—the reading gave 25·3 revolutions. In general, it may be said that the greater the velocity the greater the number of revolutions for a given distance. This is due to the friction and inertia of the wheel; when slowly moved, the resistance of the water is small compared to the friction of the wheel, but as the water encounters the meter with greater speed and force, the friction is less important and the number of revolutions increases, the ratio of increase not being constant.

The Survey has, through the kindness of the officials in charge of the Denver reservoir, been able to construct there a rating station to which all meters are sent before use and at other times to test their accuracy. This reservoir is very conveniently arranged for the purpose, as it is decked or floored over to exclude the sunlight. A narrow slit about 150 feet long has been made in the floor, and on each side of this a light track is laid. A little car runs along this track, and is so arranged that it can carry the meter vertically in the center of

---

[1] See Johnson's Surveying, p. 302.

the opening. The car is pulled forward and back at a uniform speed by ropes running around a drum driven by hand power.

A course of 100 feet is laid off with sufficient length of track at either end to start the car at the speed to be kept up over the course. As the meter passes into the measured distance, the register and stop-watch are automatically started and continue until the meter leaves the one-hundredth foot, when both are stopped and the car is allowed to come to rest. The operation is repeated, at first as slowly as possible and then at greater and greater velocities.

From the observation thus made the rating is determined. This is done either by analytic or (most commonly in actual practice) graphic solution. Both of these methods are fully described in books previously quoted[1] The rigid analytical method is susceptible of great accuracy, but involves considerable time as well as skill in mathematics, and in the hands of ordinary stream gaugers may easily lead to gross errors. The graphic solution has been found to be preferable as being simpler and quicker, and has the advantage that diagrams have over columns of figures, namely, that all the results appeal to the eye and discrepancies stand out conspicuously.

The graphic method consists in plotting on cross-section or coordinate paper each observation, using the revolution per second as abscissa and the speed per second of the same observation as an ordinate. In this way a series of points is obtained, and through these a straight line, or one slightly curved, can be drawn, giving the average value of all the observations. From the position of the line thus plotted the "coefficient of discharge" can be read off corresponding to one, two, three, or any number of revolutions per second.

When in actual use the conditions are, of course, reversed: the meter is stationary and the water flows past; the revolution of the meter being then observed, the corresponding velocity of water is at once known from the values as obtained above. From what has just been written it is evident that for each rate of speed of meter there is a slightly different value of

---

[1] See particularly Survey of Connecticut River, 1878, p 60, Johnson's Surveying, 5th ed., p. 303; Merriman's Hydraulics, p. 255, Merriman's Least Squares, p. 130.

the coefficient of discharge. With most of the meters it has been found sufficiently accurate to use only three or four of these values, for instance, one for very sluggish water, another for an average of about 4 feet per second, and a third for swift currents.

There are several ways in which the meter can be used in determining the total flow of the stream, depending upon the fact that the velocity of the water varies in different parts of the stream, being swiftest as a general thing in the center near the surface. If a river flowed as a solid mass it would be a simple matter to make a few measurements of the speed of any portion; but as it is, the speed of water at one place in a given cross-section has no definite relation to the speed in another, and many separate measurements must be made to obtain the flow of all portions

In wide, deep rivers meter measurements are made at a number of places evenly distributed across the stream, and at each of these places observations are made of the velocity near the surface, near the bottom, and at various intermediate points, say 5 to 10 feet apart in a vertical line. In this way the velocity is obtained at a large number of points symmetrically distributed in the cross-section, and the average of all is taken to be the velocity of the whole river, the discharge being obtained by multiplying the total area of cross-section at this point by this average velocity.

In shallow streams, however, as are most of the rivers of the arid region, the work can be shortened by what is called *integration*. Instead of using the meter at various given points in a vertical line, it is moved at a very slow, uniform speed, down and up, from top to bottom, and back again, to obtain an average of the velocities at all points in the vertical. In this case the river is considered as being divided into a number of independent narrow streams, of equal width, the discharge of each being obtained by multiplying its area into the observed average velocity in its central portion; and then by adding these discharges together the total for the whole river is found.

With a little practice the stream gauger can raise and lower the meter at a constant rate in any given number of seconds;

say with water 5 feet deep starting at the top and going to the bottom in 20 seconds, then back to the top in 20 seconds more, and repeating this three times, taking in all 2 minutes.

For measuring the discharge of canals or small streams with nearly level bottom, horizontal or diagonal integration has been occasionally used, obtaining at once an average for the whole flow. The meter is carried slowly from side to side horizontally, or is moved diagonally from the top on one side down on the cross-section at an angle of about 45 degrees, then up at about the same angle to the top, then down, continuing in this way until the opposite side is reached. In the same way a return trip is made up and down, crossing the path of the first, the meter coming out at the top each time over the spot where before it reached the bottom, and vice versa.

RIVER STATIONS.

In beginning a series of measurements by which the daily discharge of the river for long periods is to be calculated, the first requisite is a good locality on the river, adapted by both nature and convenience of access. The bed and banks should be permanent, or at least not shifting with every rise, and the current of moderate velocity. Such places are, unfortunately, rare, and the best gauging points are often found far away from roads or habitation. In such cases it becomes a question between relative cost of maintaining a station and value of results. In general, concessions must be made in accuracy to bring the cost of results within the sum allotted.

After finding several places at which fair gauging can be made, the point which determines the final location is, usually, one at which a trustworthy resident observer can be found. This is really the most difficult and vexatious detail of the organization of hydrographic work in the West. It is obvious that, excepting in rare instances, no survey can afford to employ a man to watch the fluctuation of a river, or to attend an automatic register or nilometer, but must procure the services of some person whose occupation compels him to live within accessible distance of the gauging station, and who will keep the daily records for a small sum. The compensation paid ranges from $4 to $10 per month, depending upon the number of observations per day and the time required to go to the station and return.

EQUIPMENT OF STATION.

The rivers gauged up to the present time have seldom exceeded 500 feet in width, and have generally been much narrower, and thus it has been possible in all cases to stretch one or more wires or cables over the stream at the cross-section. The equipment of the station varies with the method of gauging, but the following description will apply to most of the stations operated by this Survey. First, a tagged wire is fastened securely over the section chosen for gauging, at a height out of reach of the highest floods. This carries fifteen or twenty tags, 5, 10, or 20 feet apart, according to the width of the stream. These tags are marked in some way plainly to be distinguished, and serve to locate the points of measurement at uniform distances across the stream.

At a short distance upstream from this tag wire, 20 to 50 feet or more, a wire cable one-half to seven-eighths of an inch in diameter is stretched across the river, the ends being brought up over struts or shears to keep the cable above the water, and then fastened to anchorages securely embedded in the river bank. On this cable a pulley or small trolley runs, and from this a rope is fastened to a boat, the whole arrangement being, in short, a small rope ferry. The boat is secured so that its bow comes directly under the tag wire, and by standing or sitting on a small platform over the bow the stream gauger can place the meter at any desired point in the cross-section.

In high floods, however, a boat can not be held in this position on account of the velocity of the water and the danger from logs and driftwood. To overcome this difficulty two methods have been tried: that of gauging from a car suspended above the water, and the "cable and traveler" method, by which gauging can be conducted from shore.

The suspended car (illustrated in Fig. 123) consists simply of a stout box about 3 feet wide and 5 feet long hung from pulleys running on the wire cable. The stream gauger, sitting in the car, moves himself from side to side of the river and uses his meter as from a boat, lowering or raising it by hand or by a rope and pulley. This has been found very satisfactory. All parts of this apparatus are made of great strength, the cable being capable of holding from ten to fifty times the greatest load put upon it.

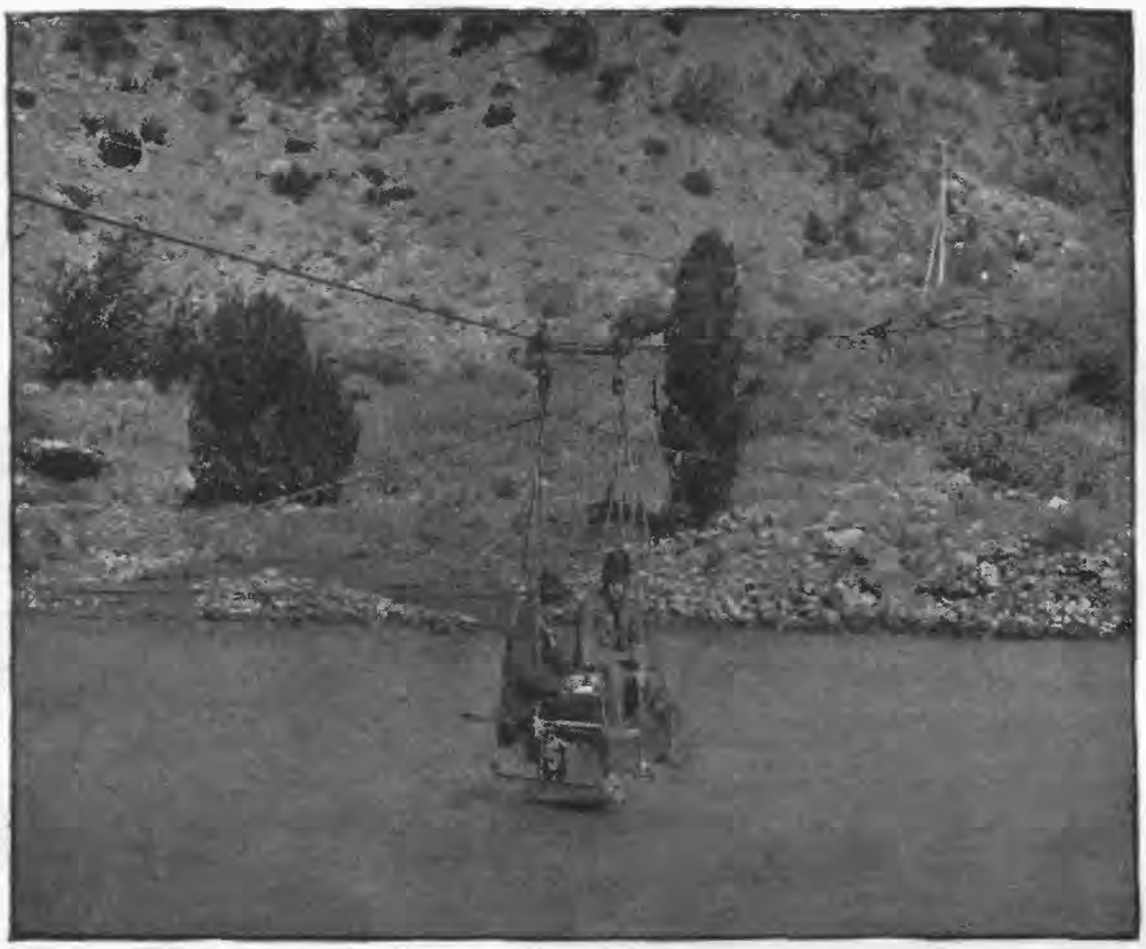


Fig. 123.—Method of using the current meter from suspended car.

In the cable and traveler method the main feature is that the observer stays on shore, and has no necessity, after the cables are once in position, of going out upon or over the water. The apparatus as used by the Survey was devised by Mr. Hall, and put into practical operation on the Carson and Truckee Rivers in Nevada by Mr. Trowbridge, hydrographer for that division, who commends it highly, and states that in his opinion it is the best system, especially for torrential mountain streams.

In general principle this apparatus is similar to that used in the gauging of the river Severn in 1880,[1] the most notable difference being in the manner in which the meter is held from being carried downstream In the first device the cord which steadied the meter was held in place by a cast-iron anchor plate weighing 70 pounds which rested in the bed of the river, while in the Hall apparatus the meter is held from being swept backwards by a stay line running upstream.

The meter is run out on the main cable by means of halyards, and is lowered and raised by a double incandescent-light cord, or insulated wire, which serves the two purposes of conveying the electric current from the battery and instrument on shore to the meter and of acting as a suspending and sounding cord. The stay line just mentioned is fastened to a pulley which travels on a second smaller cable crossing the river above the main cable. The lower end of this stay holds the meter from being swept downstream. By manipulating the various ropes the meter can be placed and held in any position in the cross-section, the revolutions being reported by an electric sounder near the observer.

Soundings can be made in the same manner, quickly and accurately, the rod being held in a vertical position by the stay line, and the depth, if necessary, read off by the amount of movement of the cords on shore, the sounding and insulated circuit cord being graduated to correspond with the marks on the sounding rod.

With careful training and experience one man is able to do all the work of gauging more easily, it is probable, by this method than by any other As stations are at present located, however, in most of the basins, the necessities of transportation and subsistence require that the hydrographer or steam gauger shall have an assistant; and even at stations which can easily be reached by rail it is found to be economic to employ the resident gauge observer for the few hours during which the

---

[1] Minutes of Proceedings of the Institution of Civil Engineers, 1885, vol. 80, p. 327.

gauging is made, as helper or recorder of notes, as his regular compensation at best is very small.

In addition to the cables, wires, and other apparatus necessary for measuring the discharge, there is required some means of measuring the height of the water, that is, a gauge rod of some kind. Usually this is a stick of timber, or heavy scantling, fastened securely to the bank and at the general inclination of the shore. This when in position is marked by means of a level into divisions corresponding to vertical feet and tenths. In favorable situations, as on vertical banks or a bridge pier, an upright rod marked to feet and tenths is placed, but these localities are few. In general it is necessary to establish an inclined gauge, as a vertical rod or pile would not only be in danger of being washed away in high water, but the shore line having retreated at that time the observer could not get sufficiently near the gauge to read it. With the inclined gauge the reading is always at the shore line, and driftwood is not liable to catch upon it.

As soon as this gauge or "nilometer" rod is set, the observer is instructed in the routine of noting down, once, twice, or three times a day, the height of water on the gauge, and the observations should then be continued throughout the year.

DIURNAL VARIATION.

While the hydrographer is putting up the cable and other apparatus for river gaugings, or at the first opportunity, a series of observations should be made to determine the diurnal range, if any, of the river height. In most of the rivers of the arid region, especially near their headwaters, this daily range is quite noticeable, and it is of considerable importance to determine the time of day at which the maximum and the minimum usually occur. This alternation of high and low water is caused by changes of temperature, the heat of the day melting the snow and the cold during the night checking this, or even freezing a portion of the water. The time at which this effect is shown at any given point on the stream below is evidently dependent upon the distance from the source of supply. The maximum flow at one place may occur at midnight, lower down stream it will be early in the morning, and still farther away the highest point will be at noon.

The main stream formed by the union of many such tributaries does not show such a decided daily range, as the maximum and minimum points of the various streams do not coincide and tend to neutralize one another.

The number of gauge readings per day is determined largely by this preliminary examination. If the stream does not fluctuate noticeably during the day, a single observation for that period is sufficiently accurate for all purposes, provided the observer takes careful note of any unusual or sudden flood. On the other hand, it is obvious that a single observation will be deceptive if this happens to fall each day at the usual time of high or of low water; at least two observations are then necessary to determine the mean daily height.

For greater accuracy, a self-registering gauge[1] or nilometer is used. This consists of a cylinder or dial driven by clockwork at such a rate that one complete revolution is made in a week. A marking device connected with a float, which rises and falls with the river, traces on paper placed on this cylinder a line which, by its position, gives the height of water at any hour of day or night. A record of this character gives data, not only for determining the daily mean flow with great precision, but also the maximum and minimum discharges.

RATING THE STATION.

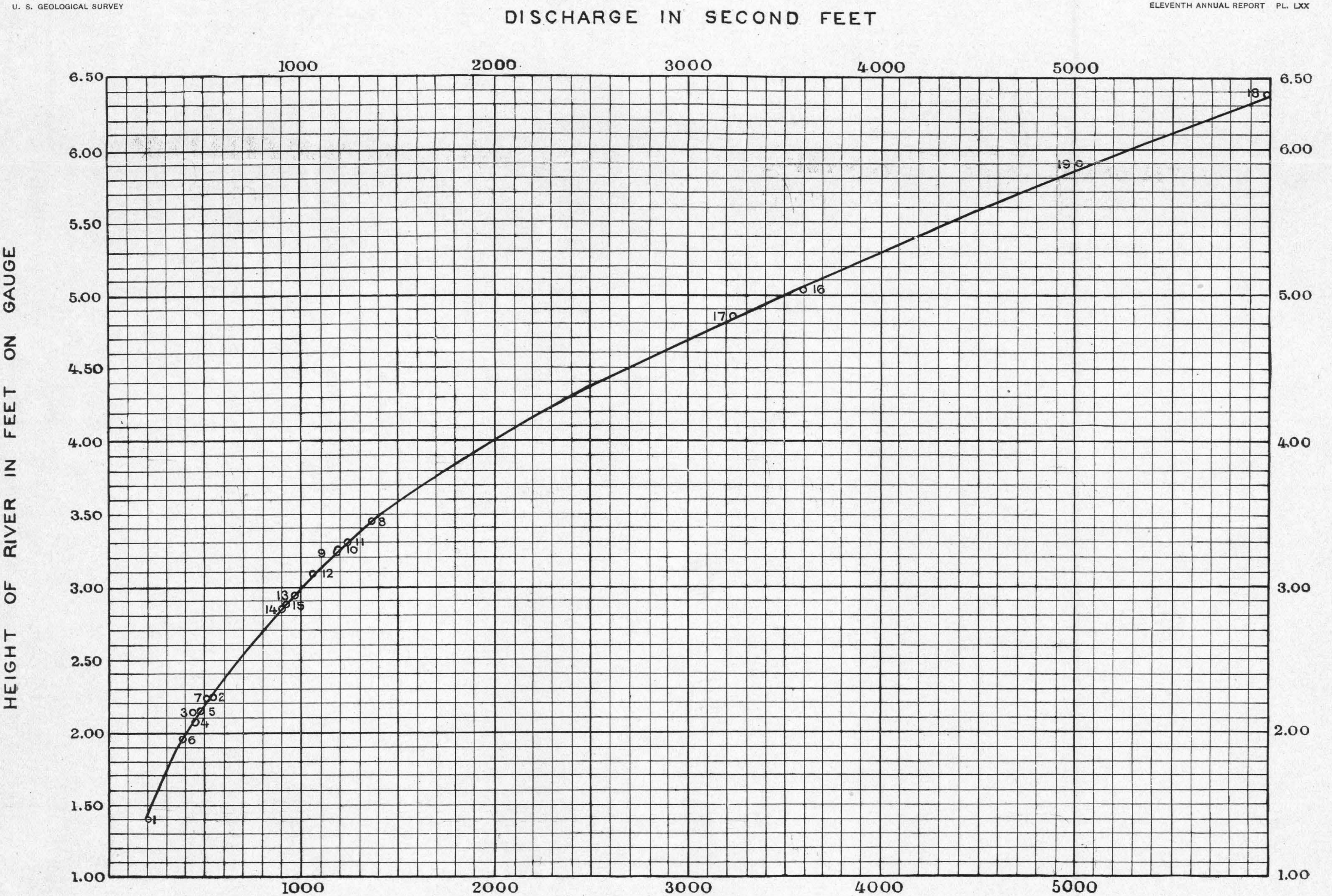
After the station is equipped and daily gauge readings begun, the rating of the station is undertaken. This is the main and most expensive operation of the hydrographic work, as it is necessary to measure the discharge at various heights of water, both at high and low stages, as well as at intermediate points. The measurements are made by the hydrographer or his assistants, who visit each station from time to

---

[1] One form described in Fourth Biennial Report of State engineer of Colorado, 1888, p. 54. Another form is illustrated in the Second Annual Report of the Territorial engineer of Wyoming, 1890.

time in their round of the basin To get a complete series of measurements is thus usually a matter of several months, as the height of the river can not be predicted except in the most general way. The hydrographer and his party can not remain encamped on the banks of a stream waiting for the variations of high and low water, but must take his chances of finding the river at the stage at which he desires to measure it when he arrives.

The results of these measurements, finally obtained, are plotted on rectangularly ruled paper, the gauge height of the river as ordinates, the corresponding discharge as abscissæ. These points generally lie in such a position as to suggest the path of a simple curve. This line is therefore usually sketched by eye, the hydrographer from his knowledge of circumstances giving intuitively more weight to certain observations than to others. On Pl. LXX is given an illustration of one of these rating curves. The points obtained by observation are indicated by dots surrounded by circles and numbers in order of dates of measurement. The finer rulings of the paper ordinarily used have been omitted in order to make the position of the dots more apparent to the eye. When the curved line has finally been adjusted, the *rating table* is constructed. This is a table giving the discharge in cubic feet per second for each tenth of foot height on the gauge rod of a station. Knowing then the height of the river at any time, the corresponding discharge can be at once read off from this table. This rating table is taken directly from the plotted curve, the discharge corresponding to each tenth of foot in height being obtained by the position of the curve. It is advisable, as affording a convenient check on the numerical accuracy, to note down in a column at the right the differences between successive discharges, i. e., the increase of discharge each time due to rise of 0·1 foot. If these at any place become constant the discharge curve evidently has flattened into a tangent, and if the differences decrease, the curve is reversed and should be slightly changed or adjusted, so that the differences show a constant, though slight, increase. There may be one exception to this rule. It is conceivable that a river may,



RATING CURVE FOR THE

RIO GRANDE AT DEL NORTE, COLORADO

in rising, encounter obstacles which tend to pond the water and hold back the flood so that the discharge will not increase in relation to height of water at so rapid a rate as at a medium stage. This condition of affairs has, however, not been actually encountered.

The construction of this curve is similar in all respects to that of the rating line for the meters, noted on a previous page. As in that case, the analytic method of obtaining the curve can be employed to advantage in connection with the plot of discharge, but for most practical purposes the graphic method—if only one is used—is preferable, as its accuracy is far within the probable error of the observations. Thus, for rapid work, as in preparing estimates of discharges, the purposes of this survey were best accomplished by the use of the sketched rating line.

The question now arises, for how long a period will this rating curve be true, or its values fall within the range of allowable error? Every river is constantly modifying its channel to some extent, alternately scouring and filling its bed to suit the everchanging conditions of velocity and volume. The station is, in the first instance, selected at a point where this action will be at a minimum, but usually there is an appreciable change, especially during and after floods or protracted periods of low water.

The rating curve is founded, however, on measurements made, as far as possible, under all the varying conditions of water depth, and is in itself of the nature of an average or compromise between all these conditions. Thus it is evident that for any one height of water at a particular stage, the discharge as given by the rating table may not be as accurate as the result of a direct measurement made on that particular day, but the value given by the rating table should be the average value of the discharge (for that particular height), whether the river be rising, falling, or stationary. In other words, it is assumed that for a given height of water the discharge varies within certain limits, depending upon circumstances, such as amount of silt carried, condition of channel above and below, and other modifying features, and that the rating tables can not be brought to the refinement of discriminating between all these conditions, but must represent an approximation at their mean.

It is interesting to observe, however, that there is, taking a season through, a general return to former conditions, even in certain quite sandy channels, where the change from day to day is noticeable, the deep portion shifting from side to side, while the relation of gauge height to discharge takes a wider and more irregular range, the plotted points being scattered on each side of the average line. Thus it has been found practicable to rate certain stations and obtain mean discharges whose probable error is within an allowable limit at places where at first sight it would seem hopeless.

The above remarks apply particularly to places where the material of the bed is continually rearranged and replaced; but if the action of the stream is to build up the bed as a whole and then to wash this out bodily, height of water alone can have no meaning—the bed of the stream itself is rising or falling. It has been proposed to meet such exigencies by neglecting the arbitrary height of water surface and considering the hydraulic mean radius in its place; that is to say, instead of having the river height read daily at the shore, to have the observer make soundings at definite points of the cross-section.

Rating tables are usually made as soon as possible after six or eight observations of discharge have been obtained, if these are well distributed along the path of the curve, and subsequent points are plotted when obtained. The curve is modified, if necessary, to take account of these new data, and corrections are made in the rating table. The experience of the last year has shown, however, that after six or eight well distributed gaugings have been made subsequent measurements during that season are not in general of sufficient value to justify the expense of obtaining them. In other words, the corrections in the rating table are not worth what they cost.

This Survey has not been in operation for a sufficient time to be able to determine whether these rating tables can be used a second or third year without material change. It is probable, however, that they can be used to give approximate values in case they can not be checked by observations in later years.

RAINFALL.

At the beginning of the operations of the Hydrographic Survey the necessity of rainfall measurements was appreciated, and an examination was made of the methods in use by the Signal Service of the Army, which had that subject in charge. It appeared at that time that the Signal Office was not in condition to extend its observations to the points at which measurements were most needed for the Hydrographic Survey, and therefore the attempt was made to supply this deficiency by establishing a system of volunteer observers, in general details fashioned after that already in operation under the direction of the Chief Signal Officer. Standard rain gauges were placed in the hands of observers, wherever these could be found, in the basins in which the hydrographic work was at first begun. In the Rio Grande basin, for example, about forty rain gauges were thus located at accessible points; nearly the same number in the Gila basin, principally around the headwaters of the river and its tributaries; and a few in the basin of the Arkansas in Colorado and that of the Truckee River in Nevada.

The principal difficulty is to secure measurements at points where they are most needed. As is well known, the greater portion of the population is in the lower valleys, and at these points observers of rainfall can be found with comparative ease, but it is from the high mountains that the principal water supply comes, and there the measurements should be made. Unfortunately it is almost if not quite impossible to obtain volunteer observers in those places, and it is evidently impracticable to hire men to reside at these high altitudes for the sole object of noting precipitation. Thus it happens that all the data concerning rainfall and snowfall relate mainly to the low valleys where the precipitation is least, and estimates based upon these figures are in general below the truth.

The results obtained from the measurements of precipitation carried on by this Survey were transmitted from time to time to the Chief Signal Officer and by him published in the Monthly Weather Review in connection with the results from his own observers. The relation which exists between the rainfall and the discharge of the river has been a matter of careful consideration by the hydrographers of this Survey, and, while at the present time it is premature to state conclusions, some general facts are given as introductory to a more detailed discussion.

This relation between the rainfall, as measured in various places in a river basin, and the subsequent rise of the river is by no means one of simple arithmetical proportion; in other words, if 1 inch of rain falls during one day and 2 inches during another, the river discharge following the second rainfall is not necessarily twice the first; it may be less or greater.

The rate at which the rain falls determines most largely the amount which collects at once in the streams and river. In a heavy, short thunder-storm or "cloud-burst," the rain does not have time to soak into the ground, but rushes down the slopes into the ravines and is massed in great torrents. The same amount falling gently during one or two days would slowly saturate the parched soil and have little, if any, effect upon the river flow.

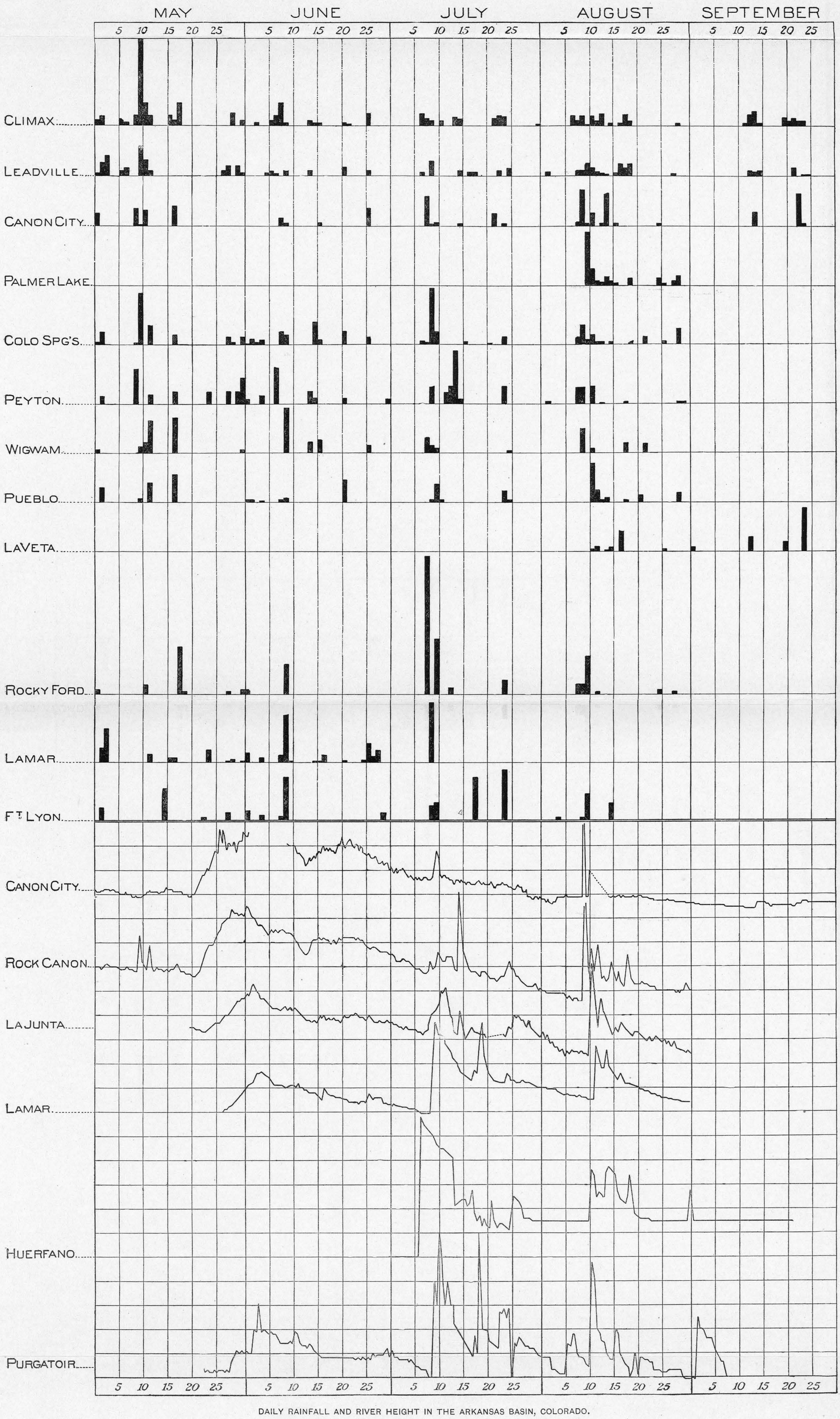
The extent of floods, especially in a large drainage basin, depends upon so many factors—such as the condition of the soil, vegetation, geologic structure, topography, winds, and temperature—that the law of the immediate dependence of these upon the amount of rainfall is obscured. However, it is essential for purposes of agriculture, navigation, and protection of property that the matter be fully studied, and therefore men in various parts of the world have worked upon this problem with results of greater or less practical value. For example, Belgrand,[1] by long studies of the basin of the Seine, has arrived at a rule, perhaps more experimental than rational, by which, knowing the meterologic conditions in the headwaters and the rise of certain affluents, he computes the time and height of flood at Paris.

In this country, also, Prof. Thomas Russell, of the Signal Service, has constructed a formula[2] by which, using certain coefficients combined with the rainfall and the possible evaporation, he obtains for the rivers under examination certain dis-

---

[1] See in particular "Travaux Souterrains de Paris," vol. 1, La Seine.

[2] See Annual Report Chief Signal See Officer U. S. A., 1889, p. 170.



DAILY RAINFALL AND RIVER HEIGHT IN THE ARKANSAS BASIN, COLORADO.

charges which are reasonably comparable with the measured results. By such methods floods have been predicted and warnings given in sufficient time to save property of great value, encouraging the further study of individual basins with the hope of obtaining at least some rule, perhaps of local application, by which river changes can be predicted in time to be of value to the farmer.

The *run-off* is a term applied to the quantity of water which is discharged or flows from a given catchment area, both in floods and at low stages. This is expressed either in terms of the average quantity flowing past a certain point on the stream draining this area or in terms of the depth of an equal bulk of water if this were spread in a layer over the whole area. For instance, it may be said that the run-off is 1,000 second feet; that is, the mean discharge from the given area is, for the time under consideration, 1,000 cubic feet per second Or the run-off may be 2 inches, which is equivalent to saying that during the given time a quantity of water flowed out of the basin or area, which, if put on a plain of the same size, would cover it to the depth of 2 inches.

The run-off comes primarily from the rainfall or snowfall within the catchment area. There are cases, however, where, by a peculiar structure or tilting of the rocks, the rain falling on one side of a watershed may pass through, reappearing as springs in a topographically different basin; but these cases are too rare and the amount usually involved is too small for general discussion.

From the fact that the rain is the source of the run-off, it might be supposed that, the rainfall and the catchment area being measured in the ordinary manner, it would be a simple matter to estimate the water available at any one point, or at least that, the rainfall and run-off for one year being known, it would be simply an example in proportion to estimate the run-off for the succeeding years from the measurements of rainfall alone.

This relation is not so simple, however. In past time many estimates have been based on the direct dependence of the one on the other, but in many instances these have resulted in disastrous consequences. The accumulation of data bearing upon this problem shows a condition of facts and theories requiring detailed study before results apparently contradictory can be harmonized

The relation which actually exists between the rainfall and the run-off is not only a problem, of great scientific interest and value, but to engineers and sanitarians it has a practical importance which justifies the most careful investigation. For several decades there has been no lack of interest in this matter, and the student of the subject finds voluminous discussion and diverse conclusions. There are formulæ and rules for obtaining this relation, but unfortunately these are widely divergent in form and use, and give results as discordant as the theories of their constructors. One can not but be impressed with the fact that the mass of discussions and formulæ far outweighs the data on which they are founded. In short, as in so many other matters of this kind, each man, reasoning from partial and incomplete data, has built a more or less elaborate structure almost obscuring the fundamental facts.

This is from the nature of the case almost unavoidable. The essential facts for such a study are those requiring long-continued, elaborate, and expensive observations by trained bodies of skilled men, and are investigations such as only governments can undertake. Up to the present time these have not been carried on in a broad, systematic way, and fragmentary and incomplete material has from necessity been used in making deductions

Even in countries whose climate and topographic structure are best known, it is rash to attempt to apply these general formulæ for run-off unless they have been derived from adjacent localities whose climatic conditions are essentially similar. For instance, the errors made in proportioning hydraulic structures, as bridge openings and dams, the calculations for which were based on the best known engineering formulæ, are too well known for comment, and serve to enforce the rule that these can be safely applied only in the localities where made and under similar circumstances.

There are, however, certain conclusions about which there can be little doubt, and, when these are grouped with the best and latest data, they will unquestionably aid the solution of certain portions of the problem. These may be stated as follows:

The coefficient of run-off increases with the rainfall.

This, in its broader applications, is one of the most general and well-established facts; namely, that in humid countries the percentage of run-off to rainfall is larger than in the arid regions; and, of several localities, that one having the greatest mean annual rainfall will, cæteris paribus, have a run-off disproportionally large to the others

The annnal run-off of any one basin is not directly proportional to the measured annual rainfall.

While the first proposition, that the coefficient of run-off increases with the rainfall, is true in speaking of averages and in comparing extreme cases, yet the facts do not justify the application of this rule to the annual variations in any one basin The run-off is the resultant of many modifying conditions beyond the actual amount of rain, such as the rate of precipitation, the distribution through the year, the temperature of the air and ground, the previous condition of saturation of soil and subsoil; all these and many others are of almost as great importance as the actual depth of rainfall. One cause of the discrepancies that appear in this comparison of the annual rainfall and flood discharge may be that our rainfall measurements are not accurate This is unquestionably true, for in most of the river basins, both in this country and others, in which this relation has been studied, the rainfall measurements in the places where most needed, namely, in the high mountains, are the poorest. But even in the oldest and best settled countries, where the rainfall is most accurately known, the same lack of agreement between annual precipitation and total discharge is shown.

The influences above mentioned which modify the relation of run-off to rainfall may be divided into two classes, *topographic* and *climatic.*

The topographic are: area of catchment basin, altitude and slope of different portions, soil, culture, and subsurface structure, including texture and porosity of rocks. For any given basin these are practically unchangeable, although changes do sometimes occur—as by burning or cutting off forest and draining lands—which are sufficient to modify the whole regimen of a river.

The climatic influences beyond the total amount of rain or snow are: the distribution of precipitation over a catchment area, rate of fall—not only per minute or hour, but whether coming in protracted, gentle rains or sudden, copious showers—humidity, temperature of air and ground and wind movements, these latter causing the rainfall to disappear rapidly by evaporation or (at the other extreme) to stay frozen as snow and ice.

These climatic factors are variable in a given basin from point to point and from day to day, and are not susceptible of detailed, accurate measurement over a large basin in any practicable manner. In the better settled countries, where habitations are found near the headwaters of the streams, observations of many of these, as rainfall, temperature, and wind movements, have been carried on in a general way, but by no means with that detail necessary to compute the run-off. But while the details of these factors day by day are not known with the exactness necessary for computation, yet in a general way their ranges and averages are readily obtained.

In considering adjacent catchment areas it is obvious that in a broad sense the climatic conditions found in one will be nearly repeated in the other, except as modified by the topography. For instance, of three basins in succession, if the general climatic range of the first and third be known, it may be assumed that the effect of temperature, wind movements, and other factors in the intermediate basin will be between that of those lying outside, except as these are modified by altitude, slope, and other topographic details. In other words, the climatic influences which are measured with difficulty are largely dependent upon topographic features which can be determined with precision.

In any one drainage area, the topography being constant, the variations in run-off are evidently dependent upon alterations of all climatic influences modifying the rainfall. These, as above mentioned, are so many and varied, and in a catchment area of mountains and valleys are so divergent locally, that it is impracticable to measure them all in detail from day to day and properly weigh and combine the figures obtained, and individual judgment and training must enter largely into an attempt of this kind. But the resultant of all these, the run-off itself, is susceptible of exact, direct, and simple observation; and the general range of the run-off, the habit of the river, can be more easily and cheaply obtained by measurements carried on through a few years than by the most elaborate and prolonged study of meteorologic data. In short, the climatic elements of the investigation must be in the main grouped and studied by their combined resultant, the run-off, rather than individually. The total rainfall is the only one which can be obtained with any degree of accuracy.

If this is the case, if formulæ and computations can not be depended upon for general application, it would seem that the only method left is to gauge each and every stream in detail in order to obtain a working knowledge of water distribution and supply.

This extreme position, however, can be modified. If the discharge of a certain basin is known, it has been found practicable to estimate the discharge of a neighboring basin, knowing the topographic details of each. In fact, it may be said that all successful computations have been made in this manner; and while general rules have not applied, special and empirical means have.

In other words, there are these two classes of variables, topographic and climatic, producing a given result, the run-off. In applying the equation which connects these, the climatic variables must be in the main eliminated by using the empirical equation in such a restricted area that the climatic changes, except as affected by the topography, do not enter at all. The relation between rainfall and run-off, being known for one area, is applied to the next, and this only so far as can be checked by results obtained under similar conditions.

In order, then, to obtain information of the water supply of a large and diversified country, as the western portion of the United States, it will be necessary to select, in different portions of the country, certain convenient drainage basins and make discharge measurements in one or two places in each of these, not only of the total run-off but of the discharge of one or more branches. By this careful study carried through a few years, the general habit of the stream can be known. At the same time the other essential information can be obtained from carefully prepared maps, showing the area, altitude, slopes, and general character of the catchment basin; and measurements of the rainfall, and information bearing upon evaporation from water surfaces and other related data, can also be had.

By this means a body of information, an empirical formula, perhaps, can be obtained for this particular stream, and no one will gainsay that this knowledge, intelligently qualified, can be applied within safe limits to the adjacent catchment areas, yielding results of value far above their cost.

With these basins well distributed in the northern, southern, eastern, western, and central portions of the country, the characteristic features of each can be ascertained in something more than the general qualitative way. It is evident that such an investigation can be carried on only by a scientific bureau of the General Government. It is impossible for a State to undertake this work, for scarcely any State includes the whole of a typical drainage basin, and the higher results to be obtained are not of the character of immediate financial benefits that would stimulate any State to undertake such an investigation.

EVAPORATION.

The evaporation measurements mentioned in the First Annual Report of the Irrigation Survey have been continued at places where there was especial need of data for engineering estimates. Although there is a demand for information regarding the loss of water from different classes of soil, from cultivated or barren ground, or from various crops and kinds of vegetation, practical difficulties and uncertainties surrounding such operations[1] are so great that it has not been deemed wise to undertake measurements of this character. The evaporation from the surface of the water, however, is something that can be measured with a fair degree of accuracy. Long series of experiments[2] have been carried on in this country and in Europe, and results of value, though of local application, have been obtained. In attempting to procure data of immediate use in the investigations in the arid region, it was thought best not to undertake at first very refined and delicate experiments, but to make, in as many localities as convenient, certain measurements which should show as near as possible the actual loss of water from the surface of lakes and canals.

The rate of evaporation from water surfaces varies with the temperature of the water, the velocity of the wind at the water surface, and the dryness of the air. Consequently this loss from rivers, lakes, canals, or reservoirs varies widely in different localities and for the same locality in different seasons.

The method adopted consists in measuring the loss of water from a pan (see fig. 124), so placed that the contained water has, as nearly as possible, the same temperature and exposure as that of the lake or canal which it is intended to represent. If this could be perfectly accomplished, the observation would give directly the rate of evaporation desired; but since the inclosing of the water in the pan tends to change its temperature and exposure, the observation is an indirect one. In order to know how closely it represents the evaporation from the natural water surface, the observations should include the water temperatures and the wind force, from which the difference of temperature and exposure may be estimated.

The evaporating pan used by the Survey is of galvanized iron, 3 feet square and 10 inches deep, immersed in water and kept from sinking by means of floats of wood or hollow metal.

---

[1] See "On Evaporation and on Percolation," Chas. Greaves, Min. Proc. Inst. C. E. Vol. XLV, p. 19

[2] Prof. Thos. Russell, "Depth of Evaporation in the United States," Monthly Weather Review, September, 1888.

Also see "Evaporation," by Desmond Fitzgerald, Trans. Am. Soc. C., E. vol. XV, 1886, p. 602, Dorsey, Trans. Am Soc. C. E., vol XVI, 1887. p. 94; and Wild's Repertorium fur Meteorologie, vol. VIII, p. 12, supplement.

It is exposed as nearly as possible to the average wind movement of the body of water from which it is desired to ascertain the evaporation, care being taken to place it in such a position that trees or buildings do not shade or protect it. The device (shown in the upper left hand corner of Fig. 124) for measuring the evaporation consists of a small brass scale hung in the center of the pan. The graduations are on a series of inclined cross-

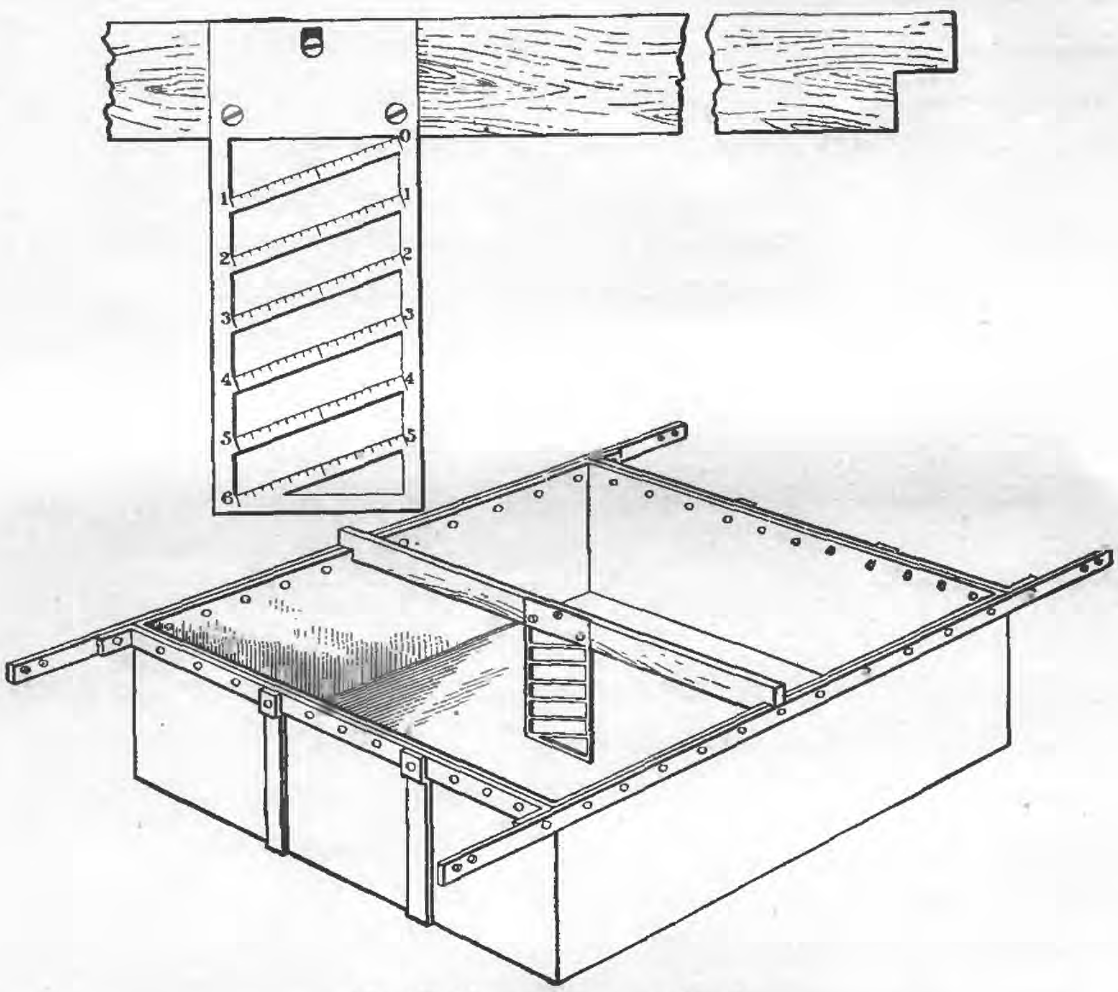


FIG. 124—Evaporating pan and scale.

bars, so proportioned that a rise or fall of a tenth of an inch causes the water surface to advance or retreat three-tenths of an inch along one of the bars. The marks are placed 0·15 inch apart, equivalent to a vertical distance of 0·05 inch, and by this device for multiplying by 3 it is possible to read to 0·01 inch change of level.

Observations have been made at the following places: Fort Bliss, near El Paso, Texas, pan floating in the Rio Grande; Embudo, New Mexico, pan floating in a small ditch near the

Rio Grande; Tempe, Arizona, in the Gila River; Florence, Arizona, in the Salt River; also at Yuma, Arizona, at Cherry Creek, near Denver, Colorado, at Canyon City and Lamar, Colorado, and at Fort Douglas, near Salt Lake City, Utah; besides certain other localities in Utah and in Montana at which the records from various causes are fragmentary.

The results at the different stations depend largely upon the character of the body of water on which the evaporating pan is placed The temperature of a small pond or ditch is subject to great fluctuations during the day, and may have a higher mean value than that of a deep lake or large river, and the evaporation, other things being equal, will thus be greater from the smaller body of water. Experience has shown that the water in the pans, though it heats slightly during the day, perhaps from 1 to 2 degrees above that of the surface of the lake or stream, and cools at night proportionately lower, yet it is maintained at an average temperature for the month within a fraction of a degree of that of the surrounding water.

A lack of correspondence between the water temperatures and the rates of evaporation has been noticed. This disparity is to be expected, inasmuch as the water temperature is only one of three variable factors which control the rate of evaporation Thus, at El Paso the water temperature in March, 1890, was about the same as that of November of the previous year, but the evaporation was 7 inches in March against 4 6 for November This is explained by the increased wind velocity in March, being nearly 50 per cent greater than in November, and by a greater dryness of the air

The results obtained are given below in tabulated form, the depth of evaporation for each month at the various stations being given in inches. In several cases where the results for a month are incomplete, the total for the month is calculated by direct proportion. It should be borne in mind that these are actual measurements of evaporation for the particular time and places under consideration, and while they have value in estimates and comparisons, yet like all results depending upon alternations of temperature, wind, and distribution of moisture, they must vary from year to year in the same locality.

Depth of evaporation per month, in inches.

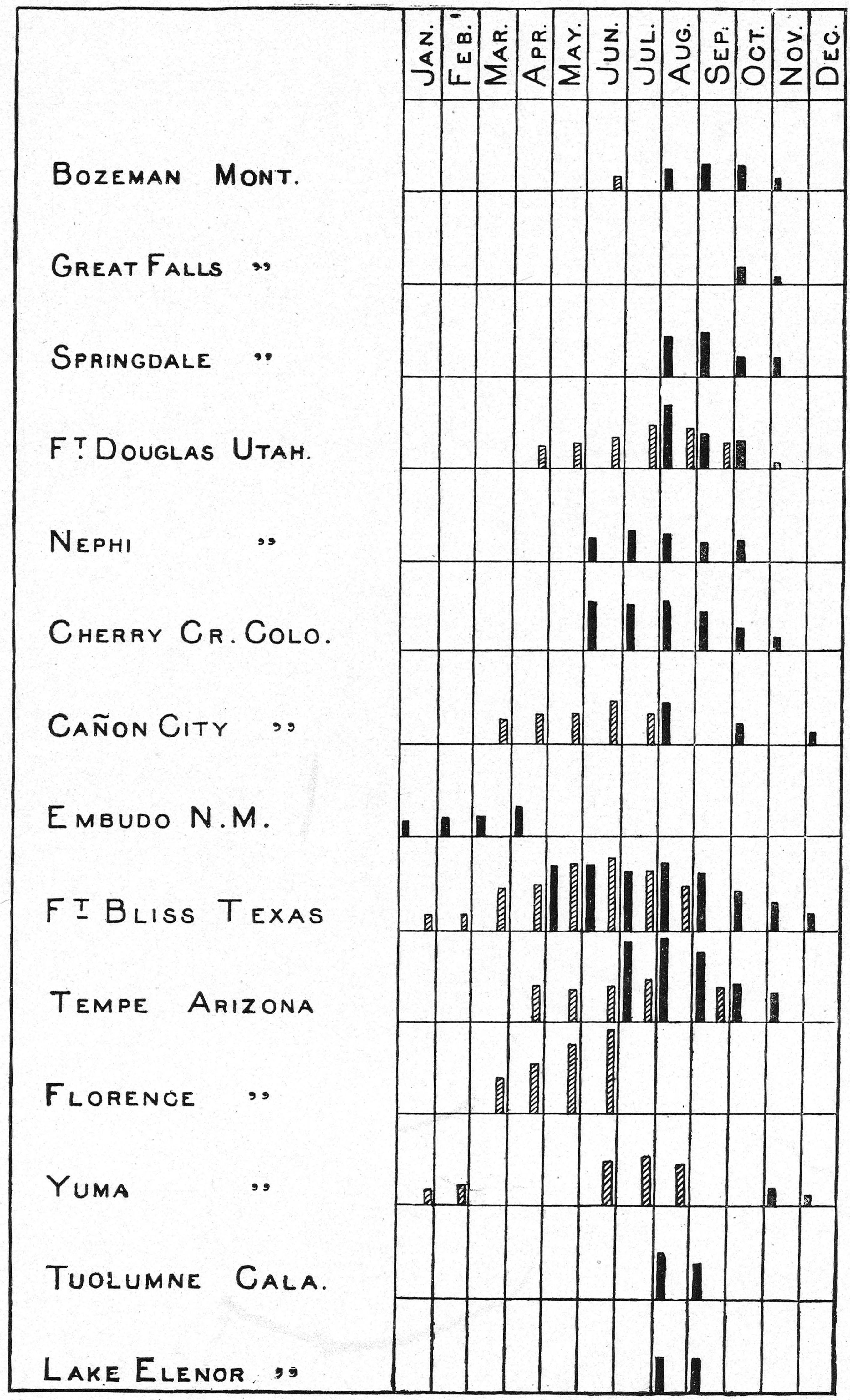
Year	Place	January	February	March	April	May	June	July	August	September	October	November	December
1889	Bozeman, Mont								*c*3 4	*a*4 5	*a*5 3	*a*1 9	
1890	do						*a*2 6						
1889	Great Falls, Mont										*b*2 7	*c*1 0	
1889	Springdale, Mont								*c*6 8	*c*7 1	*b*3 1	*a*2 9	
1889	Hogan, Mont									*b*6 1			
1889	Fort Douglas, near								*b*10 5	*b*5 7	*c*4 9	*c*1 0	
1890	Salt Lake City, Utah				*a*3 7	*a*4 1	*a*5 1	*b*7 6	*a*6 5	*a*4 6	*a*2 1	*b*1 2	
1889	Nephi and Provo						*a*3 9	*a*5 0	*a*4 6	*a*2 9	*c*3 5		
1889	Cherry Creek, Colo						*b*8 1	*a*7 9	*a*8 6	*a*6 2	*a*4 2	*c*2 5	
1889	Canyon City, Colo								*b*7 1		*a*3 6		*a*2 2
1890	do			*a*3 8	*a*4 8	*a*5 2	*a*7 3	*a*6 0					
1889	Lamar, Colo									*a*7 2			
1889	Embudo, N Mex	*a*3 0	*a*2 9	*a*3 6	*a*4 9								
1889	Fort Bliss, near El					*a*10 9	*a*10 7	*a*9 6	*a*11 4	*a*9 2	*a*6 8	*a*4 6	*a*2 9
1890	Paso, Tex	*a*2 0	*a*2 0	*a*7 0	*a*7 3	*a*10 8	*a*11 7	*a*9 6	*a*7 6			*a*3 7	*a*3 0
1889	Tempe, Ariz							*a*13 7	*a*14 1	*a*11 0	*a*6 4	*a*4 4	
1890	do				*b*5 8	*a*5 5	*a*5 6	*a*6 6		*a*5 8	*a*5 2	*b*3 2	*a*4 6
1890	Florence, Ariz			*a*5 8	*a*8 2	*a*11 5	*a*13 5						
1889	Yuma, Ariz											*a*2 7	*a*1 8
1890	do	*a*2 0	*a*2 8				*a*7 2	*a*8 5	*a*7 2	*a*7 1	*a*4 3	*a*3 6	*a*2 5
1890	Bloods, Cal								*c*7 9				
1890	Lake Eleanor, Cal								*c*7 2				
1890	Tuolomme Mead, Cal									*c*5 9			
1890	Lake Tenaiya, Cal									*c*5 7			
1890	Little Yosemite									*c*6 2			

a Indicates that measurements were continued less than a full month and over 20 days.
b Measurements from 10 to 20 days
c Measurements less than 10 days

Besides the table of depths of evaporation, the same results are shown in graphic form on Pl. LXXII, appealing more directly to the eye. On this diagram the average depth of evaporation each day is shown in full scale by the height of the little column The full black columns represent the results obtained in 1889, and the cross-hatched columns those for 1890.

HYDROGRAPHY OF THEDRAINAGE BASINS

In each of the basins in which the hydrographic work of the Survey has been carried on the operations were placed in charge of young men educated as engineers and trained for this particular purpose. These hydrographers, as they were titled, were empowered to employ suitable assistants and were given general instructions, but these were sufficiently broad to allow each man to conduct the work in his basin in accordance with the necessary local conditions, and to exercise such choice of methods as should beget a personal pride in his own undertakings. Reports were made periodically to the Office at Washington showing the progress of the work, and an exam-



DEPTH OF EVAPORATION PER DAY.

ination of these led to more detailed instructions and inquiries from time to time, as the assistant engineer in charge of the work, Mr. F H. Newell, deemed advisable. It is from these monthly reports that the following description of the hydrography of each basin and the results there obtained have been compiled, the substance and sometimes the wording of the reports being given.

In the Yellowstone and upper Missouri Basin the work was under Mr. J. B. Williams; in the Arkansas, under Mr. Robert Robertson, assisted by R. P Irving; in the Rio Grande, under Mr. George T. Quinby, succeeded later by Mr. H M. Dyer, who was assisted by William B. Lane. On the lower Rio Grande, at El Paso, was an observing station almost entirely detached from the work of the upper river; the operations there were conducted under the supervision of Maj. Anson Mills, U. S. Army, who employed Mr. H. P. Croft to take direct charge of the details. In the Gila Basin Mr. W A. Farish had charge of the work, and, in addition to the stream gauging, supervised a large number of measurements of rainfall and evaporation In the basins of the Truckee and Carson, in Nevada, Mr. William P. Trowbridge, jr., conducted the operations; and in the Salt Lake and the Sevier Basins, in Utah, Mr. T. M. Bannon was in charge. In the upper Snake, in Idaho, Mr. L. D. Hopson took charge during the spring of 1890, and after his death by a deplorable accident at Eagle Rock, he was succeeded by Mr F. M. Smith, who up to that time was conducting the measurements in the lower Snake Basin.

In the following pages a short description is given of each drainage basin in turn and of the localities at which stream measurements were made, together with remarks upon any peculiarity or modifying circumstance.

The results of these measurements are given in a concise form in the tabulations beginning on page 93, where are shown the maximum and minimum daily flows, as well as the mean or average of all the days of the month. The maximum is not the greatest flow for any one second or minute, but is the average flow on the day which had the greatest total discharge. During this day, therefore, there was probably a short period during which the rate of flow was far greater than shown by this maximum.

Besides the discharge in second-feet, there is given the total for the month in acre-feet. This is obtained by multiplying the mean of the discharge for the month by the number of seconds in each month and dividing by 43,560, the number of cubic feet in an acre-foot. From the result thus obtained the depth of run-off for the entire basin is calculated.

YELLOWSTONE BASIN.

The Yellowstone River has its source in the high mountains of northwestern Wyoming and flows northerly through the National Park, receiving numerous tributaries and forming on its way the lake of the same name. At the outlet of the lake the catchment area is about 1,300 square miles, embracing in this extent many lofty peaks over 10,000 feet in altitude, some of which are nearly destitute of soil. In general, however, this basin may be said to be heavily timbered; the mean elevation is approximately 9,000 feet. Judging from the accounts of men who have been longest in that country, the annual precipitation probably amounts to over 30 inches, the major part falling as snow. The land bordering the streams has a decided slope, even precipitous, causing the melting snow to run off rapidly.

Measurements of the discharge of the lake have been made at various times with the following results:

	Second-feet.
Aug. 25, 1875, Henry Gannett[1], by floats	1,200
Sept. 1, 1886, Dr. Wm. Hallock, by meter	1,525
Sept. 7, 1886, W. H. Weed, by meter	1,016
Oct. 9, 1889, J. B. Williams, by meter	583

All of the above measurements were made at times of low water and in unusually dry years.

From the lake the river glides gently for 15 miles northerly before entering the Grand Canyon of the Yellowstone. Through

---

[1] For general description see U. S. Geol. and Geog. Survey, Hayden, 1878, part II, p. 473.

this and the lower canyons it flows fully 50 miles before reaching open country, receiving on its way numerous tributaries, the most important of which are Lamar River, or East Fork, and Gardiner River. About 10 miles up this canyon, near the town of Horr, the permanent gauging station of the Survey was established, where the total discharge of the river above all possible irrigating canals is obtained. Measurements were begun on August 12, 1889, and continued at intervals during the rest of the year. In the following March the station was moved about a quarter of a mile lower down and the work continued. The width of the river here is 150 feet, the cross-section is excellent, the river being of nearly uniform width above and below, the bed rocky and firm, and with banks of sufficient height to prevent overflow in high water. The average daily mean discharge per month is given in the accompanying tabulations The conspicuous feature of this is the great annual flood, caused by the melting of the snows accumulated during the winter. This rises rapidly during May, culminates in the latter part of that month or in June, and falls off almost entirely in July. There are numerous minor fluctuations, doubtless due to alterations of temperature, retarding or hastening the thawing. Other floods, as from heavy storms, are exceptional, the lake acting as a regulator. None occurred during the last year.

The total drainage area above the Horr station is approximately 2,700 square miles, with a mean elevation of 8,000 feet, and in general character is similar to the catchment-area basin above the lake.

From the mouth of the canyon, 10 miles below Horr, to Springdale, a distance of about 70 miles, the river flows in a narrow valley one-half to one mile in width, with bench lands of small extent at an elevation of from 50 to 200 feet above the river.

The river itself varies from 200 to 300 feet in width, has a rapid fall, causing a swift current, and carries little or no sediment except in flood season. The bed of the stream is rocky, being composed of stones the size of ordinary paving stones, and the banks are low and gravelly. The river is frequently beset with small islands. Along the valley are cultivated lands irrigated from some 12 or 15 small streams heading in the mountains 8 or 10 miles from the river.

At Springdale a few measurements of discharge were made in the fall of 1889, giving the following results:

	Discharge, second-feet.
Aug. 24, 1889	2,111
Sept. 5, 1889	1,931
Oct. 3, 1889	1,581

It was not deemed advisable to establish a permanent station here, as that at Horr gave the flow with an accuracy sufficient for all demands.

UPPER MISSOURI BASIN.

The Missouri is formed by the union of the three rivers Gallatin, Madison, and Jefferson, all rising in the order given west of the National Park and flowing northerly from the Continental Divide, which at that place turns off abruptly to the west. The catchment areas of these rivers are somewhat similar in character, being in the main timbered mountain lands, with steep slopes scantily covered with soil, the minor basins, however, becoming more open and less elevated toward the western or Jefferson drainage.

GALLATIN.

The west or main branch of the Gallatin heads in the northwestern corner of the park, in a number of small lakes, of which that of the same name as the river has an elevation of 8,900 feet. The river has a rapid fall, flowing with swift current through short and narrow valleys, in a rocky channel and between high banks, the greater part of its course being in gorges. Its width just before emerging from the mountains is from 100 to 150 feet. It finally issues from its cañon upon a broad, fertile plain, the greater portion of which lies between the East and West Gallatin Rivers and the foothills of the mountains—a magnificent stretch of country containing over 250 square miles of the richest farming land in the State.

The greater part of this is quite level, while the rough places are not too broken for irrigation. The country on the left or west consists of light, rolling land, of which probably one-third could be reclaimed by irrigation.

The river still has a rapid fall and swift current, the slope being about 25 feet to the mile. The banks are low and composed of gravel, as is also the bed of the stream. The river divides into numerous channels, forming small islands, and in the lower part of its course there are many sloughs and a few swamps. The elevation of the land in the valley is from 4,100 to 5,400 feet. There is one large canal taken out of the West Gallatin River, claiming an appropriation of 150 second feet, but it does not carry over 100 second feet. The head gate of this canal is about a half mile above the mouth of the gorge.

The gauging station is located at the mouth of the canyon, a few hundred feet below Spanish Creek. It is above the head-gates of the high-line canal which runs northeasterly to Bozeman, 20 miles distant. The bed of the river is rocky and not liable to wash out, the banks high and steep, the river straight and of nearly uniform width, in every way suitable for stream measurements. The results of the measurements are given in the appended tabulation.

MADISON.

The Madison River also rises in the National Park, receiving the drainage of the Geyser Basins through the Firehole River. The upper catchment area, while similar to that of the Yellowstone and Gallatin, is perhaps less steep and less heavily wooded. After leaving the mountains, the river enters the narrow, fertile Madison Valley. This open land has a length of about 40 miles, is from three-quarters to one and one-half miles wide, bounded by benches on either side; the elevation is a little over 5,000 feet. The fall of the river is approximately 18 feet per mile, the channel rocky or gravelly, the banks generally low on the right-hand side and rising in high bluffs on the left. The stream is usually clear and nearly free from sediment, excepting in flood. Little of the water used for irrigation in this valley is taken from the river, but most of it from the various small creeks flowing from the Madison range on the east and from the Jefferson range on the west.

At the lower end of the valley the river again enters a canyon, about 10 miles in length, and finally debouches upon the western prolongation of the Gallatin Valley, which it crosses to join the other rivers in forming the Missouri. In the lower end of the canyon, at a point below the mouth of Hot Spring Creek and 4 miles from the town of Red Bluff, is located the gauging station of this Survey, at what is known as Hayward Bridge. The river here has a swift current and a rocky bed, with a high bank on the left and a low one on the right.

This river is more constant in its flow than is usually the case with rivers of the arid region, its steadiness being due primarily to the perennial supply from the hot springs in the National Park.

JEFFERSON.

The Jefferson has a much larger but lower catchment basin than the two rivers just mentioned, the average elevation probably being not over 6,000 feet. The valleys are broader, open country extending nearly the whole distance from the junction of the three rivers up to the point where the Jefferson is, in turn, formed by the union of the Big Hole and Beaver Head Rivers. These valleys are fairly well settled, but the population is somewhat scattered.

On August 19, 1889, the river was discharging at Willow Creek, 202 second feet, and on October 15, at Three Forks, 333 second feet. There is no permanent gauging station on the Jefferson itself, the work being confined to measurements of Red Rock Creek, at the town of Red Rock, on the Utah and Northern Railroad. At this point the bed is of gravel, the banks about 4 feet high and the channel very tortuous. This locality was selected from the fact of its being one of the places on the river which were not dry during the summer in 1888 and 1889. This creek is the headwaters of the Missouri, or, in other words, is the stream which is farthest removed from the mouth of the river, as the water flows. It rises in a loop in the Continental Divide, about 15 miles west of the National Park, and continues nearly due west for 60 miles before turning northerly, passing on its way through the elevated and open Red Rock Valley.

A comparison of the discharges of these three rivers, the Gallatin, the Madison, and the Jefferson, is interesting as showing the low-water discharge of 1889 into the Missouri. In the following table are given the results of gaugings made on the three streams at about the same time in August and again in October. In the last column is given the run-off in second-feet for each mile of drainage area obtained by dividing the discharge in second feet by the number of square miles of catchment above the gauging point.

Comparison of discharges.

Date	River	Discharge	Area	Discharge per square mile
1889		*Sec -feet*	*Sq miles*	*Sec -feet*
Aug 16	West Gallatin	437	850	51
Oct 14	do	402	850	47
Aug 17	Madison	1,104	2,085	53
Oct 14	do	1,191	2,085	·57
Aug 19	Jefferson	202	9,450	02
Oct 15	do	333	9,450	03

THE MISSOURI RIVER.

The Missouri River, formed by the union of the three streams above mentioned, flows north from Three Forks about 20 miles before reaching an open valley. This valley, at the head of which is Toston, is over 40 miles in length and has good bench land on either side. At the lower or northern end of the valley the river enters a narrow gorge or canyon about 60 miles long, the sides of which are timbered and have highly inclined slopes. Issuing from this canyon, the river flows through a narrow valley, which broadens out occasionally. On the west side, beginning near Cascade, are wide, flat bench lands of immense area, 50 to 300 feet above the water, extending, with occasional breaks, for several hundred miles down the river Between Three Forks and the mouth of the Dearborn River no large tributaries are received, the streams which enter between these points being short and carrying a small amount of water, except in flood.

The current of the river is sluggish in low water, the fall being only about 4 feet to a mile; its width varies from 300 to 450 feet; the bed is rocky or of gravel, as are also the banks. It carries little sediment except in high water, frequently forms small islands, and is fordable at many points in low water. Few ditches are taken from the river and these are of small size. The elevation of the agricultural land varies from 3,700 to 3,900 feet, that of the benches in the vicinity of Great Falls, from 3,400 to 3,500 feet.

Measurements of discharge have been made at three places on the river: (1) at Toston, at the head of the valley, 20 miles below Three Forks; (2) at Canyon Ferry, at the lower end of the same valley, nearly 40 miles below Toston; and (3) at Craig, about 40 miles farther down.

A station was located at Toston on account of the ferry at that place, it being the only point convenient of access on that part of the river. The section was found to be far from good, however, and the results did not give entire satisfaction. The measurements are herewith given.

Date.	Discharge.	Drainage area.	Run-off per square mile.
1890.	*Sec.-feet.*	*Sq. miles.*	*Sec.-feet.*
April 8	3,843	14,280	0·27
May 6	12,377	14,280	·86
May 13	14,440	14,280	1·01
June 6	13,745	14,280	·96
July 4	6,838	14,280	·48
July 26	3,697	14,280	·26

At Canyon Ferry, 18 miles from Helena, a temporary station was established in the latter part of August, 1889, and continued through the succeeding three months. The location was favorable for obtaining the low-water discharge, but during the spring and early summer floods the stream flows in two channels; accordingly, before the next field season the equipment was moved farther down the river to a point more convenient of access and better suited for current meter measurements.

The station at Craig was put in operation April 18, 1890. The river at this point is of nearly uniform width, is straight for a short distance above and below the section, and has a good gravel bed.

THE SUN RIVER.

The mountain catchment area of the Sun River lies at an elevation of from 4,500 to 7,000 feet. It is heavily timbered and has highly inclined slopes well covered with soil. The total drainage area is estimated to be 2,240 square miles. The river has a fall of about 40 feet to the mile, a rocky bed, banks generally high, but in some cases low, with bluffs on at least one side of the river. It frequently flows through narrows, canyons, and deep gorges, and is free from sediment except in flood season. Below the catchment area the river flows through a narrow valley, having an elevation of from 3,300 to 3,800 feet, with broad bench lands on the left bank, extending to the Missouri River on the east and to the Teton River on the north. On the right or south bank the bench lands are more limited in area, but are nevertheless of large extent. A portion of the country is rough and broken, with "flats" here and there.

The regular floods are caused by the melting of the snows in the mountains, which sometimes disappear with great rapidity, due to the "Chinook wind." The snows which fall in April and May are melted by the warm rains before they become consolidated, and thus irregular and overwhelming floods are liable to occur. The water for irrigation is taken out by means of small ditches only. There is one good-sized ditch partially completed, on which no work has been done for the last two years.

The gauging station is about 18 miles above the town of Augusta and 58 miles from Craig, the most convenient railroad station, and it is above all the irrigating ditches. Measurements were begun August 5, 1889, and carried on during September, October, and November. In the following spring a better locality was chosen about 200 yards below, and observations of height and discharge begun on April 1. The area of catchment above the gauging station is about 1,175 square miles.

CACHE LA POUDRE BASIN

The gauging station on the Cache la Poudre was constructed in the spring of 1884 under the supervision of Mr. E. S. Nettleton, at that time State engineer of Colorado. A record of the amount of water passing this station has been kept, usually from March to October of each year, since that time, giving the longest record yet obtained of the annual fluctuations of any stream in this part of the arid region. During 1889 this Survey cooperated with the State engineer in continuing the work at this important point to preserve an unbroken record of the summer discharge The station is about a half mile above the mouth of the canyon, and 12 miles above Fort Collins. A description of the station, the equipment and self-registering height gauge or milometer, together with results, may be found in the second, third, and fourth biennial reports of the State Engineer to the governor of Colorado.

The results obtained here are of more than local interest; they may be taken as in a certain degree representative of the condition of other streams, not only in Colorado, but over a large portion of the arid region, in the gradual decrease of discharge during the last few years, culminating in the unusually dry seasons of 1888 and 1889, when there was great loss and even suffering in many settlements in Colorado, New Mexico, and Utah, due to shortage of water and failure of crops.

The mean discharge of the several years, as obtained by the State engineer and by this Survey, is given in the tabulations further on.

In the following table of the average daily flow by months the great decrease from year to year can be seen by inspection.

Mean discharge of Cache la Poudre River in second-feet.

Year	April	May	June	July	Aug.	Sept
1884	219	2,537	4,812	2,144	792	305
1885	447	1,410	2,910	1,857	657	272
1886	405	1,309	1,875	717	338	185
1887			1,401	735	307	175
1888	181	483	1,113	420	213	109
1889	113	649	1,338	514	187	67
1890	200	1,044	1,280	649	287	103

THE ARKANSAS BASIN.

The Arkansas is, in many respects, a typical river of the arid region, in both its topography and regimen. Geographically, it is intermediate between the large rivers of Montana, with their superabundant water supply and regular spring floods, and those of Arizona, with usually small flow and spasmodic, disastrous deluges in the late fall or winter months. It rises in the snow-mantled mountain slopes of central Colorado in an area varying in altitude from about 5,000 feet at the eastern base to 10,000 on the west, and dotted over with peaks rising to 14,000 feet above sea level

At the higher altitudes (above 10,000 feet) most of the precipitation is in the form of snow, which accumulates from October to April. The melting of this snow is the source of water for the river during the irrigating months of spring and early summer. The snow falls frequently, and the winds blow it into the gulches and ravines until these are often filled to a depth of 50 or more feet. Were the snow uniformly spread on the ground a large portion would evaporate without melting or would melt much more rapidly in the spring, causing higher and shorter floods than is now the case Though as a whole this portion of the arid belt is denied a rainfall sufficient for the needs of agriculture, this condition is somewhat ameliorated by the fact that the mountain areas receive more than their share of moisture in the form of snow. This, being stored up during the time of the year when not needed and loosed when the requirements of irrigation demand, is borne downward by the rivers to be delivered on the land by the irrigators in such time, quantity, and place as are needed. At present there is a time of scarcity in early spring and in July and early August, and it is the inability to get water at this time that limits agricultural development. To supplement the action of nature, storage reservoirs are built to furnish water in these months

Above Canyon City, Colorado, the Arkansas River has, in the main, the character of a mountain torrent, descending from an altitude of 10,000 feet near Leadville to 5,300 feet near Canyon City, a distance of 120 miles. Below that point it begins to traverse the Great Plains, and assumes a different type; its gradient is diminished, its breadth increases, and, owing to its reduced velocity, it assumes a sinuous course. With this lessened velocity it is unable at ordinary stages to carry the load of detritus collected in the more rapid portion above, and this is deposited, forming low, sandy banks and bars, blocking the course and causing the stream to shift its bed. But at high stages this material is again caught up, the banks are eaten away, and the loops are sometimes cut. Very considerable changes of channel are thus produced by a single flood. Owing to this instability of the bed and banks of this portion of the river, dams and other headworks for irrigating canals are constructed and maintained with difficulty

On the headwaters of the river are eight gauging stations, located chiefly at points where the results will be of greatest value in any discussion of storage problems. At these altitudes the climate is too cold for crops to mature, except hay, of which but one cutting is made in a season.

The first and highest of these gauging stations is on the East Fork of the river, about 3 miles north of Leadville, at the outlet of a reservoir site examined by this Survey in 1889. The next is on the Tennessee Fork, about 5 miles from Leadville and ¼ mile from its junction with the East Branch. The third station is on Lake Fork, about 6 miles from Leadville.

About 10 miles below the union of the forks there is, on the main river, a fourth station, 1½ miles below Hayden, a stopping place on the Denver and Rio Grande Railroad. At this point are to be the headworks of the diversion canal, outlined in the report of Mr. S. H. Bodfish, Division Engineer, to take the water from the river around the base of the hills into the Twin Lakes Reservoir site. Gaugings are also carried on below the outlet of these lakes to obtain the present discharge.

The sixth station is on Clear Creek, the next tributary coming in from the west, about 4 miles below Twin Lake Creek. The measurements are made a few hundred yards above the place where it empties into the Arkansas. The two remaining gauging stations are on Cottonwood Creek, a stream which enters also from the west about 15 miles below Clear Creek.

The measurements are made on the Middle and South Forks just above their junction and about 7 miles from the town of Buena Vista. These branches are typical mountain streams—their fall is rapid and the channels are blocked by bowlders and fallen timber, rendering it a matter of difficulty to find a place suitable for gauging.

Measurements were begun in the spring of 1890, as soon as the roads were opened, and were carried on continuously. The results obtained are shown in the following table:

Mean discharges of tributaries of Arkansas River above Canyon City, Colo., 1890, *in second feet.*

	April.	May.	June.	July.	Aug.	Drainage area.
						Sq. m.
East Fork	*46	213	224	103	46	44
Tennessee Fork		*239	141	64	38	44
Lake Fork	*75	324	243	73	35	21
Twin Lake Creek	*24	252	552	365	176	102
Clear Creek		187	356	238	98	72
Middle Fork Cottonwood	*26	83	121	70	25	37
South Fork Cottonwood	*10	71	121	98	53	28

* Month not complete.

The principal station on the Arkansas River is near Canyon City. This was located[2] in the spring of 1888 by the State Engineer of Colorado at a foot bridge crossing the river near the Hot Springs Hotel, about 2 miles above town. Previously gaugings had been made farther down the river, at Pueblo in 1885 and 1886, and at a point 9 miles above Pueblo in 1887, but both of these places had been abandoned as unsuitable from the frequent change of cross-section. In 1889 the Canyon City station was reestablished by this Survey and work carried on continuously from that time. The discharge at this point gives the flow of the river little diminished by diversions for irrigation, as at this locality the stream makes its exit from the mountains. Above this point there is comparatively little irrigation and there are small possibilities of future development of it, in the few small patches of land adjacent to the river. The channel here is straight for several hundred yards both above and below, the current is neither too swift

---

[2] See Fourth Biennial Report of the State Engineer to the Governor of Colorado, p. 58.

at high water nor too sluggish at low water for satisfactory work with the current-meter, and the banks are of a height to retain the floods.

A comparison of the mean discharge by months for the past three years gives some suggestions of the range in discharge of the river at this point.

Mean discharge of Arkansas River at Canyon City, Colorado, in second-feet.

Year	April	May	June	July	Aug	Sept
1888		1,440	2,090	1,350	932	605
1889	300	600	1,374	602	340	220
1890	477	2,090	2,611	1,571	670	519

Below Canyon City the Arkansas River receives ordinarily but little water from its tributaries, though in summer there are occasional very violent floods due to storms, locally called "cloud-bursts," on the plains or in the foot-hills. These storms do much damage and but little good. The downpour is very great for an hour or two, and, falling on the bare, baked earth, the rainwater runs off so rapidly that it only serves to swell the streams to abnormal proportions and to sweep away dams, bridges, and other structures in its course. The amount of water precipitated by these storms is large, but its utilization presents great, if not insurmountable, difficulties. They occur, however, at the time when water is scarce and very much needed, and if only a small portion of their waters could be stored it would be a great boon to the country. The principal difficulties to be overcome arise from the fact that the area over which a given storm will extend is very limited and the time of occurrence exceedingly irregular. A reservoir site might have such a storm in its drainage area one year and none for several successive years. The violence of these storms, when they do occur, is such that, even if dams can be constructed sufficiently strong to withstand the force of the torrents, it is to be feared that their cost will be too great, since there is no certainty of filling them every year, and, owing to the large amount of débris carried by such waters, the reservoirs would silt up very rapidly. On the other hand, if the storage could be made, water would be available at a time of the year when it is much needed

In the summer of 1889, after one of these storms, the Arkansas River at Lamar, Colorado, discharged enough water in 24 hours to keep the river at a height sufficient for all the needs of irrigation for more than one month if it had been gradually supplied to the stream. Instead of doing good this storm did only harm in washing out and carrying away dams, flumes, and other similar structures. Within two days after the storm the river had resumed about its ordinary low-water stage, and within a week or so thereafter the farms within the area of the storm were suffering for water.

At Pueblo, as stated above, measurements of the stream were begun by the State engineer in 1885[1] and continued during the following year. In 1887 the gauging was done at a point about 9 miles above Pueblo, and in 1888 discontinued in favor of the Canyon City station The next year, however, this Survey took up the work in the canyon above Pueblo, as well as at Canyon City. These two localities, nine miles apart, may be considered as one station, this giving results for four crop seasons with a break of an intervening year, that of 1888. The short table below shows, by eliminating the daily fluctuations, the relative discharges for the various months in these years.

Mean discharges of Arkansas River at or above Pueblo, Colo., in second-feet.

Year	May	June	July	Aug	Sept
1885	1,069	3,187			
1886	3,046	5,569	1,724	1,481	1,372
1887		3,477	3,352	1,717	1,129
1889	1,300	2,108	766	668	

The falling off in the discharge of the Arkansas River from 1886 to 1889, as shown here and at Canyon City, finds its counterpart in the diminution of the observed precipitation. This is best shown by the totals taken from January to June of each year, the period which affords the rain and snow for the May and June floods. The data for Pike's Peak and

---

[1] Third biennial report State engineer, Colorado, p. 172, et. seq.

Colorado Springs, a mountain and a plateau station of the basin, both exhibit the precipitation diminishing from 1886 to the minimum amount of 1888.

But, while the precipitation reached its minimum in 1888, the discharge of the Arkansas reached its minimum in 1889, when the outflow was considerably less than in 1888. An important circumstance contributing to this minimum flow of 1889 lies in the fact, already mentioned, that the increase of precipitation shown in the tables did not occur as snowfall in the mountains, and consequently did not contribute to the spring floods.

The winter of 1890 was once more one of heavy snows in the counties (Lake, Chaffee, and Fremont) embracing the headwaters of the Arkansas. The river began to feel the effect of the melting snows before the 1st of May, and reached its maximum discharge between May 27 and June 4. The total discharge of the river for the season has exceeded that of 1888 and 1889, but has not equaled that of 1887.

This failure of the discharge in 1890 to equal that of 1887, although the precipitation has probably been greater, and the delay of the year of minimum discharge from 1888 to 1889 illustrate the slowness with which streams of large drainage area respond to the annual fluctuations in precipitation.

The Arkansas River begins to diminish in volume at about Catlin, Colorado, 40 miles below Pueblo, owing to the diversions of its waters by irrigators and to loss by seepage and evaporation. Below this point, in the present condition of the river and with the present usages in administering its waters, there is no certainty that the farmers will get sufficient water in July and August for the needs of their crops. Just east of the Colorado and Kansas State line in summer there is frequently no water visible, though there is always more or less percolating through the loose sands of the bed.

Below Pueblo attempts were made in 1889 to measure the river at two points, and also two tributaries, the Huerfano and the Purgatoire. Owing, however, to the irregular summer floods and constant shifting of the channels during and after high water, the results were not wholly satisfactory. The two lower stations were La Junta, 60 miles below Pueblo, and Lamar, 50 miles farther down and about 35 miles above the Kansas State line

On the Huerfano a station was located at the outlet of the Cucharas Canyon on the Hermosilla Ranch, 20 miles south of Pueblo. This stream is subject to very violent summer floods, though its normal discharge is small. Two trips were made for purposes of gauging, one in the latter part of June and the other on July 30, 1889, but on neither occasion was there enough water flowing in the bed to allow the use of a current-meter, the discharge being from 3 to 5 second-feet At La Junta, in spite of the great changes in contour of river bed, the discharge for any given height was fairly constant, and quite good results were obtained

The station on the Purgatoire was one and a half miles above its junction with the Arkansas and about the same distance east of the town of Las Animas. This stream is very small except at the time of melting snows, when it swells to a considerable size, and after storms or "cloudbursts" of summer, when it becomes a raging torrent. The unstable character of the bed rendered the measurements somewhat unsatisfactory; the following estimates contained in the tables of monthly discharges are, however, of value, as showing the size of the stream.

At Lamar the scour and fill of the bed of the Arkansas was so great that the bottom at one time was above the water surface of a later date; hence, the height of the water referred to any permanent bench-mark could have but little meaning. The banks of the river are low, the surrounding country being a plain or prairie. The channel is about 325 feet wide and very shallow, in low water the depth averaging perhaps a half foot. Eastward the stream diminishes rapidly, until at Coolidge, Kansas, the flow sometimes ceases in summer. Lamar being about the eastern limit of Colorado irrigation, the water which passes here may be considered as waste or drainage. Instead of attempting to compute averages for this locality, the section being so poor, the results of measurements only are given, viz: May 26, 1889, 300 second-feet; July 19, flood estimated at 15,000 second-feet; July 22, 851 second-feet; August 3, 284 second-feet; August 7, 187 second-feet.

In order to illustrate the influence of the rainfall upon the river height, the progress of the floods, and other related facts, there is given on Pl. LXXI a hydrograph or plot showing the fluctuations in river height from May to September, 1889, for the four stations on the Arkansas, viz, at Canyon City, Rock Canyon (9 miles above Pueblo), La Junta, and Lamar, and also for the two tributary streams, the Huerfano and Purgatoire. On the same page, above these diagrams, is shown graphically the daily rainfall as measured at twelve stations in the basin during this period. By studying these the relative effect of the melting snow, of the sudden local showers or "cloud-bursts," and of periods of drought can be seen, as well as the progress of the floods down the main stream.

RIO GRANDE BASIN.

The Rio Grande rises in the mountains of southern Colorado, flows easterly into the great San Luis Valley, then turns southerly into New Mexico, traversing that territory from north to south. It forms for a few miles the boundary between New Mexico and Texas and then is the dividing line between Texas and the Republic of Mexico. From Del Norte to the Pecos River in Texas its waters are diverted by hundreds of ditches. Some of these are of great antiquity, dating back to the Spanish conquest, and perhaps earlier. Communities and towns in Colorado, New Mexico, Texas, and in the Mexican republic are dependent for their life upon the waters of this river, and anything that affects the flow is of vital importance to thousands of people.

The diversions of water have proceeded from the south up stream, the Mexicans gradually extending their settlements and taking out small tortuous ditches along the bottom lands. Within the last few years, however, following upon the development of mining in Colorado, agriculture has been found very profitable in the San Luis Valley, and canals as large as, if not larger than, those of any other locality in the United States have been built. The enormous diversions of water in this valley and the unusually dry seasons have resulted in a diminished flow in the river below, so that for two summers the bed of the stream has been dry below San Marcial As a consequence, loss of crops and great suffering have ensued among the farmers who have been accustomed to depend upon the river water.

Such a succession of dry years is, of course, likely to occur again, and even if the drought is not so severe, with the continual diversion of water in Colorado and upper New Mexico there must finally come a time when scarcity of water will be the rule in the lower part of the Territory and in Texas and Mexico The water-storage problem, therefore, is of momentous importance, and a study of all the facts bearing upon hydrography is demanded at once

The investigation of the water supply of the Rio Grande basin was begun by the establishment of river-gauging stations at Del Norte, Colorado, at Embudo, New Mexico, and at El Paso, Texas The tables of monthly discharges for these three places will give the main facts of the water measurements.

The total amount of water which passed Del Norte during the year ending June 30, 1890, was 0·23 cubic miles, or an average of 1,090 second-feet for the 12 months. This amount, if distributed uniformly over the drainage basin above the gauging station, would cover the ground to a depth of 10½ inches. There are but few small ditches taken out above Del Norte, and no large bodies of level land, so that the results obtained there may be considered as the total discharge unmodified by artificial means.

The distance from Del Norte to Embudo by river, omitting the tortuous meanders, is about 130 miles. During this course the river receives many small tributaries, as will be seen by a glance at a map. Many of these, however, at ordinary stages, lose all their water by diversion to irrigating ditches, or by its sinking into the sandy beds long before it can reach the trunk stream. Only in times of flood do they actually contribute to the discharge of the river.

At Embudo the total discharge (see Pl. LXXIII) for the year was 0·26 cubic miles, or a daily mean of 1,240 second-feet, only

150 second-feet more than at Del Norte. Considering any such point as Embudo, it becomes a difficult matter to compute the drainage area which actually contributes to the flow. As just stated, the rain which falls upon vast areas included in the drainage basin seldom or never reaches the river. In the northern portion of the San Luis Valley the streams flow into the San Luis Lakes, from which there is no outlet. All this part of the drainage basin can therefore be excluded at once, as not contributing to the Rio Grande. Farther south, however, the difficulty of discriminating between the portions of the basin which do or do not supply water becomes greater, and it is impossible to decide what particular areas should be considered as tributary to the stream. The total area of the basin above Embudo, excluding the drainage into the San Luis Lakes, is 7,000 square miles. Distributing the total flow for the year over this area, the depth would be 2·4 inches. The excess of the discharge of Embudo above that of Del Norte, if distributed over the drainage included between Del Norte and Embudo, would cover the ground to a depth of only 0·36 inch. It should be noted that in this comparison no account is taken of the results of the canal diversions.

El Paso, according to the survey made by army engineers[1] is about 517 miles below Embudo, following the course of the river. The slope ranges from 4 to 52 feet per mile. The principal tributaries are the Chama, Jemez, and Puerco, all coming in from the west. As is shown by the diagram of discharge and monthly averages, the water received from tributaries below Embudo is not sufficient to supply the loss by evaporation and diversion.

The total flow for the year at El Paso was 0·22 cubic mile, averaging 1,050 second-feet, or 190 second-feet less than at Embudo. From the latter part of July to the middle of December the water ceased flowing, the bed being dry except in deeper pools.

The following comparison of the mean daily discharge in second-feet at Embudo and El Paso gives some facts of interest:

---

[1] Annual Report Chief Engineer U. S. A.; 1889, p. 1571.

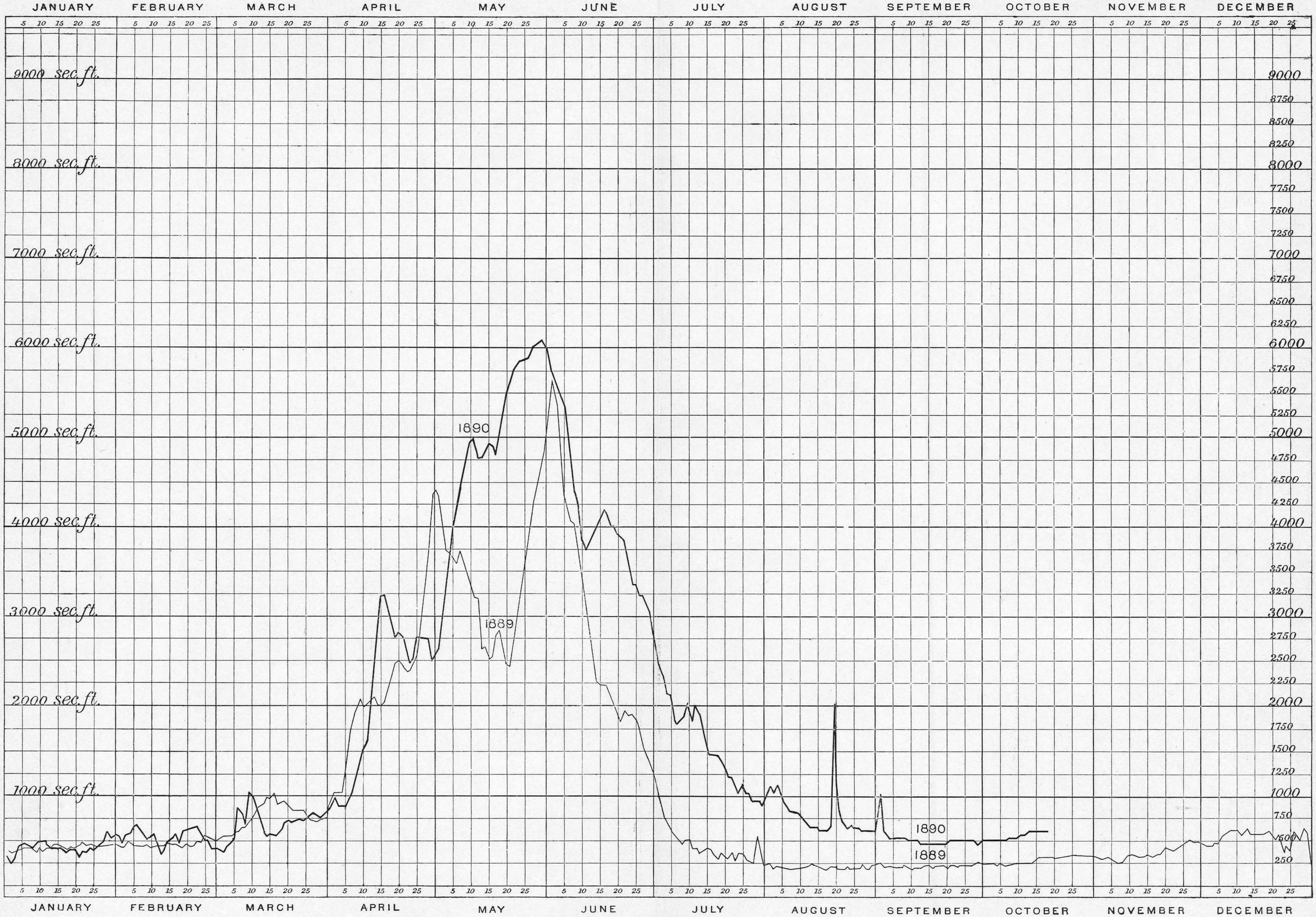


DIAGRAM OF THE DAILY MEAN DISCHARGE IN CUBIC FEET PER SECOND OF THE

RIO GRANDE

AT EMBUDO, NEW MEXICO.

Mean daily discharge of Rio Grande in second-feet.

	1889.						1890.		
	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March.
Embudo	471	206	212	283	366	542	437	553	682
El Paso	237	0	0	0	0	70	196	290	424
Difference	234	206	212	283	366	472	241	263	258

It is evident that from 300 to 400 second feet must pass Embudo, in addition to the ordinary discharge of the tributaries, before any water can reach El Paso.

SEDIMENT.

The sediment observations were begun at Embudo, New Mexico, January 15, 1889, and were continued for three months. The apparatus was then shipped to El Paso, where samples were first taken on July 10, the work being continued from that time through the following fiscal year. In these measurements the object in view was not so much the obtaining of results of scientific accuracy as the procuring of certain data for engineering purposes, viz, the approximate proportion of silt carried by the river water at various stages and seasons. The equipment for doing this work was necessarily simple and rather crude, owing to the original requirements that these measurements should be made in camp and that all parts of the apparatus should be strong and portable.

In the previous annual report[1] mention is made of the conclusions reached as to the most convenient way of taking samples and drying filtrates. These methods have been in use during the year and give quite satisfactory results. With the sediment trap, a horizontal cylinder with vertical sliding doors at each end, water was taken at about one-half foot below the surface for the top sample, and at about one-half foot above the bottom for the bottom sample. These were then placed in covered jars and allowed to settle for three or four days. At the end of the time the clear water was carefully drawn off with a glass siphon and the sediment washed out upon filter paper by means of a jet of clear water. The filter papers were

---

[1] Tenth Annual Report U. S. Geol. Surv., Part II, Irrigation, p. 85.

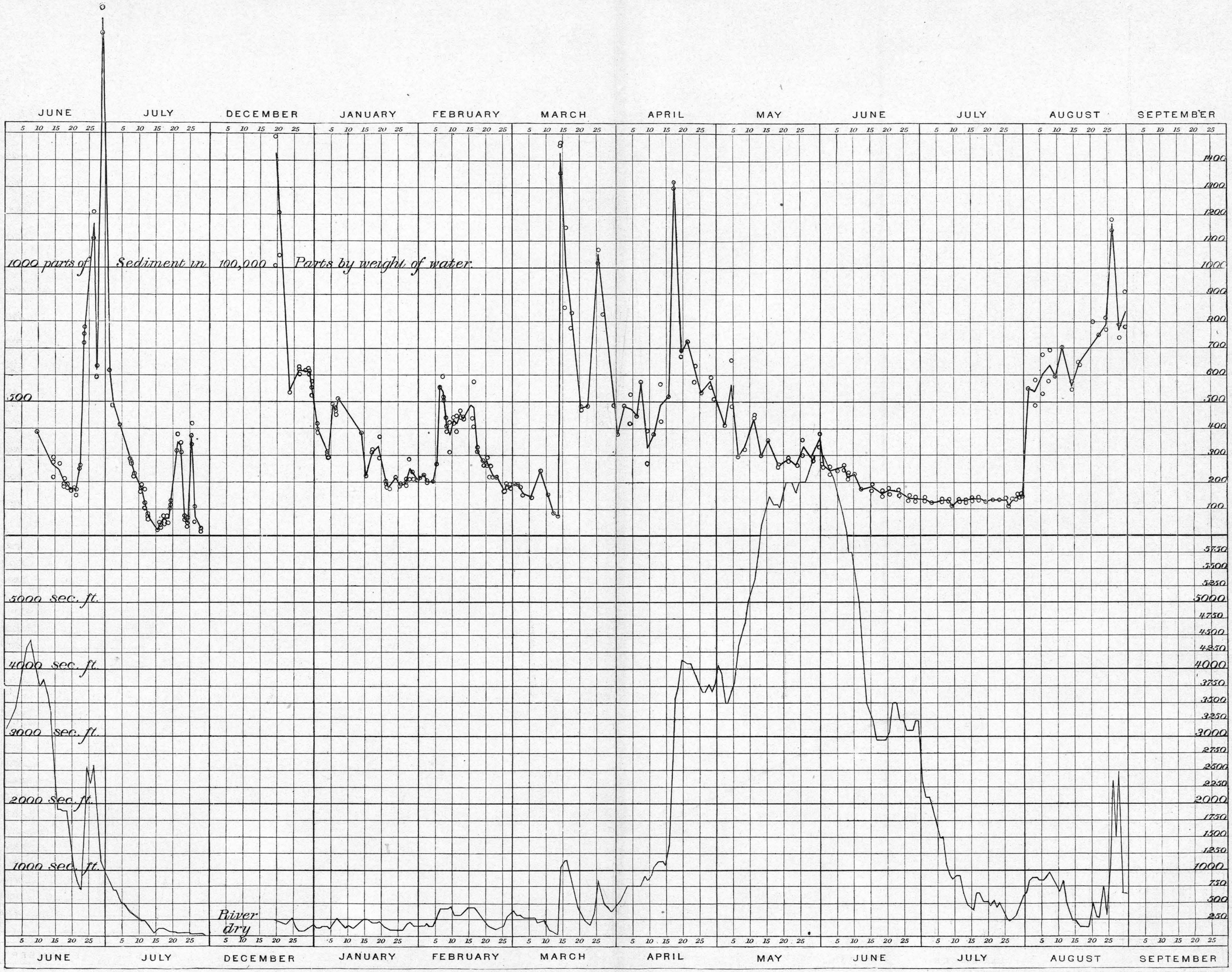
previously dried and weighed, and after receiving the sediment were again put into the drying oven. This was kept at a temperature of from 50° to 60° C. by an oil stove. After 24 hours' drying the papers containing the sediment were carefully weighed, due precautions being taken against increase of weight by absorption of moisture from the air.

On the diagram, Pl. LXXIV, are given the data from the El Paso station, showing graphically the number, date, and agreement or lack of agreement of the observations. One, two, or three samples were taken on the same day. As above stated each sample was, in general, made up of portions taken from near the surface and bottom, being intended to represent the average sediment of that vertical plane.

The river at that point is 220 to 230 feet wide. The samples were taken on this section in the center and usually 30 to 60 feet from either shore. On the diagram the parts by weight are given on a vertical scale of 100,000. The horizontal line marked 1,000 represents a thousand parts in 100,000, or 1 per cent, and the 2,000 line 2 per cent by weight. It will be noticed that the greatest divergencies of observations made on the same day are those at the time that the per cent increases suddenly; and that as the sediment falls the observations come closer together. This is what might be expected from the nature of the case, as high ratio of sediment means an increase of the larger, coarser particles, whose distribution is probably far less uniform than that of the finest silt.

In addition to the points marking the individual observations, a broken line is drawn connecting the mean of the observations for each day, or the single observation when there is but one. This line serves merely as a guide line for the eye, and of course can have no further value. Comparing this sediment diagram with that for discharge, it is seen that during the low water of the winter the sediment follows, in a general way, the discharge, an increase of discharge being accompanied by an increase of percentage of sediment. In other words, the small storms bring down muddy water. This is especially noticeable on March 15.

After the main flood of the year has set in, however, and the



SEDIMENT AND DISCHARGE AT EL PASO, TEXAS earlier storm waters have presumably washed out the silt most easily moved, the percentage drops off rapidly by dilution, although the actual amount in suspension is far greater than before, as shown by the table below. Again, as the flood decreases, the minor disturbances following on its decline give an immense increase in ratio of sediment, especially noticeable in the last week in June, 1889.

The river bed being dry from the latter part of August to the middle of December, no observations, of course, appear. In December, however, the first water coming down the dusty channel might properly be termed fluid mud; the determinations therefore run very high, as shown on the diagram at the extreme right

In order to express in a few figures the results shown in the diagram, the following table has been constructed, making several assumptions which may or may not be true. It is assumed that the mean of the determinations for a month is the average sediment for that month. This is given under the column headed "Sediment ratios" The averages of the daily discharges in second-feet for the same month is then taken. In the next column is given the weight of the water making up this number of second-feet. Multiplying this rate by the ratio for that month gives the sediment in pounds per second passing the station. This is then multiplied by the number of seconds in the month, and the result is given in tons per month.

The total for the year ending June 30, 1890 is, in round numbers, 3,830,000 tons; this earth, at a weight of 100 pounds per cubic foot, would cover a square mile two and three-fourths feet in depth.

Silt in the Rio Grande at El Paso.

[Estimates by months]

Month	Sediment ratios	Average discharge	Weight of water	Sediment per second	Sediment per month
1889		*Sec feet*	*Pounds*	*Pounds*	*Tons*
June	00468	2 638	165,000	772 2	1,000,570
July	00201	237	14,810	29 6	39,800
December	00813	71	4,440	36 1	48,380
1890					
January	00295	196	12,250	36 2	48,500
February	00362	290	18,130	65 5	79,200
March	00613	424	26 500	162 6	217,700
April	00585	2,190	136,900	794 6	1,029,800
May	00347	5,771	360,680	1,248 5	1,671,700
June	00196	4,404	275,250	539 5	699,200
July	00131	854	53,375	70 0	93,730
August	00710	734	45,875	325 7	436,100

GILA BASIN.

In this basin are found rivers most difficult and dangerous to examine and control, differing in character and habit from those of the North as widely as in geographic position. In place of the regularly recurring annual floods of spring and early summer, so strongly marked on the discharge diagrams of other basins, these rivers show conditions almost the reverse, being at that season at their very lowest stages—even dry—and rising in sudden floods at the beginning of and during the winter. These floods are of the most destructive and violent character; the rate at which the water rises and increases in amount is astonishingly rapid, although the volume is not always very great. For instance, in an ordinary flood the Salt River, the principal tributary of the Gila, has risen in about three hours from 500 second-feet to 30,000 second-feet, falling again almost as rapidly, so that the average for the day or for two or three days would not be more than 10,000 or perhaps 5,000 second-feet.

From this it will be recognized that the onset of such a flood is terrific. Coming without warning, it catches up logs and bowlders in the bed, undermines the banks, and, tearing out trees and cutting sand-bars, is loaded with this mass of sand, gravel, and driftwood—most formidable weapons for destruction.

The Gila rises in western and southwestern New Mexico, receiving its waters from mountains having an elevation of from 7,000 to 8,000 feet; at the point at which it crosses into Arizona it still has an elevation of 6,000 feet. From this place it continues between mountain ranges, falling rapidly, until at Florence, 180 miles away, it is about 1,500 feet above sea level. At a point 15 miles above Florence the river emerges upon the plains, which it traverses for about 75 miles before receiving the waters of the Salt, its principal tributary. After receiving the Salt drainage the Gila continues west and southwest, crossing Arizona and flowing into the Colorado River at Yuma, near the southwestern corner of the Territory.

Along the headwaters of the river are several open valleys, and in those of southeastern Arizona agriculture is steadily increasing by the use of water from the river or from side streams. On the extreme eastern edge of the territory, near the town of Duncan, some 2,000 acres have been reclaimed, and in the valley from Solomonville westward for 20 miles down the river fifteen irrigating ditches, covering in the aggregate 45,000 acres, have been constructed. There are in addition several other irrigated areas near the mouth of the San Pedro.

The principal tributaries are the San Pedro and Santa Cruz Rivers, on the south side, and the Salt, Aqua Fria, and Hassayampa Rivers, on the north side. The floods of the upper Gila and its tributaries are usually short and violent, the highest water occurring during the months of January and February. During a freshet the river rises 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 in places has the appearance of a vast 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 for miles.

SAN PEDRO.

The San Pedro River, entering from the south, rises in the northern part of the Mexican State of Sonora. Flowing northerly for more than 100 miles, it empties into the Gila a few miles below the town of Dudleyville, 45 miles above Florence. It has a total watershed of 2,700 square miles. Rising in a country of very light snowfall, the San Pedro depends for the greater part of its water supply on the frequent showers of the rainy seasons. It flows over a sandy bed between high and steep banks, and during the dry season the river shrinks to an insignificant stream of clear water, which rises and sinks in the sand with the varying depth of bed rock. During the rainy seasons it rises very suddenly, sometimes to the height of 12 feet, and, assuming the character of an angry torrent, carries everything before it.

In Cochise County the San Pedro flows through a valley 80 miles long and from 1 to 10 miles wide For a distance of 70 miles along the river small ditches have been taken out, reclaiming, it is estimated, about 10,000 acres of land, on one fourth of which crops are annually raised. The soil is fertile and produces large crops of wheat, barley, oats, alfalfa, vegetables, and the hardier kinds of fruits

In the upper San Pedro Valley there are several thousand acres of land, at present utilized by stock-raisers, susceptible of cultivation under a judicious system of irrigation

Near Dudleyville a gauging station was established to obtain the total discharge of the San Pedro into the Gila. Measurements were begun here April 9, 1890, and observations carried on continuously. During the summer of 1890 the water has been extremely low, hardly flowing. For instance, the average flow for the month of April was only 16 second-feet; for May, 5 second-feet; for June, 3; and for July, 6.

The Santa Cruz rises in the southern part of Pima County near the Mexican line, and flows northerly to a point a few miles northwest of Tucson, where it sinks, finding its way to the Gila, if at all, by percolation or underground passages. About 3,000 acres, it is reported, have been reclaimed in Pima County by the use of the waters of this stream.

Below the San Pedro for a distance of 25 miles the valley of the Gila is very narrow, in places becoming a gorge a thousand feet or more in width. The narrowest point is at The Buttes, 15 miles east of Florence. Below this point the Gila Valley proper begins, widening out rapidly toward the west, and extends to the banks of the Colorado River, a distance of about 200 miles. That portion of the valley situated between the mouth of the Salt River and the Colorado is known as the Lower Gila Valley.

In the Upper Gila Valley, beginning just below the canyon and about 12 miles above Florence, fourteen canals are taken out at intervals, from the river, covering many thousands of acres. Above all these canals, at the Buttes, it is proposed to construct a dam of sufficient height to hold back the greater part of the flood waters, and for this preliminary surveys and estimates have been made.

To obtain data concerning the discharge at this point a gauging station was located a short distance above the Buttes, near an abandoned smelter. Observations were begun August 26, 1889, and continued through the succeeding year, the floods, however, were unusually low, and the results given in the tables are probably far less than the average discharge for several years.

SALT.

This river, though considered as a tributary of the Gila, is in fact larger both in catchment area and discharge, and might properly be considered the main stream. It receives the drainage from central Arizona, its principal tributary, the Verde, flowing southeasterly and south from the mountains and table-lands south of the Colorado River There is a little irrigation along the upper waters of the Verde and in the Tonto Basin, but the diversions of water are too small to be noticeable on the main stream.

The Verde Valley is situated in Yavapai County, on the headwaters of the stream, and extends from a canyon above Camp Verde to a point 10 miles below the fort, where a branch of the Mogollon Mountains on the east and another of the Verde Mountains on the west approach the river. About 3,000 acres of land in this valley are under cultivation, and large crops of alfalfa, small grain, corn, and potatoes are raised, as well as fruits in great variety and perfection. The military reservation comprises about 1,000 acres of farming land, much of it capable of irrigation.

About a mile below the junction of the Verde, and 30 miles above Phœnix, the river begins to enter upon the plains of the Gila Valley. At this point the Arizona Canal Company have built a dam or weir across the river to raise the water and turn it into their canal. The engineer of this company, Mr. Samuel A. Davidson, has calculated the daily discharge over this weir for a number of years, and with his permission these results are given herewith, as they show in a general way the character and range for nearly three years of the rivers of this portion of the arid region While these calculations, being based on weir formulæ, may be in error to a considerable degreè, yet they are comparable among themselves, and show the sudden fluctuations and the relative size of the stream.

Attempts have been made to establish gauging stations on the Verde and Salt above their junctions, but great difficulties have been encountered, and, after moving the stations, that on the Verde was finally abandoned and work on the Upper Salt suspended during the winter of 1889–'90. The measurements on the Salt, made at about a half mile above the junction of the Verde, are as follows:

Discharge.	Sec. ft.
June 27, 1889	251
July 10, 1889	195
July 17, 1889	272
August 16, 1889	213
August 30, 1889	216
September 16, 1889	212
September 22, 1889	306
September 26, 1889	225
September 30, 1889	212

In the spring of 1890 a new station was located at a more favorable though remote place up in the canyons about 50 miles above Phœnix. The mean discharges in second feet are: For May, 500; for June, 298; for July, 21.

The measurements on the Verde, made at a place a mile above the Salt, are as follows:

Discharge.	Sec. ft.
June 26, 1889	127
July 11, 1889	234
July 20, 1889	436
August, mean, 1889	200
September, mean, 1889	192

Besides the Arizona Canal Company, at whose headworks the estimates of daily discharge have been made, there are below it a dozen other canals taking water from the Salt River. These vary in length from 3 to 22 miles, and cover in the aggregate 300,000 acres of land, of which about 35,000 are annually cultivated. All the water in Salt River has been utilized and little 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 many times 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.

TRUCKEE AND CARSON BASINS.

These rivers rise in the Sierras, receiving drainage from mountains 7,000 to 10,000 feet high, and, flowing easterly, lose their waters in the sinks of the interior basin. The catchment areas, though small, yield a considerable amount of water, owing to the steepness of the slopes and the general elevation of the basin. In the drainage of the Truckee is Lake Tahoe, the highest lake of its size in the country. From its elevated position, however, the catchment area of the lake is very restricted, being only 522 square miles, less than four times that of the water surface, which is 195 square miles As a consequence the run-off from the lake is comparatively small.

The situation of this basin in regard to political divisions is somewhat peculiar The line between California and Nevada, running through Lake Tahoe, cuts the catchment area into two portions, of which 793 square miles are in California and 283 square miles in Nevada, measuring the drainage above Reno. The water is most largely utilized in Nevada, but any comprehensive system of water conservation for the further benefit of these desert tracts is rendered complex by questions arising from differences in jurisdiction and in water privileges in the two States.

Measurements were begun in the Truckee Basin in the latter part of May, 1889. The high water of that year came very late on account of light fall of snow during the preceding winter. There was a very heavy snow storm about the middle of May, followed by warm weather, causing floods of short duration, which were followed by unusually low water during the summer and fall.

The results obtained are here given, beginning at the outlet of Lake Tahoe and taking the various tributaries in succession.

Near the dam of this lake the measured discharges were as follows:

	Sec. ft.
July 9, 1889	136
August 8, 1889	75
August 14, 1889	56
August 18, 1889	49

The maximum for that year is estimated at 170 second-feet.

A small mountain stream entering the Tuckee from the west or left bank about half way between Lake Tahoe and Truckee, known as Squaw Creek, was measured and found to have, on June 3, 1889, a discharge of 92 second-feet, and on June 22, 15 second-feet. The mean flow from June 7 to 22 was 50 second-feet, falling after this latter date to an insignificant stream.

The creek above Tahoe Tollgate on June 3, 1889, discharged 74 second-feet.

Donner and Cold Creeks.—The first of these is the outlet of Donner Lake, and has a drainage area of 16 square miles. It flows easterly for about 2 miles into the Truckee, being joined at a point three-quarters of a mile from the lake by Cold Creek, which drains the valley south of Donner. In 1888 this creek carried, it is estimated, about one-half more water than in 1889. The measured discharge of these creeks in second-feet is as follows:

Date.	Discharges.		
	Donner Creek.	Cold Creek.	Total.
1889.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
June 28	....	11	....
July 3	8	10	18
July 6	5	5	10
July 11	2	1	3
July 16	1	....	....
August 7	0·9	1	1·9
August 10	0·2	1	1·2
August 17	0·3	0·7	1

More detailed measurements (see appended tables) were made of Prosser Creek, the outlet of Twin Valley, flowing into the Truckee a short distance above Boca, and of the Little Truckee, which receives the drainage of Weber and Independence Lakes and flows into the Truckee at Boca.

Other small tributaries were measured in 1889 when they were at about their maximum, except at the second measurement of Martis Creek, the result being as follows:

Date	Location	Discharge
1889		*Sec.-feet*
June 1	Martis Creek	19
June 22	do	7
May 30	Juniper Creek, at Clinton	22
May 31	Joe Grey Creek, at Cuba	88
May 31	Bronco Creek, at Bronco	42
May 22	Dog Creek, at Verde	7

Gaugings on the main stream were begun in May, 1889, at Essex, Nevada, a point near the State line and about 12 miles above Reno, the results being as follows:

Discharge.	*Second-feet.*
May 20, 1889	2,330
May 21, 1889	2,570
May 22, 1889	2,510
May 29, 1889	1,716
June 20, 1889	350

The maximum flow for the year was on May 21st. The mean discharge for the last ten days of May was 2,134 second-feet; for June, 771 second-feet; for July 278, and for August and September approximately 200 second-feet, these latter results being considered in doubt, however. In the spring of 1890 the Essex station was abandoned and gauging made at a point a mile below Boca and 12 miles above Essex, also at Laughtons, 6 miles above Reno, and again 8 miles east of Reno at Vista

Carson Basin.—This basin, like that of the Truckee, is partly in California, 464 square miles being in that State and 444 square miles in Nevada above Carson City A measurement was made in 1889 of the West Fork in Hope Valley, giving, on June 14, 72 second-feet, while the main river below the junction of the forks, about a mile from Geneva, showed on June 10, 1889, a discharge of only 527 second-feet, many ditches being taken out above this place. In 1890 stations were established on the East and West Forks and also on the main river at Empire, 7 miles east of Carson City. That on the East Fork is at Rodenbah, about 14 miles from Genoa and 22 miles from Carson. That on the West Fork is about one-half mile above the town of Woodford, California, which is 20 miles from Genoa and 32 miles from Carson. During the high water the velocities at this point were so great that the measurements were made at Fredericksburg, California, 1 mile south of the Nevada State line, gaugings being made on Jarvis's bridge.

SALT LAKE BASIN.

BEAR RIVER.

The study of the hydrography of the Bear River, of the present utilization of its waters and their future conservation, offers problems of unusual interest, not only from the geologic and engineering sides, but from political, economic, and social standpoints.

This river rises in the lofty Uinta range in northwestern Utah, flows through the southwestern corner of Wyoming, a high, rolling country devoted mostly to grazing, then turning west, crosses the line again into Utah, where the drainage waters begin to be utilized on a considerable scale for raising grass. It then turns to the east and recrosses the line into Wyoming, where the valleys contain hay ranches. Beyond these the river swings abruptly to the west into Idaho, winds through a mountain chain, and enters a large valley having an elevation of about 6,000 feet. Here is found the distinctive feature of this drainage basin—the peculiar lake and marsh, which act as a great natural reservoir, or rather as an equalizer of the flow of the lower Bear River. The river does not, as shown on the Land Office maps, enter the lake, but passes along in front of or below the open lake, meandering through the great marsh or level plain. In times of high water it spreads out through and over the marsh and its waters back up into the lake. In times of drought the marsh dries, much of it becomes good hay land, and the water from the lake finds its way through tortuous channels down to the river.

Around this large valley and beautiful lake, the southern half of which is in Utah, are clustered many prosperous towns and villages, which depend for their subsistence upon the waters of the smaller tributaries of the Bear. The center of the valley north of the lake is still public land, though dotted by houses, corrals, and haystacks. The occupiers of this land can not get a title from the Government, as it is designated a lake on the official maps.

From the north or lower end of this broad, level valley the river, again in a defined channel, winds north through hilly and broken grazing lands, then west along and through great lava plains, and finally, as though cut off by this lava sheet, turns abruptly south. Having passed the lava, the valley broadens, forming Gentile Valley, at the northern end of which there is a large body of high arable land. It is proposed to irrigate this land by a ditch taking water from Bear River itself. But at present the river is not attacked in or below this valley; all the water for irrigation is taken from the lateral streams, which are largely fed by springs.

Below Gentile Valley the river flows through narrow passes and over rapids to enter the beautiful Cache Valley, "the granary of Utah." This valley lies due west of Bear Lake Valley, but about 1,000 feet lower. Like the former, its upper end is in Idaho, its southern in Utah, the latter portion being the most thickly settled.

All the streams which go to join the Bear, from Gentile Valley southward, are diverted during the growing season upon the land, but the water in the river itself is untouched, because it has cut for itself a channel so deep below the general level that the communities along its banks have not been able to divert it upon the dusty plains.

The river flows through the Cache Valley nearly to its lower end, finally turns back toward the northwest, and rushes through a very deep, precipitous canyon and enters upon the Salt Lake Plains, where, after meanderings more and more tortuous, it finally is lost in the Great Salt Lake.

Until recently there has been no attempt to utilize, except on a few acres fringing the stream, any of the river water below Bear Lake. In 1889, however, a company began to construct in the canyon below Cache Valley two canals of the aggregate capacity of 2,000 second-feet. This system was designed to be one of the largest and best constructed works of the kind in this country, and to cover ultimately upwards of 200,000 acres, embracing within these limits many large towns as well as a portion of the city of Ogden.

During the last two years, 1888 and 1889, the rainfall has been unusually small. The Bear River, like others, showed the effect of this in diminished flow, the discharge shrinking to an unprecedentedly low amount.

Gauging stations were established on the main stream in 1889: one at Battle Creek railway station at the upper end of Cache Valley, and the other at Collinston, in the canyon below Cache Valley, near the headworks of the new canal system. As seen by the tables of monthly averages for 1889, the flow at Collinston is far below the future needs of the new canal. This condition was abnormal, but may it not happen again?

There are dimly outlined for the future, as shown by the brief statement above, several questions of great importance, upon whose correct solution hang the peace and prosperity of many communities, embracing over 30,000 inhabitants. Here is a river crossing State lines five times, its water furnishing subsistence for scores of communities differing in laws and customs, flowing first through grazing countries, where its waters are lavishly used for raising hay, then through broad valleys of great elevation, where it is again robbed of its waters to raise the hardier grains and vegetables, and finally delivering its surplus waters to one of the most fertile valleys and genial climates of the West.

In times of scarcity who is to apportion this water? How much belongs to this community and how much to that corporation? What protection do the present users enjoy against the stronger and richer canal companies or the aggressive adventurers at the headwaters? These questions are seriously disturbing the minds of the inhabitants of that country, and are being discussed in the market places and in conventions. Each year, as population becomes more dense and a larger acreage is brought under cultivation, the demands upon the water increase, and the time is fast approaching when, instead of the demand exceeding the supply for, say, 1 in 15 years, it will be 1 year in 10, and later 1 in 5, and perhaps oftener. Thus questions of economic distribution and of priorities and equities of rights must depend upon the measurements of water, the knowledge of the distribution—in short, the results of the hydrographic studies begun now while the matter can be impartially investigated.

The total amount of water which passed the Battle Creek, Idaho, gauging station during the year ending June 30, 1890, was 0·32 cubic mile, or a daily mean of 1,480 second-feet, very nearly equivalent to 3,000 acre feet. This water, if spread out uniformly over the drainage basin, would cover it to the depth of 4½ inches.

At Collinston, Utah, the discharge for the same time was 0·53 cubic mile, or a daily mean of 2,500 second-feet, nearly 5,000 acre feet. This would cover the entire drainage basin 5⅔ inches in depth.

Comparison of these figures shows that the run-off from the Cache Valley is larger than from the upper part of the Bear drainage basin. Taking the difference between these, it is found that the run-off for the drainage basin above Collinston and below Battle Creek is 9¼ inches.

This can be accounted for by an examination of the topography of the country. A glance at a map shows that the streams entering below Battle Creek come directly from a high mountain range with precipitous slopes cut by deep canyons, while the upper part of the drainage basin consists largely of rolling country.

Unfortunately there are no records of continuous rainfall measurements in this basin. The nearest localities where rain has been measured are as follows.

Fort Bridger, in Uinta County, Wyoming, at an elevation of 6,643 feet, had, from 1859 to 1887, a mean of 8·5 inches.

Fort Hall, in the Snake River plains, in Oneida County, Idaho, at an elevation of 4,870 feet, had, from 1871 to 1880, an average rainfall of 17·5 inches.[1]

Taking Fort Bridger as representing the rainfall for the

---

[1] Report of rainfall in Washington, Oregon, etc., Fiftieth Congress, Senate Ex. Doc. No. 91.

upper Bear, and Fort Hall for the Cache Valley drainage, the run-off would be nearly one-half the rainfall. This assumption is, however, erroneous, as the rainfall on the basin of the Bear must be far greater than that at either of these forts.

On examining the daily average discharge for the last year it can be seen that the maximum discharge at Battle Creek occurred on June 1, when the amount reached 6,000 second feet. Down the river at Collinston, however, the maximum occurred earlier, from the 21st to the 23d of May, at which time the discharge was 8,700 second feet. The spring flood was marked by gradual increase day by day, and after the maximum by a quite steady decrease; there was not that irregular fluctuation so characteristic of the mountain streams, especially of the southern territories.

The minimum flow at Collinston was in the middle of July, when the discharge barely reached 300 second feet. The "oldest inhabitants" united in declaring this the lowest amount ever reached by the river. The rain and snow fall had been for two years unusually light, giving less river flow, and also indirectly resulting in its diminution by the increased diversion of water for hay lands as well as for the raising of other crops. The area of meadow lands and cultivated lands had also increased, especially near the headwaters. At this juncture the project of the great canal starting in the canyon above Collinston, and the notices of appropriation posted in various places, caused general uneasiness among the individuals and communities in the drainage basin of the Bear, especially in Idaho, from the undefined fear of a contest regarding water arising with this great rival. This fear was largely founded on the fact that the newcomer was carefully protecting every point by an elaborate compliance with the law, while the former appropriators had relied wholly upon possession and custom, taking water wherever found, without notice or formal record.

UTAH LAKE SYSTEM.

The Utah Lake drainage system receives water from the Wasatch range from Mount Nebo northward to a point about opposite Salt Lake City. Besides this drainage area, there is, on the west side of a line drawn north and south through Utah Lake, a large area of mountainous and valley lands which is topographically a portion of this drainage basin, but from which, owing to small rainfall, there are few intermittent streams. The characteristic feature of this system is the interposition of a large shallow lake in its midst, at a point where the tributaries of the main river would naturally unite. The trunk stream is called the Jordan River. The principal tributaries are the American Fork, Provo, Hobble Creek, Spanish Fork, and Salt Creek, which, instead of uniting to form the Jordan, flow first into Utah Lake.

The lake in this position has a peculiar modifying effect upon the régime of this river system, inasmuch as the great floods which are liable to occur in these torrential tributary streams are discharged into this broad and shallow sheet, where the mass of water finds its way out gradually through the main river below

Beginning at the south end of the drainage system, the first tributary is Salt Creek, which rises on the rear or eastern side of Mount Nebo, flows south and west around the mountain, and enters the Juab Valley at about its center. At the mouth of the canyon through which Salt Creek flows is situated the town of Nephi, where all the water of the creek is used on the town lands or the agricultural areas below Leaving Nephi, the stream channel turns north and winds through the northern end of Juab Valley, finally passing out through a range of low hills into the Goshen Valley and eventually disappearing in the extensive marshes at the south end of Utah Lake

In Goshen Valley are thousands of acres of fertile lands, which, however, can never be irrigated, as there is no probability of this creek, even with all the flood waters stored, ever being able to cover more than a very small proportion of the land along its course.

Following the mountain range northward from Mount Nebo, there is, near the towns of Santaquin and Payson, a succession of small torrential streams entering Utah Valley, whose waters are all used on the lands belonging to these communities. Beyond these the first stream of notable size is the Spanish Fork, which in times of flood, its drainage area being large, carries an enormous volume of water. In ordinary crop seasons, however, its entire discharge is claimed and utilized. In 1889 the scarcity was so great that on only about one-seventh of the land on which crops are ordinarily raised by its waters were these able to mature. North of this is Hobble Creek, whose waters are used almost entirely by the town of Springville.

The Provo River heads on the east side of the Wasatch Mountains, through which it cuts in a deep and ragged canyon. On this stream, near the headwaters, there is considerable agricultural land, Provo Valley containing a broad extent of fertile land at an elevation of about 6,000 feet. In this valley several ditches are taken out to supply the land around Heber and Midway; also at Wallsburgh, south of these, there is a large body of land under ditch.

After leaving these upper valleys and passing through the canyon, the river is diverted by a number of large canals upon the bench lands and lower grounds bordering the lake.

These canals are the largest, excepting those of Salt Lake Valley, in this drainage system, and the water at the end of the crop season is entirely utilized, the lower canals taking the seepage and waste water from those above. There is already such scarcity of water in this river that the question of prior rights between canals of Utah Lake Valley and those of the upper Provo Valley is already a matter of discussion.

The canal system at Provo is typical of that at every large settlement where old and small ditches have been enlarged and new ones built at higher and higher grades, finally resulting in long lines of parallel canals each covering a narrow strip of country and perhaps crossing each other and conducting the water with little economy and great expense to the owners. The lower canals, being in general built first, have the better rights, while the higher canals, last built, have rights only to surplus waters; but from their position up the stream, they have the best facilities for getting what they wish.

In the north end of the Utah Lake Valley is the American Fork River and a few other streams, whose waters are entirely taken out to supply the settlements of Battle Creek, Pleasant Grove, American Fork, and Lehi

In each of these rivers the flood of the spring comes about the time of growing crop, but falls away before the grain matures. It is after the crop has been planted and is well along that the scarcity of water begins to be felt, and every effort is then made to economize and to produce the greatest effect with a small stream

The gauging stations on each of these rivers, viz, the American Fork, Provo, and Spanish Fork, were placed at the mouths of the canyons above the heads of all canals in order to obtain the total flow of these streams undiminished by divisions.

The water which passes these stations or flows in smaller streams is either diverted by canals or, as in times of flood, flows directly into Utah Lake Part of the water taken by the various canals finally makes its way by seepage to the same place, so that the lake may be considered as receiving all the unutilized waters From this body the water which is not lost by evaporation flows into the Jordan.

The use of the water of this stream is limited only by its quantity—that is, the irrigable land in the valley of the Jordan is in excess of the water supply, and hence the growth and future extension of the City of Salt Lake and the agricultural resources of the beatuiful county of the same name are proportional to the economic use, and more especially to the prevention of a portion of the enormous loss by evaporation of the waters coming into Utah Lake. The main canals depending upon Utah Lake are taken out at the point where the Jordan enters the Salt Lake Valley, and in addition to these there are numerous canals and ditches farther down which irrigate the lower-lying areas.

Besides the waters of the lakes the people of that portion of Salt Lake Valley depend largely upon the waters of the streams flowing in from the east. These streams, of which the principal are Little and Big Cottonwood, Mill Creek, Parleys Canyon Creek, Emigration Creek, and others, are in times of flood tributary to the Jordan, but in dry seasons their waters formerly sank into the sand beds. The inhabitants of the valleys have, however, built extensive systems of ditches, by which all of their waters are utilized upon the ground between the foothills and the Jordan. There are thus in this valley two general systems of water supply, that from the Jordan and that directly from the high mountains. These two systems cross and recross and are intermingled apparently in the greatest confusion; and, as in other systems which have grown up without any comprehensive plan, the waters of the one are used on lands which could be covered to better advantage by the waters of others, and there is a very general lack of economy both in canal construction and in the use of the water.

An examination of the conditions in this basin, the pressing need of water in the lower valleys, especially in that of Salt Lake, and the many fine natural opportunities for saving the floods which now run to waste, leads to the conclusion that a comprehensive and general study must be made of the water supply of the whole region, in order that vested rights may not be disturbed and that the best results may follow any attempt at storage, for which there are unexcelled facilities in the high mountains.

SEVIER.

This river rises north of the Grand Canyon of the Colorado, in the high plateaus of southern Utah, at elevations of 7,000 to 10,000 feet, and flows northerly through deep canyons and narrow valleys about 170 miles, then turns abruptly to the west, passing still between high rocky walls, and finally emerges through a deep cutting in the old delta upon the level plains, once the bed of a large lake. This ancient lake has shrunken to the lowest point in the basin, and is now merely an alkaline sink into which the river water flows in flood time and is lost by evaporation, leaving behind an expanse, miles in extent, of white, glistening salts.

Along the course of the river are many narrow valleys of great fertility and in these agriculture has sprung up rapidly since the Indians have been held in check. Settlements have progressed from the north southward and canals are being taken out higher and higher up along the stream. The increase of population in the older towns, the enlargement of ditches, and the development of a comprehensive system of high-line canals, covering more land, has gone on rapidly, while at the same time newcomers have settled in the higher valleys and have dug new ditches. Thus the time has come when the need of water in the older and lower settlements has already far exceeded the summer discharge, and the younger men and emigrants in want of farms have gone higher and higher up stream, above other settlers, even to altitudes where only the hardier crops will flourish, but where water, fuel, and grass abound. In these high plateaus the water is turned from the small streams lavishly upon the gently sloping land, making hay meadows; but this greatly decreases the flow of the river at the points where most needed, 50 or 100 miles below. The matter left to itself is thus becoming a striking instance of the survival of the man highest up the stream, irrespective of his rights or of the best use of the water.

Six counties, depending largely for the support of their population upon this river, are thus involved in rancorous disputes, and are threatened with interminable litigation as the questions of priorities have been complicated by shifting of settlements, enlargement of ditches, and transfers of water rights, and the effect of water diversions in one part of the river upon any portion below can not easily be foreseen. In these straits, despairing of any immediate or certain settlement of the rights of each canal to the flowing water, the farmers are agitating the question of the storage of the flood waters in the hopes of thus providing water for all. There are in the upper catchment areas many fine reservoir sites where, by a small expenditure for embankments, large bodies of water can be held.

The largest and most important valley through which the Sevier flows is that from Joseph or Munroe northward to Gunnison, at the outlet of the San Pete Valley. Here are about a dozen towns of considerable size, surrounded by excellent farming lands of great extent. All the summer water of the river is taken out, the bed of the stream having been dry at three different points along the valley in the summers of 1888 and 1889. Below each of these places, however, a notable amount of water returns to the bed by leaks or seepage, to be in turn diverted into a canal lower down. At the lower or northern end of this valley the river enters the canyons and flows north and westerly for about 40 miles through broken country, with but an occasional strip of bottom land along its course. Finally, at Leamington, the river debouches and begins to wind through the great plain, or Sevier Desert. Here are enormous tracts of fertile land, far greater in extent than the volume of the river can ever cover. The principal canal of this plain is the Deseret, taken out about 25 miles below Leamington and carrying water to the town of that name. Two or three small ditches are taken out at Leamington, but as they do not extend back from the river to any considerable distance their water largely returns again within a few miles.

The history of the Deseret Canal gives an illustration of the manner in which the first canal systems were laid out and the costly experiments that were made before permanence was obtained. The project, as first planned, was to take water from the river at a short distance above Deseret by building a dam across the channel and thus raising the water to an elevation sufficient to cause it to flow into the ditch. This could readily be done, as the banks of the stream are somewhat higher than the surrounding country.

The settlers came to the country in 1876, and two years later built the first dam, only to see it washed out by the next high flood. Dam after dam was built, each in turn, founded, from necessity, upon the alluvial clay deposits from the old lake, being undermined or flanked by the spring torrents. Finally the river forced its way into a waste ditch and cut a new channel, thus ruining the whole system in spite of much labor spent in fruitless efforts to turn the river back into its former place. After every resource had been tried, successive crops being lost, and the farmers nearly brought to ruin, they awoke to the fact that they were attempting the impossible, that a dam built in the clay banks and bed of the river could not stand. The first system was then abandoned and a new canal taking water from the river higher up, was constructed at considerable expense. This promises success, as the necessity of raising the water by a dam has thus been obviated.

All this expense has been incurred to save what are practically waste waters from the numerous canals above, and there are now grave doubts as to the permanence of this supply—whether any water will be left in the latter part of the crop season. As in cases previously mentioned, where inhabitants of the large valleys of the upper Sevier were anxiously discussing the storage problem and how to get the stored water down to those who pay for it, the settlements about Deseret are eagerly questioning the advisability of attempting storage in lower valleys or in depressions among the foothills along the edge of the desert adjacent to the river. Hopes are entertained that by diverting some of the flood water of the river into such reservoirs these lowest and last users of the river water may be independent of the river during the critical periods.

The amount of water which passed Leamington—and which would be thus available for storage—during the last year has been measured at the gauging station located at a convenient point near this town, giving the results shown in the tables of monthly discharges.

SNAKE RIVER BASIN.

The Snake River and its tributaries receive the drainage of that part of Wyoming west of the Continental Divide, of nearly all Idaho below the forty-fifth parallel, and also of southeastern Oregon and northeastern Nevada. The elevation of the main river at the junction of the North and South Forks is about 4,800 feet, and at its union with the Columbia River, near Ainsworth, Washington, under 340 feet.

The headwaters of the Snake may be divided into two distinct catchment areas, separated by a high mountain range. One of these, the basin of the North Fork, receives its water entirely from the mountains on the east, while the South Fork Basin includes all the area between the Bear River range on the south and the Continental Divide on the north and east.

NORTH FORK.

The basin of the North Fork may be subdivided into three distinct areas, commonly known as the Henry Lake, Fall River, and Teton Basins. Henry Lake, the real head of the North Fork, is a shallow sheet of water, about 7 miles long, with a varying width of from 1 to 3 miles. It is situated almost on top of the divide of the Rocky Mountains, the elevation between its watershed and that of the Madison River in Montana being very low. It is only during the melting of the snow in the spring that there is any discharge of note from this lake, and in 1889 the flow ceased entirely about September 1. The average elevation of the basin is approximated at 6,500 feet.

About 20 miles below the lake the North Fork receives a large tributary on the east or left bank, evidently the flow from large springs in the high mountain range on the west line of the National Park. The flow of this creek on August 1, 1889, was 300 second-feet.

The total discharge from this basin was measured at a point about a mile above the mouth of Fall River, which is 10 miles from St. Anthony post-office and about 65 miles from Eagle Rock.

The Fall River and Teton Basins are similar in extent and elevation of catchment area, being separated from each other by a spur of the Teton Range, and receiving the drainage of these mountains. The elevation of the highest peak, Grand Teton, is about 13,700 feet, and of the plateaus at the base 5,500 to 8,000 feet. The precipitation of this region is almost entirely in the form of snow. Trappers and hunters who have occasion to be in this country during the winter report the snowfall to be from 5 to 10 feet on the level, and in drifts 50 feet or more in depth.

These mountain basins may all be described in the same words: very heavily timbered, with no undergrowth except along the streams, and occasionally large parks or open stretches of immense natural pasturage, surrounded by peaks rising abruptly from plateaus on which the snow lies for five months of the year.

The streams flowing through this plateau country have during most of their length a very slight grade, are wide, and consequently quite shallow. Their fall is nearly all gained in rapids, sometimes sheer descents of 20 to 30 feet, followed by long stretches of sluggish water. After leaving the mountains their fall becomes more uniform, and some have carved deep channels. Fall River has a decided and continuous slope after leaving the foothills, while the Teton River, only 10 miles south, has a very gentle decline.

The discharge of Fall River was measured at a point 6 miles from the junction with the North Fork and above most of the irrigating ditches, the Springville Canal being the only canal of importance taking water above this point.

The Teton was measured at the mouth of its canyon, about 3 miles from the town of Wilford, the point being a half mile above the highest irrigation ditch and above all water diversions.

There is as yet no irrigation carried on in the mountain valleys. The settlers lower down cut the natural hay along the streams in the mountains and haul it for use during the winter. On Henry Lake Fork, above the mouth of Fall River, the country is unsettled. On Fall River the first steps towards irrigation were taken in 1889. Two small canals were built, but no land has yet been brought under cultivation.

In Teton River Valley all the water of that stream has been appropriated, but is sufficient to irrigate only a small part of the land in the valley. The divide between the Fall River and Teton Valleys near the foothills is very low, and there is a movement on foot among the settlers in the latter valley to attempt to bring the waters of the Fall River onto the Teton side.

SOUTH FORK.

The South Fork heads in Lewis Lake and flows into Jackson Lake, and then in a southwesterly direction through Wyoming, receiving all the drainage between the Teton Range on the west and the Continental Divide on the east. After reaching the Idaho line it flows in a northwesterly direction until its union with the North Fork east of Market Lake.

After leaving its canyon and entering the Snake River Valley, about 25 miles from Eagle Rock, it flows in several channels, and in time of high water floods a considerable area included between the old dry bed of the South Fork and its present main channel. The island formed by the Main Snake, the South Fork, and its old channel is almost wholly irrigable and contains a large area of rich land.

Gaugings were made September 14–17, 1889, of the various canals taken from the South Fork on the left bank, with the following results:

	Second-feet.
Eagle Rock and Willow Creek Canal	103
Farmers' Friend Canal	65
Burgess Canal	38
Lewisville Canal	74
Menan Canal	236
In old bed of river	70
La Belle Canal	14
In South Fork, below these	874

The total flow from the South Fork at that time, obtained by adding these and other gaugings, was 1,600 second-feet.

Most of the present irrigation in the Snake River Valley is done with water from the forks above mentioned, the land being along the South Fork and between this and the North Fork. The method of applying the water is by flooding, and at present, owing to the abundance of water and the ease with which it can be taken from the river, the greater portion is allowed to run to waste. Wheat, oats, and other small grain, vegetables, and grasses are the crops grown at present.

West and northwest of this irrigated region there is a large catchment area which is included in the basin of the Snake, but from which apparently there is no discharge. This is the basin of the Big and Little Lost Rivers, both heading in the mountains of the same name and receiving the drainage of a considerable area. During ordinary seasons the Big Lost River is generally dry below Arco, although the "sinks" in the lava are some distance farther east. The water of both of these rivers is nearly all appropriated for the irrigation of hay lands in the upper valleys.

The main Snake River is formed by the union of the North and South Forks at the "Buttes," about 10 miles east of Market Lake, the elevation being about 4,780 feet. From this point to Blackfoot, a stretch of about 50 miles, the boundaries of the valley are not well defined. On the east side the width may be taken as from 20 to 30 miles, but on the west side the valley extends over the lava plains to the Lost River Desert and has no well marked limit. It is all sage-brush land, with narrow strips of timber along the streams.

The large tract of desert land south of the junction of the North and South Forks of the Snake River is already irrigated, or capable of irrigation, as far south as the town of Eagle Rock, by canals completed or in process of construction.

For about 10 miles above Eagle Rock the river flows in a lava canyon of a width varying from 100 to 200 feet and with walls 20 to 30 feet in height. At Eagle Rock it leaves the canyon and widens, having below this point a general width of 300 to 400 feet, with bold gravelly banks 10 to 20 feet high. The slope is small, the general fall being gained in rapids, followed by long stretches of sluggish water. The portion of the river examined at the gauging station at Eagle Rock showed the bottom to be exceedingly uneven and covered with bowlders of varying size. The water carries at ordinary stages but little sediment. The principal measurements of the river have been made at this point. The total drainage area, excluding the Lost River Basin and the lava plain west of the river, is 10,100 square miles.

There are sometimes two distinct floods in the main stream, the first occurring in the early spring, caused by sudden melting of snow in the valley, and the second, the main flood, caused by the melting snows among the headwaters. The range of discharge, from extreme low water to flood, is very great in all the streams heading in the mountains. Measurements made in 1890 show the ratio to be at least 1 to 25.

The main flood generally occurs about June 1, and is usually a steady rise and then a rapid fall. The greatest portion of the flood water comes from the South Fork, but on account of the high mountain range lying between the headwaters of the North and South Forks the flood periods in the two may be some days or weeks apart. The extreme low water in 1889 extended, in the main river, at Eagle Rock, from September 1 to October 15. From October 15 to December 31 there was a steady rise of 2 feet on the gauge. No gauge readings were made after December 31, but during the coldest weather in January and February the freezing of the mountain tributaries undoubtedly decreased the discharge in the main river.

The ice covered the stream at Eagle Rock about December 1, 1889, and broke March 16, 1890. It was reported to be 2 feet thick. The discharge at the time of freezing was 2,600 second feet, and the estimated flow for January, February, and March is 2,000 second feet.

At present very little irrigation is done from the river itself. The ease and cheapness with which canals can be taken from the Forks have led nearly all the settlers to occupy the lands in that section. Irrigation has gradually crept northward; as yet it has reached but little farther than the north side of Fall River. Nearly all the settlers came from the towns in Utah or from the vicinity of Bear Lake, in Idaho. As is the custom in Utah communities, the canals were constructed by the settlers, unaided by outside capital, and are nearly all owned by the present landholders, the distribution of the water being governed by the same system of rules as is now in use in Utah.

The irrigation season usually begins about May 15 and extends to July 15. If the spring is a rainy one the first irrigation, about May 15, is omitted. Three thorough irrigations are considered sufficient for raising a grain crop. The first frosts in the valley occur about September 1, thus making the growing season but a little over 3 months in length.

Below the forks the principal tributaries entering the river from the east or left-hand side are the Blackfoot and Portneuf Rivers. The Blackfoot River rises in the mountains lying to the east and joins Snake River at Blackfoot, about 25 miles below Eagle Rock. The Portneuf River drainage system lies almost wholly within the Fort Hall Indian Reservation. This river flows northwesterly and joins the Snake about 15 miles west of Pocatello.

Considerable irrigation is carried on along the Blackfoot

River, but in the main Snake River Valley, between Blackfoot and Eagle Rock, little cultivation is possible, owing to the great difficulty of getting water out of Snake River. At present the owners of several of the canals now being built contemplate a southward extension of their canals to Eagle Rock, and in a few years others will be constructed, taking water from the main Snake, to cover the vast extent of fine agricultural land lying between Eagle Rock and Blackfoot.

In the vicinity of Eagle Rock but two of the canals appropriate water from the main Snake, there being many engineering difficulties in the way, due to the fact that the river flows in a deep lava canyon for a large part of its course.

From the Forks for 200 miles down, on the right bank, until Wood River is reached, there are no tributaries draining into the stream. Between these points is a strip of land lying along the right bank, with a varying width of from 20 to 30 miles, that is comparatively free from lava, but north of this strip are the Snake River lava beds, extending as far north as the foothills and as far west as Wood River. There is but a very small amount of irrigation carried on, probably not over 1,000 acres, from Market Lake southward are cultivated.

WOOD RIVERS.

The confluence of Wood and Little Wood Rivers is about 8 miles from Snake River. Below this point Wood River is sometimes called the Malade. Above the confluence up the Wood River for a distance of about 40 miles, to the mouth of Camas Creek, there is no surface drainage into the river. For most of this distance on either side there is a lava bed ranging in width from 1 to 5 miles. On June 20, 1889, the river at Hailey was flowing about 300 second-feet, while at the junction of Big and Little Wood Rivers, 50 miles or more below, the bed was almost dry. Little Wood River, about 30 miles above this point, was flowing 30 second-feet, and its principal tributary, Silver Creek, 170 second-feet, in all 200-second-feet; there were thus 500 second-feet lost in the flow through the lava beds, only an insignificant amount being at the time appropriated for irrigation.

Camas Creek, which drains the great Camas Prairie, is the last tributary to Wood River. It has a length of about 50 miles and is fed almost entirely by springs at its head. The small streams flowing into it from the north are always dry during the summer months, but judging from the character of their channels they must during flood seasons carry a considerable amount of water. On June 28, 1889, Camas Creek at its mouth above the backwater from the Wood River was flowing only about 2 second-feet. Its grade for about 20 miles above its mouth is very slight, and the water from Wood River backs up for 6 miles.

Between this point and Hailey, where it leaves the canyon, Wood River receives no tributaries. The drainage area is small, but comprises some of the highest peaks of the Sawtooth range.

The principal branch, Silver Creek, rises in several springs at the foot of the hills on the east of the valley about 10 miles southeast of Hailey, and flows only about 14 miles to join the Little Wood. On July 1 its measured flow at a point about 15 miles from Hailey was 176 second-feet. The range of flow seems to be between very narrow limits, hardly exceeding 250 second-feet and not falling below 100 second-feet. The water of the Little Wood, as mentioned before, is lost in the lava before reaching Big Wood River. In fact it may be said that, except in unusual floods in Wood River, the Snake receives no surface drainage on the north side between Boisé River and Eagle Rock.

Between Wood River and Boisé City are eight small creeks whose channels are nearly parallel and are evenly distributed along a distance of about 80 miles. The largest of these, and the only one of importance, is Canyon Creek, receiving its supply from the low hills lying just south of the south fork of the Boisé River. On June 10, 1889, this creek was carrying about 8 second feet, and during its high water, which occurred near May 1, it probably carried about 30 second-feet.

The next stream flowing into the Snake after leaving Canyon Creek is the Boisé River, then the Payette, and next the Weiser. The latter is the last stream of importance on the south side of the Salmon River range. On the left or southerly bank of the river the number of streams flowing into it is much larger and an important part of the drainage reaches the river, as the distance to the hills is much less than on the right bank. The most notable of these streams are the Salmon, Bruneau Fall, Owyhee and Malheur Rivers.

OWYHEE.

The Owyhee River empties into Snake River at a point where the latter begins to form the boundary between Idaho and Oregon.

The sources of the Owyhee are found in three States. The North Fork and the East or Middle Fork rise in the southwestern corner of Idaho and flow northwesterly to their junction with the main river. The South Fork and Little Owyhee River rise in northern Nevada and flow in a northerly direction, uniting near the union of the North and Middle Forks. The river then flows northwest for about 30 miles, when it receives the waters of two more tributaries, Jordan Creek from the east, and Rattlesnake Creek, about 4 miles below, from the south. Jordan Creek rises in the Silver City range of mountains in Idaho and flows nearly due west. Rattlesnake Creek rises in the southeastern corner of Oregon.

The upper catchment areas of the Owyhee are wild and unsettled, being generally broken and rocky country alternating with barren desert land. A few isolated stock ranches are scattered along the upper river and its branches, but on account of the rocky character of the soil and the steep descent to the river bottom but little agriculture can be carried on. The river for the most part flows through narrow canyons, and has carved deep channels even in the open valleys. The fall is considerable in the canyon, but, as is characteristic of all the rivers of this region, there are reaches of comparatively sluggish water. Timber is found on the headwaters and at the head of Jordan Creek is a noted mining district, Silver City, where the timber is plentiful and is cut mostly for mining purposes. Large quantities of snow fall on these mountains during the winter, contributing to the drainage of the Owyhee through Jordan Creek.

About the only settlement of any note where irrigation is practiced is in the Jordan Valley. Stock ranches, upon which hay, alfalfa, and grain are raised, are scattered along the valley from its mouth nearly to the headwaters.

On Rattlesnake Creek are few ranches, and on these little cultivation is found, wild hay being the only crop.

The main river enters a deep canyon a few miles below Rattlesnake Creek, and flows northeasterly through this canyon for over 70 miles without receiving a tributary. The country adjoining this canyon is wild and rough, with Cedar Mountains lying to the west and a stretch of broken lava rock to the east. The river leaves the canyon about 9 miles from its junction with Snake River, and the country opens out on the west side into the broad Snake River Valley. The foothills swing around to the north, leaving a stretch of flat country 25 miles long and from 5 to 10 miles wide. It is at the mouth of this canyon that the Owyhee Ditch Company have their head-gate. It is estimated that a ditch could be taken out at this point to cover 50,000 acres of good land.

The flood season of the Owyhee River is in the early spring, occurring this year (1890) about the 1st of March. The flood discharge was estimated at about 15,500 cubic feet per second, this being of short duration, the river falling several feet within a few days. The record of gauge heights at the gauging station was begun on March 26, 1890, when the gauge read 5·9 feet. The river did not vary from this height more than 0·5 foot until the 12th day of May, when it rose to 7·4, a foot of this rise taking place during the night of the 11th. The discharge of the 12th of May was 11,230 cubic feet per second. From that date the river fell slowly and steadily; on August 9 the discharge was only 170 second-feet. The mean monthly discharges are shown in the accompanying tables.

Although the Owyhee flows through a barren waste for the greater part of its course, yet it has on one or two of its branches a catchment area at a level sufficiently high to hold enough snow to produce a decided increase in the river's discharge in the late spring.

MALHEUR.

The Malheur River is in eastern Oregon chiefly, in what is now known as Malheur County. The South Fork receives the drainage of the western slope of the northern end of Steins Mountains, a range extending southward into Nevada. This fork rises at about the forty-third parallel and flows slightly east of north for 40 miles, when it unites with the Middle Fork. Continuing in a northerly direction, these two streams unite with the North Fork and then flow northeasterly to the junction with Snake River, near the town of Ontario. The total length of the river to the head of the South Fork is about 125 miles. The main river receives two tributaries of importance below the North Fork, Bully Creek coming in at Vale, and Willow Creek joining the main stream about 2 miles below Vale.

The North and Middle Forks have their sources in the same range, with but a low divide between them. These forks carry the greater portion of the water all the year round, the mountains at their headwaters being higher and the catchment area considerably greater than those of the South Fork. Snow on these mountains usually lasts until June, and on "Strawberry Butte," a high peak at the head of the Middle Fork, snow lasts about all the year round. The fall of all these forks is mostly gained in rapids or series of small falls in the canyons, while in the several valleys the slope is slight.

The South Fork, as a rule, carries but little water. Although the catchment area is large, a small proportion of the precipitation reaches the stream bed. At the heads of all the forks timber is found, consisting of pine, fir, tamarack, and other conifers.

The highest water in the Malheur River occurs very early in spring, usually about the 1st of March, at the breaking up of the ice. The maximum flow in 1890 was on March 20, amounting to nearly 4,500 second-feet. The maximum flow for the last six years is estimated to be between 7,000 and 8,000 second-feet. The mean monthly flow from March to August, inclusive (1890), is shown in the table of discharge. During the summer season the Malheur is practically dry below Vale. The discharge at Vale on August 20, 1890, was about 6 cubic feet per second. This scarcity of water is due to irrigation from the upper forks and tributaries.

On the North Fork irrigation is practiced nearly up to Castle Rock, a distance of about 20 miles. The ranches are mostly those of stock-raisers, whose crops consist of wild hay and alfalfa and a little grain. The Middle Fork is also largely settled by stock-raisers, and irrigation is carried on nearly up to the headwaters. There are a few ranches on South Fork, but extensive irrigation is not possible because of the scarcity of water. Bully Creek and Willow Creek are settled nearly up to their heads, and during the irrigating season about all of the water is appropriated for irrigating purposes.

About 12 miles above Vale the Malheur enters its last canyon. On the south side of the river, between Vale and the canyon, there are four ditches taken out, covering probably between 2,000 and 3,000 acres. On the north side there are but two ditches, covering about 2,000 acres. The soil often contains alkaline salts. The top soil is a stiff adobe, with little sand, and varies from 2 to 6 feet deep. It is underlaid by a hard, compact, dark colored stratum, under which is the gravel of the old river bed, which is usually water-bearing.

The system of irrigation by lateral seepage from parallel furrows is employed to a considerable extent, on account of the great loss from evaporation when the system of flooding is used, the character of the soil causing the water to stand for a long period before absorption.

The only ditch taken out of the Malheur below Vale is the Nevada ditch, the headgate of which is 1½ miles below the gauging station. This ditch has about 60,000 acres of irrigable land under it, of which 1,500 acres are said to be under cultivation. The settlers under this ditch have suffered from a scarcity of water, caused by the great amount appropriated and used from the river above. Until more water is obtained the lower valley will remain unsettled and unreclaimed. Storage is necessary to retain the waste waters of the early spring, for use as needed during the irrigating season.

WEISER.

The Weiser River is included in Washington County, on the western border of Idaho. It receives the drainage of that county except the headwaters of Little Salmon River and also Big Willow Creek, part of the Payette River drainage, and a few small creeks emptying directly into Snake River. This river rises in the northeastern part of the county and takes a southwesterly course for a distance of about 40 miles, whence it flows nearly due west for 10 miles to its junction with Snake River at the town of Weiser.

The Weiser, Payette, and Little Salmon Rivers have their sources very close together. A high divide separates the Weiser from the Payette drainage, forming the principal watershed of both rivers. The main stream heads close to the county line, a low divide separating it from Rapid River, part of the Little Salmon drainage. The principal tributaries come in from the east, those on the west or right side having little importance. From the headwaters to the junction with the Snake the river has a very considerable fall. The elevation of the upper catchment area is from 6,500 to 7,000 feet, while at its mouth, about 70 miles below, the elevation is only 2,100 feet. The fall is gained mostly in rapids and small falls in the canyons, while in the valleys the fall is very slight and the current often sluggish.

The first valley of any consequence is called Council Valley, about 10 miles from the head of the river. It is 6 miles long and comprises a large area of fine grazing land which supports a number of large stock ranches. All of the country above Council Valley is heavily timbered with pine, fir, and tamarack.

The precipitation during the greater part of the year on the mountains lying to the east is largely of snow, which remains far into the spring, and on some of the highest peaks nearly all the year round. The highest water is generally early in spring, and is caused by the breaking up of the ice and the sudden melting of snow on the foothills and lower tributaries In 1890 the highest water occurred March 19, when the discharge was 11,220 second-feet. This flood was of short duration, lasting but one day, the rise and decline being equally sudden, since the high water was caused by several warm days occurring in succession.

The discharge from March to June was considered large. The height of the water fluctuated from day to day in the early part of the spring, an effect due almost entirely to changes of temperature. A warm day had an immediate influence in increasing the discharge, while on a cool day the discharge was checked. The variations of temperature from day to night also caused a very perceptible difference in the river height, causing it to fall at night and rise during the day.

After the lower snows had disappeared the discharge of the Weiser was kept up by the melting of the snows on the higher ranges. Thus, while the creeks and streams on the west side and the foothills snow furnished the earlier water, the Middle and East Forks and the Little Weiser, heading in the high mountains to the east, contributed the greater part of the later discharge. The table of monthly mean will show most clearly the relative discharge for each month. The latter part of August is the usual time of extreme low water and by the middle of September the river begins to rise slowly. Ice generally forms on the headwaters by the 1st of November, and rarely breaks before the last of March. On the lower river, however, it does not appear until the last of December, and breaks generally by the last of February.

The headwaters are little settled; few ranchers are found above Council Valley. There are a few settlers in Indian Valley, on the Little Weiser. At Salubria there is a settlement of four or five hundred people. Middle Valley, on the main Weiser, below Salubria, is quite thickly populated.

Irrigation is practiced on all the valleys as far up as Council Valley, the water being taken from the main stream and from its branches and tributaries. Above this point the upper Weiser Valleys are largely devoted to stock-raising. The principal crops are wild hay and alfalfa, grain, and small amounts of vegetables for home consumption. The stock is allowed to graze at will on the immense natural pasturage in the hills during the spring and summer months, but during the winter the cattle are fed on hay.

Below the mouth of the last canyon on the Weiser, in which the gauging station is located, the river opens out into a wide bottom, ranging from 1 to 8 miles in width, joining the main Snake River Valley at its lower end. On the north side of the river there are two ditches taken out below the canyon, the Weiser Water Company's ditch and the ditch of the Weiser City Ditch and Irrigation Company, also called the "Mill Ditch."

Irrigation in this valley usually begins about May 1. Owing to the wet spring of 1890, it was as late as May 15 before any irrigation was done. The irrigation of the grain crop ceases about June 15, and two waterings are deemed sufficient. Corn is irrigated up to August 1, requiring from three to four waterings. Alfalfa is the most productive crop raised; three crops of nearly 2 tons to the acre each are usually obtained. Alfalfa is watered once for every cutting; it is rarely irrigated later than September 1. Frost may be expected any time after September 15, but it rarely occurs before October 1.

On the Owyhee the first or spring flood is caused by the sudden breaking up of the ice and the melting of large quantities of low-lying snows. It is sudden and of short duration, in this respect all of the rivers of this general region being similar, all having their early spring, or more properly, late winter floods.

Those rivers having large catchment areas in high ranges which retain the winter snows long into the spring are characterized by a second spring flood, occurring at any time from the 1st of May to the 1st of June. Long after the first snows on the lower tributaries have melted and run off in the early spring the higher snows remain intact, and continue so until the protracted warm weather of the later spring months begins to have effect; this snow then melts and a second flood is experienced. Usually this is more gradual and less spasmodic in its nature. It lasts perhaps several days or weeks, and falls steadily and slowly to the extreme low-water stage, which occurs generally in August.

The Malheur River kept a very uniform discharge from the middle of March to the 1st of May. After this it began to fall slowly and steadily to extreme low stage, when it had practically no discharge at the gauging station. The Malheur experienced no second flood, as did the other rivers, there being no mountain catchment area at the headwaters high enough to keep back sufficient snow to create a very perceptible increase in the discharge when warmer weather came.

The Weiser River in Idaho has a varied discharge, sudden spasmodic floods are common, and a rise of 2 feet in one night occurred several times during the last spring.

When the gauge was established on March 13 at the gauging station on the Weiser it read 4·4 feet. On the 15th the gauge read 5·1 feet, and the discharge was about 2,400 second-feet. On March 17 the river had risen to 7 feet, increasing the discharge to 5,500 second-feet, and on March 19 the gauge read 10·5, rising 2 feet in one night. The discharge was then estimated at 13,000 second-feet. The river then fell to 5·8 on the 29th of March, and the next day it was up to 7·2. Another slight flood occurred on April 23 and 24, and another about the 1st of May, after which date the river began to fall steadily until the low stage. About the middle of August the discharge was only 160 second-feet.

MONTHLY DISCHARGES.

Factors.

Cubic feet in acre-foot	43,560
Seconds in day	86,400
Seconds in month 30 days	2,592,000
Seconds in month 31 days	2,678,400
1 second foot for 1 day equals acre feet	1·9835
Cubic feet per second into acre-feet per month of 30 days	59·505
Cubic feet per second into acre-feet per month of 31 days	61·488
Cubic feet per second to depth of run-off in inches, per month of 30 days.	1·122 / Area.
Cubic feet per second to depth of run-off in inches per month of 31 days.	1·153 / Area.

Yellowstone, at Horr, Montana.

[Drainage area, 2,700 square miles.]

Month.	Discharge.*			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
August 12 to 31	1,853	1,411	1,660	102,090	0·71	·62
September	1,653	1,126	1,270	75,565	·52	·47
October	1,126	841	976	60,024	·42	·36
November	841	651	743	44,208	·31	·27
December			*650	39,975	·28	·24
1890.						
January			*550	33,825	·23	·20
February			*550	30,525	·21	·20
March 21 to 31	620	560	585	35,977	·25	·22
April	4,495	510	1,417	84,311	·59	·52
May	11,915	5,090	7,522	462,603	3·21	2·79
June	11,915	8,720	10,086	600,117	4·17	3·74
July	9,410	5,760	7,682	472,443	3·28	2·84
August	5,600	3,145	4,375	269,065	1·87	1·62

* Estimate.

West Gallatin, 20 miles above Bozeman, Montana.

[Drainage area, 850 square miles.]

1889.						
August 16 to 31	437	402	426	26,200	·58	·50
September	640	402	450	26,775	·59	·53
October	437	367	402	24,723	·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	27,370	·60	·54
May	3,195	1,300	2,092	128,658	2·84	2·46
June	3,800	2,060	2,641	157,139	3·47	3·11
July	2,165	890	1,388	8[illegible],362	1·88	1·63
August	890	570	761	46,801	1·03	·89

* Estimate.

Madison, at Red Bluff, Montana.

[Drainage area, 2,085 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January			*1,200	73,800	·66	·57
February			*1,200	66,600	·60	·57
March			*1,200	73,800	·66	·57
April 4 to 30	2,580	1,370	1,620	96,390	·87	·78
May	6,420	3,060	4,823	296,614	2·67	2·31
June	6,360	3,780	4,977	296,131	2·66	2·38
July	3,660	1,715	2,518	154,857	1·39	1·21
August	1,640	1,375	1,535	94,462	·85	·74

* Estimate.

Red Rock, at Red Rock, Montana.

[Drainage area, 1,330 square miles.]

1890.						
January			*40	2,460	·03	·03
February			*40	2,220	·03	·03
March			*40	2,460	·03	·03
April 9 to 30	605	40	184	10,948	·15	·14
May	675	465	577	35,485	·50	·43
June	500	250	384	22,848	·32	·29
July	220	50	93	5,720	·08	·07
August	50	40	48	2,952	·04	·04
September	60	40	47	2,800	·04	·03
October	220	60	150	9,230	·13	·11

* Estimate.

Missouri, at Canyon Ferry, Montana.

[Drainage area, 15,036 square miles.]

1889.						
September	2,040	1,693	1,873	111,443	·15	·12
October	2,516	2,040	2,230	137,145	·18	·15
November	2,834	2,230	2,502	148,869	·20	·17

Missouri, at Craig, Montana.

[Drainage area, 17,615 square miles.]

1890.						
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	·14	·13

Sun, 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	12,733	·20	·18
October	200	200	200	12,300	·20	·17
November	200	180	191	11,364	·18	·16
December			*175	10,762	·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	22,074	·35	·31
May	4,085	1,990	2,804	172,446	2·75	2·38
June	4,000	1,850	2,342	139,349	2·23	1·99
July	2,440	450	961	59,101	·94	·81
August	480	315	371	22,816	·36	·19

* Estimated.

Cache la Poudre, at Fort Collins, Colorado.

[Drainage area, 1,060 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1884.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
March 15 to 31	92·0	48	67	4,120	·07	·06
April	707	64	219	13,030	·23	·21
May	5,393	453	2,537	156,025	2·77	2·39
June	5,611	3,474	4,812	286,314	5·08	4·54
July	3,970	862	2,144	131,856	2· 4	2·03
August	1,231	423	792	48,708	·87	·75
September	446	230	305	18,147	·32	·29
October 1 to 16	225	196	205	12,607	·22	·19
1885.						
April	822	241	447	26,596	·47	·42
May	1,965	954	1,419	87,268	1·55	1·35
June	3,857	2,235	2,910	173,145	3·07	2·74
July	3,186	1,076	1,857	114,205	2·02	1·75
August	1,116	369	656	40,344	·71	·62
September	387	210	273	16,243	·29	·25
October 1 to 10	210	202	203	12,484	·22	·19
1886.						
April 27 to 30	447	369	405	24,097	·43	·38
May	2,660	404	1,309	80,403	1·42	1·23
June	2,584	1,227	1,875	111,562	1·97	1·77
July	1,175	393	717	44,095	·78	·68
August	1,476	232	338	20,787	·37	·32
September	284	115	185	11,007	·19	·17
October	140	120	129	7,933	·14	·12
1887.						
May 18 to 29	2,380	1,150	1,822	112,053	1·98	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	220	307	18,880	·33	·29
September	300	110	175	10,412	·18	·16
1888.						
April	350	100	181	10,770	·19	·17
May	790	250	483	29,704	·52	·45
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	9,286	·16	·14
February	198	69	106	5,883	·10	·10
March	125	41	46	2,830	·05	·04
April	342	48	113	6,723	·12	·11
May	1,886	215	649	39,913	·71	·61
June	1,960	837	1,338	79,611	1·41	1·26
July	844	271	514	31,611	·56	.48
August	455	67	187	11,500	·20	·18
September	75	56	67	3,986	·07	·06
October	92	55	69	4,243	·07	·06
November	122	46	88	5,236	·09	·08
December	89	33	64	3,935	·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

East Fork Arkansas, near Leadville, Colorado.

[Drainage area, 44 square miles.]

1890.						
April 25 to 31	63	15	46	2,735	1·16	1·04
May	339	45	213	13,100	5·57	4·84
June	458	150	224	13,326	5·67	5·09
July	162	54	103	6,334	2·70	2·34
August	115	21	46	2,829	1·20	1·04
September	63	5	17	1,012	·43	·39
October	37	10	15	923	·39	·34

Tennessee Fork, near Leadville, Colorado.

[Drainage area, 44 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
May 11 to 31	315	182	239	14,699	6·26	5·43
June	272	82	141	8,387	3·57	3·30
July	103	42	64	3,936	1·67	1·45
August	51	31	38	2,337	1·00	·86
September	35	31	33	1,962	.84	.77
October	37	29	33	2,030	.86	.77

Lake Fork, near Leadville, Colorado.

[Drainage area, 21 square miles.]

1890.						
April 23 to 31	112	58	75	4,462	3·98	3·57
May	528	104	324	19,926	17·79	15·30
June	468	187	243	14,458	12·91	11·60
July	137	42	73	4,490	3·98	3·48
August	55	28	35	2,152	1·92	1·67
September	31	25	26	1,547	1·38	1·24
October	42	19	33	2,030	1·80	1·62

Twin Lake Creek, below Twin Lakes, Colorado.

[Drainage area, 102 square miles.]

1890.						
April 19 to 31	27	19	24	1,428	·26	·24
May	632	82	252	15,498	2·85	2·47
June	606	433	552	32,844	6·04	5·41
July	536	260	365	22,447	4·13	3·58
August	260	126	176	10,824	1·99	1·73
September	108	62	77	4,581	·84	·75
October	62	25	40	2,460	·45	·39

Clear Creek, near Granite, Colorado.

[Drainage area, 72 square miles.]

1890.						
April 20 to 30	20	12	17	1,012	·26	·24
May	420	29	187	11,500	3·00	2·60
June	435	240	356	21,182	5·52	4·94
July	330	105	238	14,637	3·81	3·31
August	270	29	98	6,027	1·57	1·36
September	80	16	24	1,429	·37	·33
October	30	12	16	985	·26	·22

Middle Fork Cottonwood, near Buena Vista, Colorado.

[Drainage area, 37 square miles.]

1890.						
April 16 to 30	34	12	26	1,547	·79	·70
May	155	34	83	5,105	2·59	2·24
June	155	81	121	7,200	3·65	3·27
July	111	40	70	4,305	2·18	1·89
August	47	18	25	1,538	·78	·68

South Fork Cottonwood, near Buena Vista, Colorado.

[Drainage area, 28 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
April 16 to 30	15	5	10	595	·40	·36
May	135	12	71	4,366	2·93	2·54
June	145	90	121	7,200	4·83	4·32
July	112	63	98	6,027	4·04	3·50
August	90	30	53	3,260	2·19	1·89

Arkansas, at Canyon City, Colorado.

[Drainage area, 3,060 square miles.]

1888.						
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	88,560	·54	·47
June	2,760	1,120	2,090	124,355	·76	·68
July	1,870	850	1,350	83,025	·51	·44
August	1,100	800	932	57,318	·35	·30
September	850	430	605	35,997	·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	180	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

* Estimate.

Arkansas, at Rock Canyon, Colorado.

[Drainage area, 4,560 square miles.]

1889.						
May	3,550	580	1,300	79,950	·33	·28
June	4,375	1,130	2,108	125,426	·52	·46
July	3,025	435	766	47,109	·19	·17
August	3,700	405	668	41,082	·17	·15

Arkansas, at Pueblo, Colorado.

[Drainage area, 4,600 square miles.]

Month.	Discharge.			Total for month.	Run off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1885.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
May 16 to 31	1,270	910	1,069	65,743	·27	·24
June 1 to 23	4,529	1,650	3,187	189,745	·79	·69
1886.						
January			*400	24,600	·10	·09
February			*500	27,750	·12	·11
March			*600	36,900	·15	·13
April			*800	47,600	·19	·18
May	7,659	1,255	3,046	187,329	·78	·66
June	6,965	2,086	5,569	331,355	1·35	1·21
July	3,082	1,279	1,724	106,026	·44	·38
August	3,924	1,159	1,481	91,081	·37	·32
September	1,935	1,195	1,372	81,634	·34	·30
October			*800	49,200	·20	·18
November			*600	35,700	·15	·13
December			*400	24,600	·10	·09
1887.						
January			*400	24,600	·10	·09
February			*400	22,200	·09	·09
March			*500	30,750	·12	·11
April			*600	35,700	·15	·13
May			2,500	153,750	·63	·54
June	4,010	2,800	3,477	206,881	·84	·75
July	6,510	2,210	3,352	206,143	·84	·73
August	2,690	1,290	1,717	105,595	·44	·37
September	1,350	990	1,129	67,175	·25	·25
October			*800	49,200	·20	·18
November			*600	35,700	·15	·13
December			*400	24,600	·10	·09

*Estimate.

Arkansas, at La Junta, Colorado.

[Drainage area, 12,200 square miles.]

1889.						
May 20 to 31	1,960	605	1,089	66,973	·10	·09
June	2,620	825	1,355	80,622	·12	·11
July	2,290	345	844	51,906	·08	·07
August	1,630	55	435	26,752	·04	·04

Purgatoire Creek, at Las Animas, Colorado.

[Drainage area, 3,040 square miles.]

1889.						
May 22 to 31	55	11	22	1,353	·01	·01
June	170	27	70	4,165	·03	·02
July	1,770	8	260	15,990	·10	·09
August	780	6	69	4,243	·03	·02
September	275	6	40	2,380	·01	·01

Rio Grande, above 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

Rio Grande, at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-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	184,530	·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

Rio Grande, above 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	0	237	14,575	·009	·007
August	0		0			
September	0		0			
October	0		0			
November	0		0			
December	252	0	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

San Pedro, at Dudleyville, Arizona.

[Drainage area, 2,819 square miles.]

1890.						
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

Gila, at Buttes, Arizona.

[Drainage area, 13,750 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
August 26 to 31	124	110	115	7,072	·009	·008
September	210	90	128	7,616	·010	·009
October	210	140	157	9,655	·013	·014
November	250	156	212	12,614	·017	·015
December	890	124	275	16,912	·023	·020
1890.						
January	2,100	310	680	41,820	·057	·049
February	1,514	405	578	32,079	·044	·042
March	710	300	387	23,805	·032	·028
April	333	158	238	14,161	·019	·017
May	150	35	87	5,350	·007	·006
June	35	27	28	1,666	·002	·002
July	3,112	11	130	7,995	·011	·009
August	6,330	1,115	3,137	192,925	·262	·228

Verde, near Fort McDowell, Arizona.

[Drainage area, 6,000 square miles.]

1889.						
August 14 to 31	480	154	207	12,730	·04	·03
September	340	140	192	11,424	·03	·03

Salt, at Arizona Dam, Arizona.

[Drainage area, 12,260 square miles.]

1888.						
August	....	....	350	21,525	·03	·03
September	....	....	350	20,825	·02	·03
October	350	300	331	20,356	·03	·03
November	5,760	425	842	50,099	·08	·07
December	43,489	1,665	6,698	411,927	·63	·55
1889.						
January	24,593	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	380	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

Salt, 50 *miles above Phœnix. Arizona.*

[Drainage area, 5,880 square miles.]

1890.						
May 28 to 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	2,200	600	1,362	83,763	·27	·23

Prosser Creek, near Boca, California.

[Drainage area, 56 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
April			*100	5,950	2·00	1·79
May			259	15,900	5·34	4·62
June			110	6,540	2·20	1·96
July			17	1.050	·35	·31
August			3	185	·06	·06
September			2	123	·04	·04
1890.						
April			340	20,230	6·76	6·07
May 19 to 31	1,230	615	817	50,245	16·34	14·45
June			580	34,510	11·67	10·40
July	865	120	382	23,493	7·86	6·82
August	120	75	102	6,273	2·10	1·82

*Estimated.

Little Truckee and Flume, near Boca, California.

[Drainage area, 179 square miles.]

1890.						
April 2 to 30	2,646	276	958	57,066	5·90	5·86
May	2,867	1,000	1,998	122,914	12·85	11·15
June	1,840	1,005	1,491	89,438	9·36	8·33
July	1,330	295	749	45,975	4·81	4·18
August	390	110	200	12,300	1·28	1·12
September	150	87	97	5,771	·60	·54
October	108	70	86	5,289	·55	·48

Truckee, near Boca, California.

[Drainage area, 902 square miles.]

1890.						
March 24 to 31	755	545	637	39,175	·81	·71
April	5,716	580	2,751	163,684	3·40	3·05
May 2 to 31	7,172	2,908	5,275	324,412	6·74	5·85
June	5,092	2,596	4,291	255,314	5·30	4·76
July	2,596	930	1,870	115,005	2·39	2·07
August	930	510	736	45,264	·94	·82
September	580	495	513	30,523	·63	·57
October	660	490	555	34,132	·71	·62

Truckee, near Essex, Nevada.

[Drainage area, 991 square miles.]

1889.						
May			*2,314	131,241	2·48	2·15
June			771	45,874	·87	·78
July			278	17,097	·32	·28
August			*200	12,300	·23	·20
September			*200	11,900	·22	·20

* Estimate.

Truckee, near Laughtons, Nevada.

[Drainage area, 1,054 square miles.]

1890.						
May 13 to 31	6,310	3,840	5,277	324,535	5·77	5·02
June	4,685	2,800	3,690	219,555	3·91	3·51
July	3,580	1,205	2,226	136,899	2·44	2.12
August	1,060	380	604	37,146	·66	·58
September	400	320	368	21,896	·39	·35

Truckee, near Vista, Nevada.

[Drainage area, 1,519 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-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

East Carson, near Rodenbah, 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	110,024	4·98	4·32
August	875	437	597	36,715	1·66	1·44

West Carson, at Woodfords, 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	8,302	2·23	1·93

Main Carson and Flume near Empire, Nevada.

[Drainage area, 894 square miles.]

1890.						
April 16 to 30	2,307	1,337	1,565	93,117	1·95	1·75
May	6,278	1,751	3,475	213,712	4·48	3·89
June	4,276	2,311	3,143	187,008	3·92	3·52
July	3,115	1,491	2,159	132,550	2·79	2·41
August	1,421	215	756	46,494	·98	·85
September	215	131	144	8,570	.18	.16

Bear River, at Battle Creek, Idaho.

[Drainage area, 4,500 square miles.]

1889.						
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	44,900	·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	242,403	1·01	·91
July	2,170	1,200	1,582	97,293	40	·35
August	1,200	880	1,000	61,500	·26	·22

Bear River, near Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Discharge.			Total for month.	Run off	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
June	....	....	*800	47,600	·15	·13
July	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	4,860	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	370,923	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

* Estimate.

Ogden River, at Powder Mills, Utah.

[Drainage area, 360 square miles.]

1889.						
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

Weber, at Devil Gate, Utah.

[Drainage area, 1,600 square miles.]

1889.						
October 13 to 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	230	549	33,763	·40	·34
August	450	200	280	17,220	·20	·18
September	....	....	....	....	....	....

American Fork, at Bridge in Canyon, Utah.

[Drainage area, 66 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
August	66	10	38	2,337	·66	·58
September	48	20	30	1,785	·51	·45
October	66	6	33	2,029	·58	·50
November	30	30	30	1,785	·51	·45
December	108	30	67	4,120	1·17	1·02
1890.						
January	276	30	62	3,813	1·08	·94
February	108	48	72	3,996	1·13	1·09
March 1 to 29	192	66	117	7,195	2·04	1·77
April	....	....	380	22,610	6·43	5·76
May	885	....	666	40,990	11·62	10·11
June	....	....	208	12,360	3·51	3·16
July	....	....	45	2,765	·78	·68

Provo River, near Provo, Utah.

[Drainage area, 640 square miles.]

1889.						
July 27 to 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	31,918	·93	·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

Spanish Fork, near Spanish Fork, 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	53	3,158	·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

Sevier, near Leamington, Utah.

[Drainage area, 5,595 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimun.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-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	·070
1890.						
January	1,058	280	625	38.437	·13	·112
February	1,140	567	713	39,571	·13	·128
March	690	567	630	38,745	·13	·112
April	976	608	726	43,197	·14	·130
May	2,329	976	1,705	104,857	·35	·306
June	2,206	649	1,250	74,375	·25	·224
July	649	185	346	21,279	·07	062
August	185	150	153	9,409	·03	·027

North Fork of Snake, at Ferry, Idaho.

[Drainage area, 931 square miles.]

1890.						
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

Fall River, in Canyon, Idaho.

[Drainage area, 594 square miles.]

1890.						
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

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	41,697	·81	·70

Snake River, at Eagle Rock, Idaho.

[Drainage area, 10,100 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
July	8,646	3,174	5,184	318,816	·59	·51
August	3,130	2,286	2,596	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

*Estimate.

Wood River, at Hailey, Idaho.

[Drainage area, 906 square miles.]

1889.						
July	238	119	163	10,024	·21	·18
August	126	113	123	7,564	·16	·13
September	126	113	123	7,318	·16	·13
October	153	126	138	8,487	·18	·15
November	153	126	145	8,627	·18	·16
December	153	126	138	8,487	·18	·15

Owyhee River, at Riggsby, 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	·01

Malheur River, at Vale, Oregon.

[Drainage area, 9,900 square miles.]

1890.						
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

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	36,275	·41	·35
August	190	100	138	8,487	·09	·08

Gaugings at temporary stations.

YELLOWSTONE BASIN.

Date.	Stream.	Locality of gauging.	Discharge.	Drainage area.	Run off per square mile.
1889.			*Sec.-ft.*	*Sq. miles.*	*Sec.-ft.*
Aug. 24	Yellowstone	Springdale, Montana	2,111	4,800	·44
Sept. 5	do	do	1,931	4,800	·40
Oct. 3	do	do	1,581	4,800	·33
1875.					
Aug. 25	do	Yellowstone Lake	1,200	1,100	1·09
1886.					
Sept. 1	do	do	1,525	1,100	1·38
Sept. 7	do	do	1,016	1,100	·92
1889.					
Oct. 9	do	do	583	1,100	·53

MISSOURI BASIN.

1889.					
Aug. 7	Teton	Choteau	26	900	·03
Aug. 17	Madison	Blacks	1,104	2,085	·53
Oct. 14	do	Three Forks	1,191	2,285	·52
Aug. 19	Jefferson	Willow Creek	202	2,280	·89
Oct. 15	do	Three Forks	333	9,400	·03
Aug. 3	Shields	Flathead Creek	25	225	·11
Aug. 3	Pine Creek	Shields Creek	10	42	·24
Aug. 3	Brackett Creek	do	10	66	·15
Aug. 3	Rock Creek	do	15	50	·30
Aug. 3	Shields River	Below Rock Creek	65	670	·97
Aug. 17	North Musselshell	Martindale	15	250	·06
Aug. 17	South Musselshell	do	10	290	·03
Aug. 17	Big Elk Creek	Big Elk	10	100	·10
Aug. 17	Lebo Creek	Big Timber road	8	10	·80
Aug. 17	American Fork	do	3	55	·05
Aug. 17	Sweet Creek	do	35	100	·35
Aug. 17	Big Timber Creek	do	40	63	·63
Sept. 4	Ruby Creek	Laurin	90	710	·13
Sept. 4	Blacktail Deer Creek	Rondexter	10	300	·03
Sept. 6	Red Rock Creek	Allerdice	10	860	·01
Sept. 9	Beaverhead	Dillon	75	4,000	·02
Sept. 8	Big Hole	Melrose	60	2,335	·03
Oct. 6	Tongue	Miles City	200	3,875	·05
Aug. 9	Dearborn	Dearborn	47	350	·13
1890.					
Apr. 15	do	do	37	350	·11

RIO GRANDE BASIN.

1889.					
Feb. 12	Embudo Creek	At mouth	20	285	·07
Feb. 23	Rio de Taos	Near Taos Pueblo	16		
Feb. 25	do	Near Cordova	52	452	·12
Feb. 26	Rio Hondo	Frasier's Mill	16		
Feb. 27	Pueblo Creek	Near Taos	12	49	·24
Feb. 27	Taos Creek	In Canyon	3		
Mar. 1	Red River	Near town of Red River.	23	153	·15
Feb. 14	Ojo Caliente	Near the Chama River.	28	919	·04
Mar. 7	do	do	50	919	·05
Mar. 9	Rio Chama	Near Abiquiu	945	2,800	·41
Mar. 11	Santa Cruz	Near Española	11		
Apr. 20	do	Near Santa Cruz	83	90	·92
Mar. 11	Pojuaque	Below junct. Tesuque.	11	160	·07
Apr. 18	do	Above Tesuque	50	65	·77
Mar. 15	Jemez River		85	900	·09
Mar. 17	Santa Clara	Near Española	6		
Apr. 17	do	do	11		
Apr. 19	Tesuque	Near Santa Fé	23	95	·24
Apr. 13	Rio Grande	Below Embudo	2,024	7,000	·29
Mar. 1	do	San Ildefonso	670	11,250	·06
Mar. 2	do	do	727	11,250	·06
Aug. 8	do	San Marcial	19		
Mar. 15	Jemez	At Canyones	85	900	·09
May 25	do	do	83	900	·09
July 3	do	do	30	900	·03
July 6	do	do	29	900	·03
Aug. 25	do	do	22	900	·03
Oct. 1	do	Below Canyones	20	900	·02

Gaugings at temporary stations—Continued.

GILA BASIN.

Date.	Stream.	Locality of gauging.	Discharge.	Drainage area.	Run off per square mile.
1889.			*Sec.-ft.*	*Sq. miles.*	*Sec.-ft.*
June 26	Verde	Above junction Salt	127	6,000	·02
July 11	...do	...do	234	6,000	·04
July 20	...do	...do	436	6,000	·07
Aug. 14	...do	...do	187	6,000	·03
Aug. 15	...do	...do	162	6,000	·03
Aug. 29	...do	...do	177	6,000	·03
Aug. 29	...do	...do	156	6,000	·03
Sept. 15	...do	...do	198	6,000	·03
Sept. 23	...do	...do	235	6,000	·04
Sept. 25	...do	...do	214	6,000	·04
Sept. 27	...do	...do	217	6,000	·04
Sept. 29	...do	...do	237	6,000	·04

TRUCKEE BASIN.

1889.					
July 4	Truckee	At Tahoe City	136	522	·26
Aug. 8	...do	...do	75	522	·14
Aug. 14	...do	...do	56	522	·11
Aug. 18	...do	...do	49	522	·09
June 3	Squaw Creek		92	8	11·60
June 22	...do		15	8	1·88
June 3	Toll Gate Creek		74		
July 3	Donner Creek	Below Donner Lake	8	16	·50
July 6	...do	...do	5	16	·31
July 11	...do	...do	2	16	·12
July 16	...do	...do	1	16	·06
Aug. 7	...do	...do	·9	16	56
Aug. 10	...do	...do	·2	16	·12
Aug. 17	...do	...do	·3	16	·19
June 28	Cold Creek	Near Donner Lake	11	14	·79
July 3	...do	...do	10	14	7
July 6	...do	...do	5	14	·35
July 11	...do	...do	1	14	·07
Aug. 7	...do	...do	1	14	·07
Aug. 10	...do	...do	1	14	·07
Aug. 17	...do	...do	·7	14	·05
May 24	Prosser Creek		312	56	5·57
June 21	...do		65	56	1·16
July 5	...do		19	56	·34
July 15	...do		16	56	·29
Aug. 17	...do		1	56	·02
June 27	Little Truckee	Near Boca	54	179	·30
July 2	...do	...do	48	179	·27
July 10	...do	...do	21	179	·12
Aug. 5	...do	...do	24	179	·13
Aug. 13	...do	...do	20	179	·11
June 1	Martis Creek		19	45	·42
June 22	...do		7	45	·15
May 30	Juniper Creek	Near Clinton	22	10	2·20
May 31	Joe Grey Creek	Near Cuba	88	17	5·18
June 21	...do	...do	16	17	·94
May 31	Bronco Creek	Near Bronco	42	19	2·21
May 22	Dog Creek	Near Verde	7	22	·31
May 20	Truckee	Near Essex	2,330	991	2·35
May 22	...do	...do	2,510	991	2·53
May 29	...do	...do	1,716	991	1·73
June 20	...do	...do	350	991	·35

Gaugings at temporary stations—Continued.

CARSON BASIN.

Date.	Stream.	Locality of gauging.	Discharge.	Drainage area.	Run off per square mile.
1889.			*Sec.-ft.*	*Sq. miles.*	*Sec.-ft.*
June 10	Carson	Near Corrells	527		
June 10	West Carson		72	70	1.03
18. 0.					
May 13	Cohn Klouber ditch		3·3		
May 13	Mountain stream		2·0		
May 15	Ditch	Between Sheridan and Fredericksburg.	3·4		
May 16	do	Grist mill, 2 miles south of Genoa.	6·2		
May 20	do	Frank Deludre's	8·6		
May 20	do	Ormsby County Poor Farm.	1·4		
May 20	Clear Creek	Ormsby County	40		
May 28	do	do	48		
May 22	Ditch	Boyd's Bridge, second east.	1·3		
May 22	Upper ditch	Daugberg's	24·5		
May 22	Ditch	Fred Dressler's	2·6		
May 22	do	Dressler & Berry	1·3		
May 22	West Carson ditch		36·4		
May 22	Ditch	Springmeyer & Daugberg's.	3·5		
May 22	Jocks Valley Creek		12·8		
Apr. 26	Rodenbahl's ditch		5·4		
Apr. 26	Heitman's ditch		5·9		
Apr. 26	Long Valley Creek	2 miles above mouth.	22·0		
May 12	do		9·4		
	do		12·0		
May 4	Daugberg's & Bartlett's ditch.		4·0		
May 12	do		10·6		
May 5	Cottonwood Slough		6·9		
May 5	12-Mile House ditch		·6		
May 10	West Carson ditch		3·0		
May 15	do		4·4		
May 12	John Scossa ditch		1·0		
May 12	Milich ditch		·6		
May 12	Springmeyer Long Valley ditch.		6·4		
May 13	Company ditch		23·7		
May 13	Hussmann ditch		4·7		
May 13	Ezell ditch		8·3		
	Springmeyer Reservoir ditch.		7·1		

SALT LAKE BASIN.

Date.	Stream.	Locality of gauging.	Discharge.	Drainage area.	Run off per square mile.
1889.					
July 25	Lehi Canal	¾ mile below head gate.	10		
July 25	Pleasant Grove Canal.	Near head gate	7		
Aug. 1	Dry Creek	Near head gate, first division.	7		
Aug. 2	Spring Creek	Near Powell's Mill	4		
Aug. 5	Hobble Creek	First bridge in canyon.	11	120	·09
Aug. 31	do	do	15	120	·12
Oct. 30	do	do	17	120	·14
Nov. 25	do	do	22	120	·18
Aug. 14	Logan River	Above high line canal.	126	218	·58
Aug. 17	do	do	128	218	·59
Aug. 24	do	do	106	218	·49
June 6	Provo	¼ mile in canyon	201	640	·31
June 6	Big Bench Canal	½ mile below head	41		
June 10	Bear	Collinston	721		
June 11	do	At English Camp	797		
June 12	Logan, Hyde Park, and Smithfied Canal.		39		
June 12	Logan and Richmond.	Near head gate	68		
June 14	Logan and Hyde Park.	In Logan	35		
June 14	Logan and Benson Canal.	do	38		
July 25	East Fork Sevier	(Floats.) Below Otter Creek.	35	1,177	·03
July 30	Sevier	Joseph	70	2,714	·03

Gaugings at temporary stations—Continued.

SNAKE BASIN.

Date.	Stream.	Locality of gauging.	Discharge.	Drainage area.	Run off per square mile.
1889.			*Sec.-ft.*	*Sq. miles.*	*Sec.-ft.*
June 15	Little Wood	Shoshone, Idaho.	32	907	·04
July 1	Silver Creek	Bellcone, Idaho	174	83	2·10
July 19	North Fork Snake	Rexburg Ferry	133		
Sept. 19	..do	Above Fall River	1,273	931	1·47
Sept. 19	South Fork Snake	Above canals	1,614	5,850	·28
Sept. 18	Teton River	Near Teton City	293	967	·30
Sept. 19	Fall River	...do	452	594	·76
Sept. 14	Eagle Rock Canal	Willow Creek head gate.	103		
Sept. 14	Farmer's Friend ditch		65		
Sept. 14	Burgess ditch	Near head	38		
Sept. 16	Louisville ditch		74		
Sept. 16	Dry bed ditch		70		
Sept. 16	Menan ditch	Head gate	236		
Sept. 16	La Belle ditch		14		
Sept. 16	South Fork		874		
Sept. 16	Moody Creek		1		

ENGINEERING.

SCOPE OF WORK.

The following brief statement of results accomplished by the engineers follows the plan of the first annual report on irrigation, there being no essential change in methods or locality of work. These results, however, are of necessity given in the briefest form, as the valuable material is so great in amount that it must be left for subsequent publication. The surveys vary in character from rapid reconnaissance work, covering great areas, to the most careful and detailed instrumental work in chosen spots, followed by elaborate computations and plans. Between these extremes are surveys of every intermediate degree of care. In each engineering division broad reconnaissance work for the purpose of discovering reservoir sites was done; at the same time preliminary surveys were carried on in a few cases, and a smaller number of very careful examinations were made in localities whose adaptability for storage reservoirs was at once recognized. An exhibition of this work in full requires more space than can be given in an annual report.

It should be noted in this connection that each engineer has been compelled to make statements regarding the feasibility of the larger projects, in a most general and qualified manner, pointing out the impossibility of arriving at definite conclusions until more is known of the actual water supply and the behavior of the rivers and smaller streams. The engineer must know not only the average flow of certain water courses, but also their greatest and least discharge for a number of years, before he can give decisive opinion as to the desirability of constructing important storage systems. It is a comparatively simple matter to plan a dam at a given place and to estimate the cost of such a structure of given dimensions; and, moreover, the calculation of the contents of the reservoir thus made is a mere matter of detail. Thus, the engineers can say that at this place or that a dam can be built for a certain sum, and that this dam will hold back so much water; but the question of far greater importance and whose answer governs all other matters is, will it pay? In other words, do we know that there is sufficient water to fill the reservoir each and every year (for the loss of a single year may mean ruin to a community), and do we know that no great flood will occur of such violence as to overtop the structure and pull it down? It is only after these questions have been satisfactorily answered that the central fact can be determined, namely, whether the cost of storing this water and bringing it to the arable land will be such as to make it feasible.

These questions of water supply, location, and proportioning of dam are so interdependent that the estimates, cost, and future returns are hopelessly involved in doubt, while there is uncertainty as to the volume of water flowing in the rivers. It is true that there are many undertakings of local importance and value which can be carried out without any but the most general knowledge of water supply and its vagaries, but the more important, comprehensive systems, upon whose proper execution depends the prosperity of great irrigation districts and in whose stability the public as a whole have a vital interest—these, as in all similar constructions made throughout the world, must await more definite knowledge of the hydrography and of the topographic and climatic features which modify them.

From the best information to be obtained, it appears that 1889 was an extraordinarily dry year, and in 1890, in spite of the abundant rainfall in certain parts of the arid regions, the rivers as a whole did not fully recover from the effects of the drought. Thus, the published results represent but one side of the case, the minimum condition, and the water supply in the localities where measured appears less than is actually the case. In the reservoir projects, which from necessity are based upon data of a dry year only, there are vital qualifications to be borne in mind in discussions of their value, and while the attempt has been made to give the best and most satisfactory treatment to each scheme, this uncertainty as to fundamental facts hangs over all.

MONTANA DIVISION.

Mr. H. M. Wilson, engineer, took charge of this division on June 14, 1889, under general instructions to devote his attention primarily to a thorough reconnaissance, especially with regard to storage facilities, and to undertake only such field work and segregation as should not divert him from the task of gaining a preliminary knowledge of the country. In this he was aided by Mr. R. S. Tarr, one of the hydrographers of the Survey, who had been, during the previous month, preparing information relative to irrigation for the use of the select committee of the Senate.

After a brief reconnaissance it was found that in the Sun River and Teton Basins, in Cascade and Chouteau Counties, there was an abundance of irrigable land and excellent opportunities for water storage. A survey of the reservoir sites in the Upper Sun River Basin was therefore begun at once and continued under the charge of Mr. John B. Rogers until the end of October, 1889.

The field operations being well under way, Mr. Wilson devoted his time to a thorough personal reconnaissance of as much of the State as could be examined in a season. In this work, lasting from July 24 until September 25, he traveled 2,000 miles on horseback and 1,650 miles by rail, examining irrigable land and water supply, and looking for possible storage sites.

This preliminary examination was for the purpose of discovering storage sites and determining the relative importance and necessity in the various localities of detailed engineering surveys, in order that these might be begun and be carried on in a systematic manner, in places where the largest and best results would ensue. Estimates sufficient for this purpose were made based upon observations by the eye, aided by simple hand instruments, but were not to be considered as final, as in matters of this character it is impossible to make accurate estimates without careful surveys. The statements of the acreage of irrigable land were based upon assumptions as to the water duty, which may not be verified in the future and may require revision as new facts are developed. The duty of water should be great, but on account of its abundance no efforts have been made to use it frugally. From statements of farmers and canal-owners, it is estimated that the duty varies from 60 to 80 acres in ordinary soils, and with clay subsoil is as high as 100 acres. In the estimates made a water duty as high as the surrounding circumstances seemed to justify was assumed in each case.

In order to determine upon the practicability of the projects reported, it is necessary to make preliminary surveys of the various reservoir sites indicated and a thorough study of the catchment areas of the streams, after which detailed mapping of the localities selected is essential in order to make reliable estimates of the cost of construction. A brief notice of the localities visited and reference to the storage facilities there discovered will serve to indicate the scope and importance of this reconnaissance.

Beginning with the Missouri River in western Montana, there is on the east side of the river, the Missouri valley 25 miles long north and south and varying in width from 1 to 8 miles. It is found that the water supply for the tract of good land, which comprises about 60 per cent of the valley, is abundant and convenient and may be derived from either of two sources, namely, from a great canal taken from the Missouri River, heading in the cañyon near Toston and carried around the eastern edge of the valley; or by augmenting by storage the discharge from small streams coming out of the Belt Mountains, by constructing reservoirs in the hills and tanks on the bench lands. Whether the one or the other of these methods, or a combination of both, will prove the best, is a matter which can be decided only after a survey of the whole has been made.

The Missouri River was examined at a point 2½ miles above Toston, and it is believed that a diversion weir of masonry, rising 10 or 15 feet above mean level, will turn as much of the stream as is necessary into a canal heading at that point, but from the hasty reconnaissance it is believed that a system of storage reservoirs will be cheaper and quite as satisfactory. A number of what appeared to be good reservoir sites were observed on Clear and Boulder Creeks and other streams, and have been pointed out for future examination and survey.

Continuing down through the canyons, about 12 miles below Craig, the river again emerges from the mountains and flows through the broad bench lands to the Great Falls. On the right bank the bottom broadens into a fine fertile plain, known as Chestnut Valley, which extends to Smith River on the east and very nearly to Great Falls on the north.

It is probable that a larger canal than that heading above Half Breed Rapids can be taken out near this point by a high diverting weir, and can be brought to the valley at a much higher level than the one now existing, controlling a greater portion of the valley. Water is abundant, for at this point the river when at its lowest stage carries about 1,800 second-feet. West of the Chestnut Valley and between the foothills of the Rockies and the Missouri River is the great plain through which the Teton, Sun, and Dearborn Rivers have cut, forming bottom lands from a quarter of a mile to a mile in width, bordered by gravelly bluffs from 200 to 400 feet in height. At the lowest stage the Teton, Sun, and Dearborn hardly discharge sufficient water to irrigate their bottom lands, much less the extensive benches; hence for the reclamation of all this fertile land it will be necessary to increase the supply by storage, the opportunities for which are excellent.

It is estimated that about 920,000 acre-feet may be stored if reservoir sites of sufficient capacity can be found on these rivers. Making allowance for loss by absorption and evaporation, this amount of water should irrigate about 552,000 acres at a duty of 1¼ acre-feet per acre. On the above basis of estimate it will appear that there is more arable land than there is water, yet it must be remembered that all the land will not be irrigated at one time, but that a very large percentage of it will be either idle or occupied for pasturage, roads, or towns.

In this region a number of reservoir sites were discovered and examined carefully, and on the Sun River the possibilities of storage were so promising that, as noted before, surveys were made of the reservoir sites, most of which proved satisfactory. Other reservoir sites besides those surveyed were found farther north, among which are several small lake basins.

In Cascade County, southeast of the Missouri River, and between it and Smith River, is a broad, gently sloping bench land, traversed by many small streams, and containing about 180,000 acres of good land. A water supply may in part be obtained by the construction of reservoirs in Sand Coulee Creek, Box Elder Creek, and other streams. There are, however, several serious difficulties in the way of water storage in this region; the flow of water in the streams is small and uncertain, requiring thorough investigation, reservoir sites are few, and there will be many obstacles in taking the water from the streams to the top of the bench land.

In the Little Belt Mountains, Belt Creek carries about 20 second feet of water during the irrigating season, but most of this is now used on the bottom lands, which are extensively cultivated. It is probable, however, that the use of storage sites, the facilities for which are excellent, will be necessary to bring all this bottom land under water.

On the eastern slope of the same mountains, in Fergus County, is a very extensive plain or bench extending from the foot of the mountains to the Missouri canyon on the north, and eastward to the Musselshell River. The area drained by Arrow and Wolf Creeks and the Judith River was examined, and it was found that each of these streams offered opportunities for storage. There is a very large area of good irrigable land on the bench through which these streams flow, and as none of them are in deep coulees, canals can readily be taken from them near the foot of the mountains and water brought upon this bench land.

The principal forks of the Judith River, which flows through the upper lands of the basin, are Willow Creek, Ross Fork, and Big Trout Creek, all of which, with minor tributaries, can easily be diverted to the irrigable lands, none of them flowing between deep banks. During the irrigating season little water is flowing, and all of this is now appropriated to irrigate the numerous ranches along their banks. Storage sites are neither abundant nor good, although a few were noted on the

Judith River. The water supply available for storage is abundant, for the catchment area of the Judith above Utica is 375 square miles, while that of Ross Fork above the junction of the Judith is 464 square miles.

In the upper Musselshell Valley the principal irrigable land lies between Lavina and Martinsdale, and consists of the rich bottom land close to the river and of the gravelly bench land on either side, a large portion of which is arable and can be watered either by canals taken from the main river, or better, by means of water storage on the smaller streams which enter the river between Lavinia and Martindale and on which a number of sites were found and reported for survey.

In the headwaters of the Smith River basin sites were found, notably on South Fork and Sixteen Mile Creek, and also on Shields River, which heads farther south in the same mountains.

The result of the reconnaissance of the great bench lands along the Yellowstone leads to the conclusion that irrigation may be accomplished by the use of storm waters stored in the coulees or in the basins on the bench, or by a great canal leading out of the Yellowstone River. The first may be practicable, but the acreage which can be reclaimed by storage on the bench is so inconsiderable as not to be worth further instrumental examination. The coulees are dry nearly all the year, and sometimes during several successive years, when suddenly a cloud-burst or heavy downpour of rain may occur, converting every coulee into a torrential river. Such floods are so irregular and turbulent in their action as to be almost uncontrollable, and are heavily laden with sediment.

The second source of water supply, the Yellowstone River, is well worth careful examination and study, but owing to the area of country which must be surveyed in order to decide upon the practicability of diverting the river to the bench the work must be most thoroughly done. It is probable that a canal may be diverted somewhere between Stillwater and Billings which would reach the summit without encountering insuperable obstacles and requiring too long a diversion line. The slope of the bench land and the fall of the river are such that, in less than 50 miles on a direct line, a canal having a grade of 1 foot to the mile would reach the summit of the bench, though, owing to the sinuous course which the canal would have in following the contour of the hillsides, it would be many miles longer.

The average discharge of the river during the irrigating season at the probable location of the canal head near Billings is about 3,000 second-feet, which, allowing 33⅓ per cent for evaporation and absorption in the canal, is sufficient to irrigate 200,000 acres at a duty of 100 acres to the second-foot.

Gallatin Valley, between Bozeman and Moreland, is the most productive and fertile section of the State. The total area of arable land is estimated to be 220,000 acres, of which about 30,000 acres are already under cultivation. The water supply at present used can be largely increased by storage among the upper tributaries of the smaller streams, for which purpose several good reservoir sites have been noted, of which perhaps the best is Mystic Lake, at the head of Sour Dough Canyon or Mill Creek.

Madison River in its upper portion flows through several canyons, from each of which it emerges into broad valleys with fine agricultural bottom lands, the largest being known as Madison Valley, considerable of which is now under cultivation. The irrigation at present is entirely from the local drainage crossing the valley to join the main river. The perennial flow of these creeks is nearly sufficient to irrigate the entire valley, and for the complete supply three reservoir sites, all located on the upper Madison River, would readily store all the water available.

The water supply of Ruby and Jefferson Valleys was examined and storage sites noted on the Ruby River and its tributaries; and in the same manner the three agricultural areas of Red Rock, Blacktail Deer, and Beaver Head Valleys were considered together, and estimates made of the amount of water to be had by utilizing the various sites on the headwaters of the river system draining them.

The following conclusions are reached: Until a well distributed series of observations has been made to ascertain stream discharges, evaporation, absorption, rainfall, and percentage of run-off, the attempt to state what amounts of water will be available for irrigation or storage from a given stream must be somewhat uncertain.

As is well known, there is more good agricultural land than water to irrigate it, and in order to increase the arable area it is necessary to increase the water supply by storing the water which falls during the non-irrigating season, that is, from September to the spring months, with their surplus water. This reconnaissance has shown that there are many opportunities for doing this, and the wide choice of locations leaves scope for wise judgment in their selection.

The western portion of Montana, although most rugged and mountainous, is more thickly settled than the eastern or plateau country, from the fact that the inhabitants were first attracted by the mineral wealth of the region, and have but slowly changed their occupation to agriculture. Thus the great mountain valleys, such as Deer Lodge, Beaver Head, and Gallatin, are at the present time the best agricultural portions of the State, owing to this cause and to the fact that there is a greater abundance of small and easily controlled streams which render irrigation possible even to the poorest settlers. The soil in the valley bottoms is generally excellent, being in part alluvial and in many places composed of rich, deep deposits of lacustrine origin. On the benches the soil is generally a rich, warm, sandy loam, and having a good natural drainage, it is in many cases preferable to that lying higher up. These benches, however, have as yet been little cultivated, owing to the difficulties of getting water to them, and it is in their reclamation that the greatest strides will be made towards the development of the country.

There are many moderate-sized streams in the State and a few large rivers, most of which carry their maximum supply of water during the early part of the irrigating season. The first floods occur in April, and continue through June, declining in July. For irrigating in the latter part of the crop season the flow of the streams must be increased by storage. The time during which water must be held being only from March to September, the total evaporation will be small; the loss from this source may be taken to be less than 2 feet in depth, as shown by the results of the evaporation measurements conducted at various places.

All the country examined, especially in the mountain valleys, has one characteristic. At the foot of the mountains on the upper benches of the valleys are generally to be found small depressions or broad coulees with low slopes, where small storage tanks can be cheaply and easily constructed.

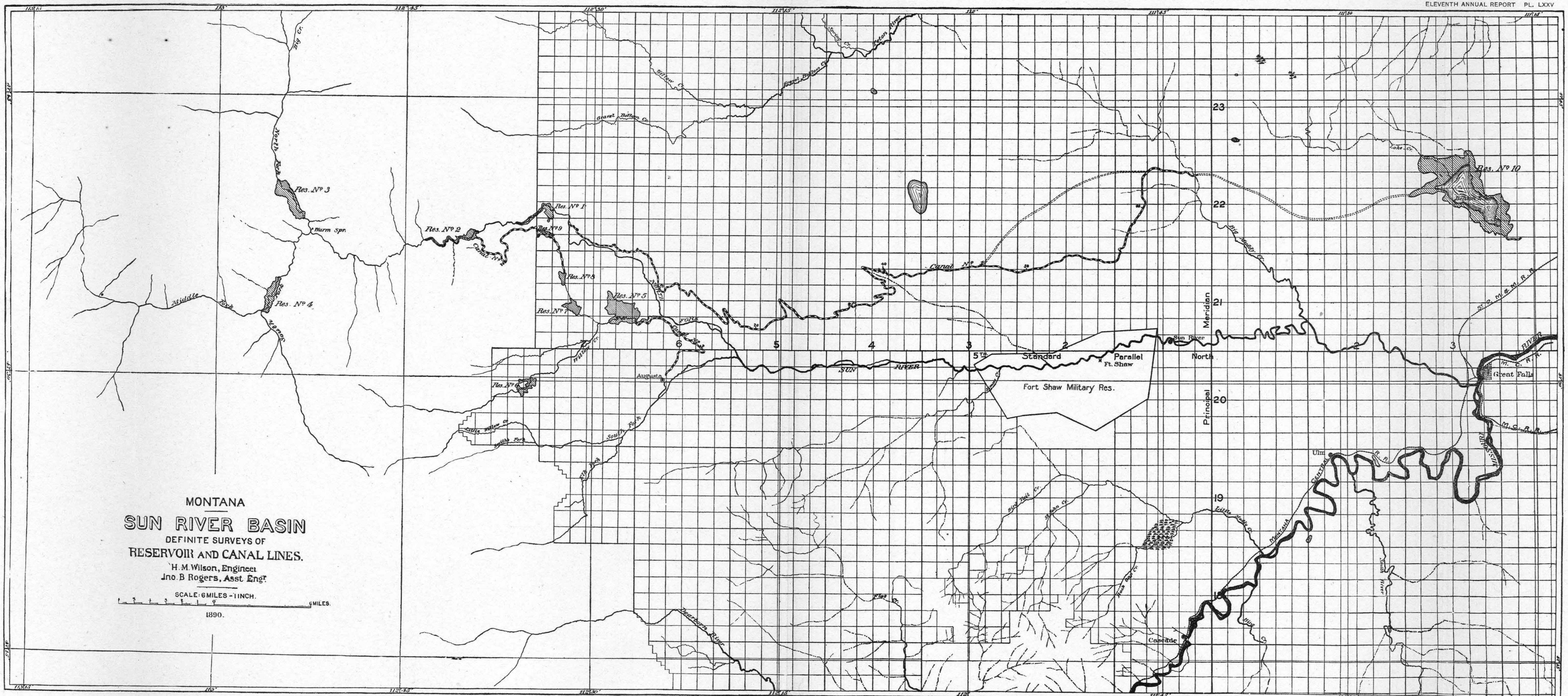
These tanks have storage capacities of from 10 to 200 acre feet, and can be constructed by the farmers at their leisure. They can be closed by low earth dams raised by scrapers or horse-power excavators, and will usually be not over 15 feet in maximum depth. Their water supply can be derived from some small perennial spring, or from the occasional storm discharge of a short coulee. Such dams have been built by use of a ditch excavator and elevator worked by horse-power. This machine automatically elevates the banks to a height of 12 feet at a cost of less than 9 cents per cubic yard of embankment constructed.

THE SUN RIVER SURVEYS.

The region comprised in the Sun River system lies between the Teton River on the north, the Dearborn on the south, the Missouri on the east, and the crest of the main range of the Rocky Mountains on the west, while the portion surveyed and studied during 1889 includes only the watershed of the Sun River, extending to the divides between the Teton on the north and the Dearborn River on the south.

The topography is simple: the Sun River, after rising in the Rockies, flows southward through them for about 60 miles, and then, turning abruptly, flows eastward through a canyon in the confining mountains and emerges on the level plain, through which it flows for 75 miles to its junction with the Missouri River at Great Falls.

Along its entire course through the plain the river has eroded a broad, level bottom which averages about 1 mile in width and is from 5 to 25 feet above the surface of the water in


MONTANA
SUN RIVER BASIN
DEFINITE SURVEYS OF
RESERVOIR AND CANAL LINES.
H. M. Wilson, Engineer
Jno. B Rogers, Asst. Engr.
SCALE: 6 MILES = 1 INCH.
6 MILES.
1890.
Res. No 1
Res. No 2
Res. No 3
Res. No 4
Res. No 5
Res. No 8
Res. No 9
Res. No 10
Canal No 1
Canal No 2
Warm Spr.
Augusta
Sun River
Ft. Shaw
Fort Shaw Military Res.
5th Standard Parallel North
Principal Meridian
Great Falls
Ulm
Cascade
Dearborn River
Willow Cr.
Gravel Bottom Cr.
Big Muddy Cr.
Lake Cr.
Little Muddy Cr.
Smith River
Bird Tail Cr.
Flat Cr.
South Fork
North Fork
Middle Fork
Teton River
St. P. M. & M. R. R.
M. C. R. R.
23
22
21
20
19
6
5
4
3
2

the river. This bottom is bordered by a steeply sloping bluff averaging from 300 to 500 feet in height, the top of which is the surface level of the plain, a bench generally flat and extending north and south to the next river channels, where a similar bluff and bottom appear.

The total area of the big bench land between the Sun and Teton Rivers is about 530,000 acres, of which perhaps 395,000 acres can be profitably cultivated if a sufficient water supply can be provided. Between Willow Creek and the South Fork are 15,000 acres, of which at least 5,000 are good irrigable land. The bottom lands on the south side of the lower Sun River east of Fort Shaw and the bench lands south of the Sun River, between it and the Missouri and east of Fort Shaw, in townships 19 and 20 north, ranges 1 and 2 east, contain in all about 60,000 acres of excellent irrigable land, which can probably be watered by a canal taken from the Sun River near Fort Shaw, utilizing any water that can be spared from the reservoirs above. Altogether there are a total of 460,000 acres reclaimable by the reservoirs, provided a sufficiently cheap supply of water can be obtained.

In order to bring this immense area to the highest state of cultivation it is probable that a water supply for not over 300,000 acres will have to be provided, since, when fully cultivated and inhabited, at least 5 per cent of the area will be occupied by roads and buildings, 15 per cent more by towns and by pasture lands, which will receive water by percolation from the surrounding fields, and a large proportion more will be idle.

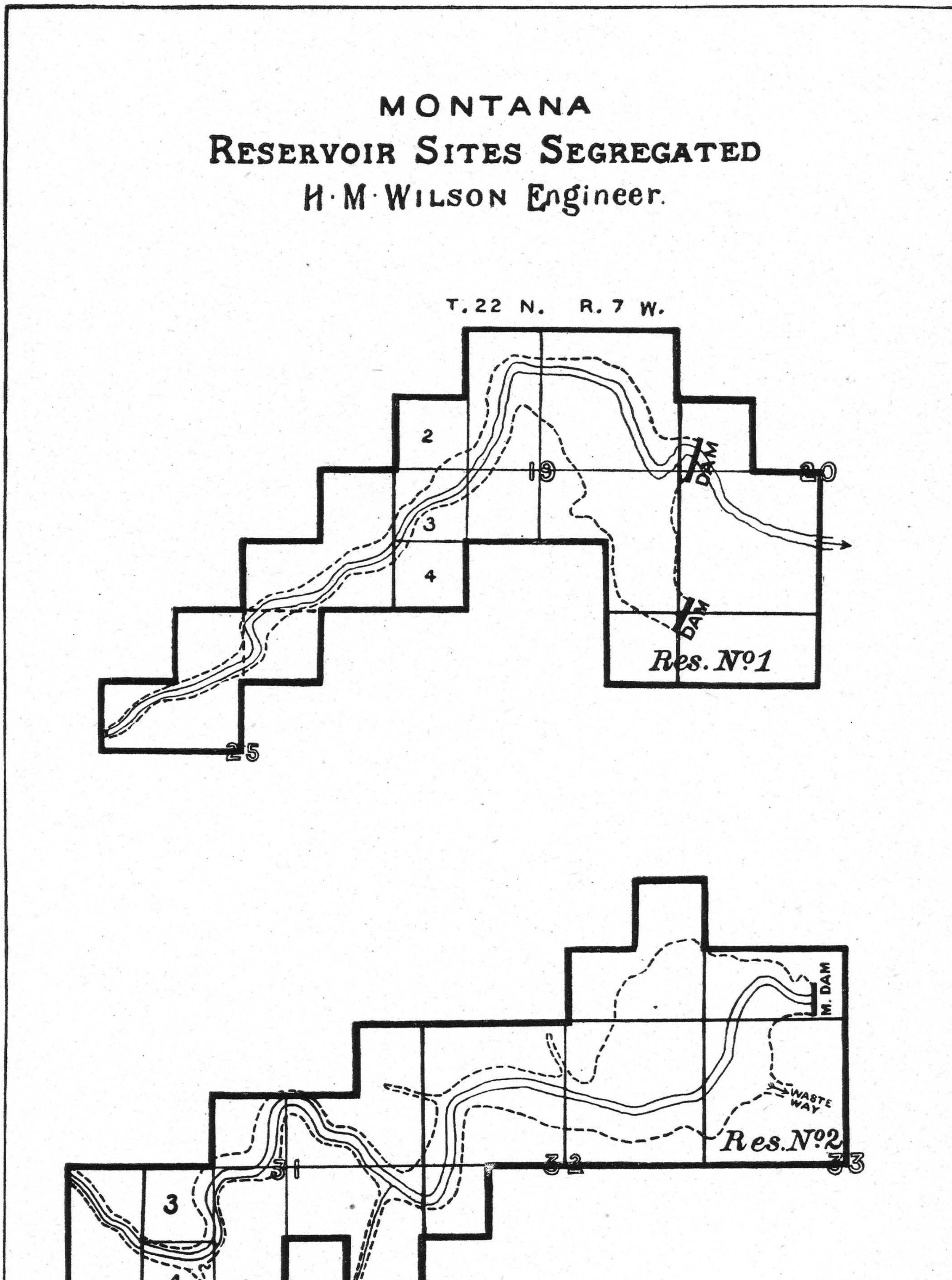
Bottom lands with a water right in perpetuity range in value from $15 to $25 per acre exclusive of improvements, and it is probable that the bench lands will bring even better prices. At present fully 95 per cent of the land is owned by the Government, and it is held at $1.25 per acre, though without water it is almost valueless except for grazing.

SURVEYS.

By reference to Pl. LXXV can be seen the general location of the reservoir sites and canal lines of this system. In the course of the work a bench-mark was located with reference to natural objects, the elevation of which was assumed. From this bench as an initial point main transit and level lines were run through and connecting the different basins first surveyed. From these main lines short lateral lines were run at frequent intervals to the top contour of each basin and the topography sketched on these lines in 5-foot contours. The horizontal control was obtained by stadia measurements and the entire system of main lines tied by making a circuit and checking back on the initial point of survey.

A careful examination was then made of the Sun River for a distance of 30 miles above the basins first surveyed. On this reconnaissance four reservoir sites were discovered, the survey of which was at once begun. Of these, reservoir No. 1 being but a few miles above the series of basins already surveyed, it was decided to run a main transit and level line up the river from the first initial point and base the season's work upon this datum, which ultimately should be connected with sea-level elevations. This main transit and level line was carried up the river a distance of 27 miles, also up the South Fork for 7 miles, making a total of 34 miles. This work was necessary in order to ascertain the relative positions of the four reservoirs lying along the river, because, with the exception of reservoir No. 1, they are on unsurveyed land.

At each reservoir the dam site was examined and its location decided upon, and a stone monument was erected at each end. An accurate profile was then made through the axis of the dam, and the topography sketched on each side of the entire line. The surveys of canal lines consisted merely of running out the grade contour, measuring the length of trestles, and ascertaining the quantities of excavation at controlling points where cuts were necessary to save grade and distance. Notes were taken of the character of excavation and embankment, so that a close preliminary estimate could be made of the cost of construction. The surveys of reservoirs and of canal lines were connected to the Land Office survey by tying to section and township corners. In plotting, the field notes were adjusted to connect with the Land Office survey, so that in segregating irrigable lands and lands necessary


MONTANA
RESERVOIR SITES SEGREGATED
H·M·WILSON Engineer.
T. 22 N. R. 7 W.
2
3
4
19
20
25
DAM
DAM
Res. No 1
M. DAM
WASTE WAY
Res. No 2
3
4
31
32
33

for reservoir sites and head-works of canals the Land Office plats were used as a base. Reservoirs No. 2, No. 3, and No. 4 are on unsurveyed land, and to locate them in reference to the Land Office survey connection was made with the township line intersected, and the land lines projected over the areas surveyed.

RESERVOIRS.

The Sun River project, as surveyed and shown on Pl. LXXVI, consists of ten reservoirs whose sites have been segregated, as described on the following pages, and three canal lines, all lying within the Sun River Basin. Reservoir No. 1, shown on Pl. LXXVI, is the lowest of four reservoirs upon the Sun River; the dam is located in the W. ½ of Sec. 20, T. 22 N., R. 7 W. The foundation and abutments are of solid sandstone, rising nearly perpendicularly on the left bank of the river, while on the right bank the rise is about 1 in 10. The river at this point is 105 feet wide and 7 feet in maximum depth, with an average fall of 15 feet per mile through the reservoir site. This reservoir is located on public land of no special value, the site being described in Land Office terms on page 127.

Reservoir No. 2, shown on Pl. LXXVI, the second one on the Sun River, is situated on unsurveyed land and lies about 3 miles above reservoir No. 1. It is 105 feet higher than No. 1, and will flood what is known as Richardsons Bottom, named after a squatter who has located there. The abutments and foundation for the dam are sandstone. By projecting the land lines over this reservoir it is found that the dam site lies in the SW. ¼ of Sec. 28, T. 22 N., R. 8 W.

Reservoir No. 3, shown on Pl. LXXVII, is located on the North Fork; in elevation it is 510 feet higher than reservoir No 2. The foundation and abutments of the dam are of granite. At this point the river is 95 feet in width and 4 feet in greatest depth, and has an average fall of 26 feet per mile through the reservoir site. This site is also on unsurveyed land; by projecting the land lines it was found that the dam site would be in the NW. ¼ of Sec. 27, T. 22 N., R. 10 W. The complete description is given with that of the other sites.

Reservoir No. 4, shown on Pl. LXXVII, is located on the South Fork, 4½ miles above the forks, and is 600 feet higher than reservoir No. 2. This reservoir is also on unsurveyed land, but the dam site would be in the SW. ¼ of Sec. 9, T. 21 N., R. 10 W., as determined by projecting the land lines to this area. The foundation and abutments are of granite. The river at this point is 45 feet wide and 3 feet in maximum depth, and has an average fall of 31 feet per mile through the reservoir site.

Reservoir No. 5, shown on Pl. LXXVIII, is located on Willow Creek, about 2 miles above its junction with the Sun River. The dam site is in the NW. ¼ of Sec. 30, T. 21 N., R. 6 W. The foundations and abutments are of earth. Willow Creek is but a small stream, discharging but a few second feet, and is entirely inadequate to supply this reservoir. A canal line was therefore run from the top of reservoir No. 2, which will supply this reservoir and three smaller ones lying above it from the flood waters of Sun River.

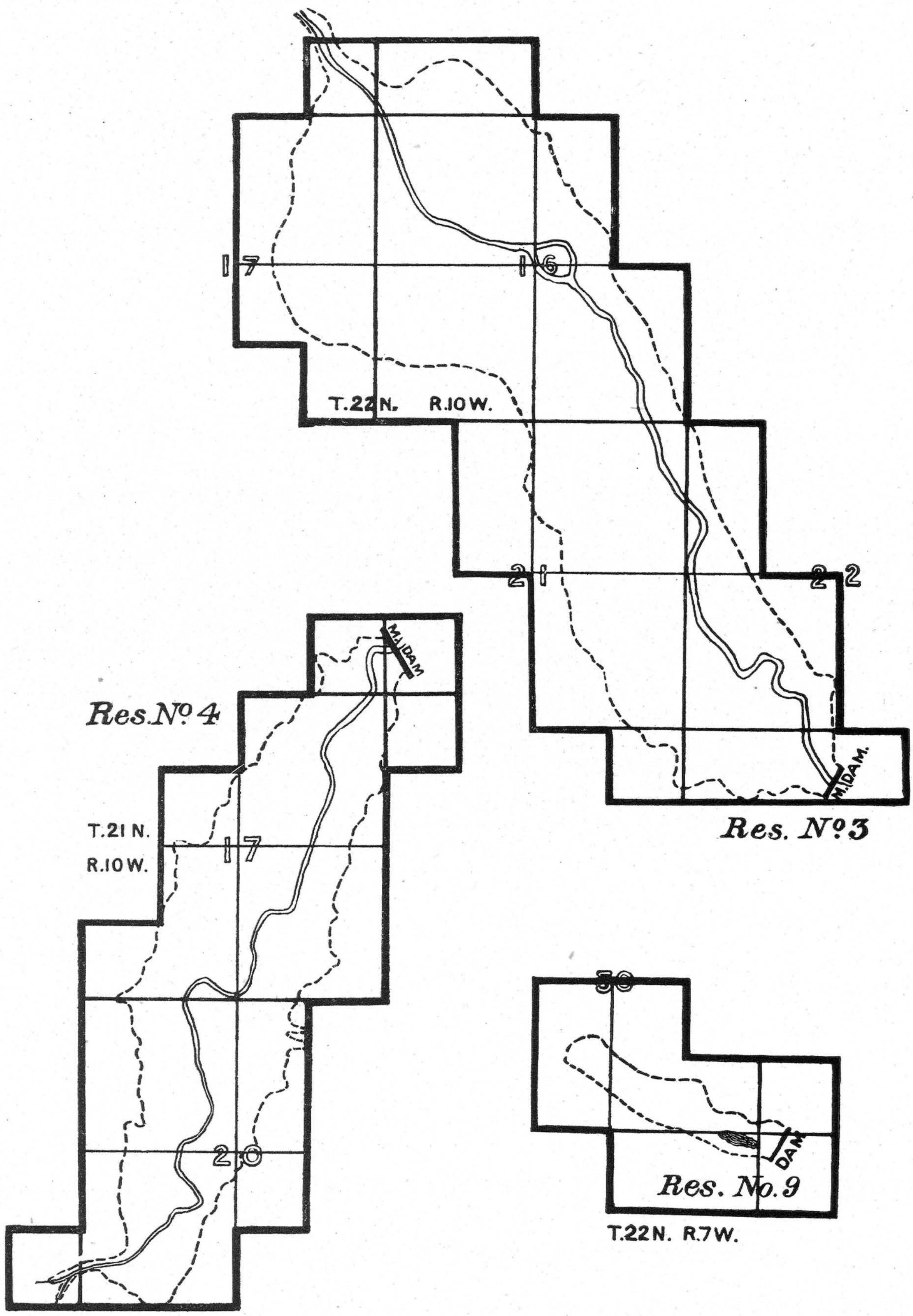
Reservoir No. 6, shown on Pl. LXXVIII, is located on Willow Creek, about 6 miles above reservoir No. 5, and is 340 feet higher. The foundations and abutments are of earth. The dam site lies in the S. ½ of Sec. 12, T. 20 N., R. 8 W.

Reservoir No. 7, shown on Pl. LXXVIII, will be formed by damming a narrow valley just below two small alkali lakes. It is located upon a natural water course about 1½ miles from Willow Creek and 2 miles west of reservoir No. 5, which lies 100 feet below it. It will be supplied by the canal taken from the top of No. 2 and will drain into No. 5. The dam, which will be constructed of earth, is located in the E. ½ of Sec. 21, T. 21 N., R. 7 W.

Reservoir No. 8, shown on Pl. LXXVIII, is situated a mile north of reservoir No. 7, and will be supplied from the same canal. It lies 110 feet higher than No. 7, and will drain into it through a natural water course. The dam is located in the NE. ¼ of Sec. 17, T. 21 N., R. 7 W. The foundation and abutments are of earth. There is a small alkali lake in this basin, flooding an area of 18 acres.

Reservoir No. 9, Pl. LXXVII, is a small basin lying below canal No. 2, from which it will be supplied. Although com-

MONTANA
RESERVOIR SITES SEGREGATED
H·M·WILSON Engineer.



paratively small, it will have a sufficient capacity to irrigate all the good agricultural land lying below it. The dam is located in the extreme NW. corner of Sec. 32, T. 22 N., R. 7 W. The foundation and abutments are of earth. The reservoir extends northwesterly through the S. ½ of Sec. 30 to the township line.

Reservoir No. 10, or Benton Lake Reservoir, shown on Pl. LXXIX, is the only reservoir the survey of which was based upon sea-level data. By running a level line from a railroad benchmark at Great Falls, Montana, the altitude of the surface of the lake was found to be 3,610.7 feet. This reservoir was surveyed by two meander lines around the lake, one following the shore line and the other tracing out the 3,632-foot contour, which was the assumed flood line. Gradienter slopes were read from these two lines at every station and the intermediate contours determined and interpolated in the office. Benton Lake is situated in the NE. portion of T. 22 N., R. 3 E. It is about 1½ miles in width. The lake is supplied by a very small intermittent stream, known as Lake Creek, which drains the catchment area of this basin, but has no natural outlet. It was the intention in making the survey, in connection with the Sun River project, to supply this reservoir from the Sun River by a long canal line. This idea, however, was afterwards abandoned, and the canal line was dropped when within 15 miles of the lake, as it was found that the canal commanded more agricultural land than it could serve, and superior in quality to that lying below the lake.

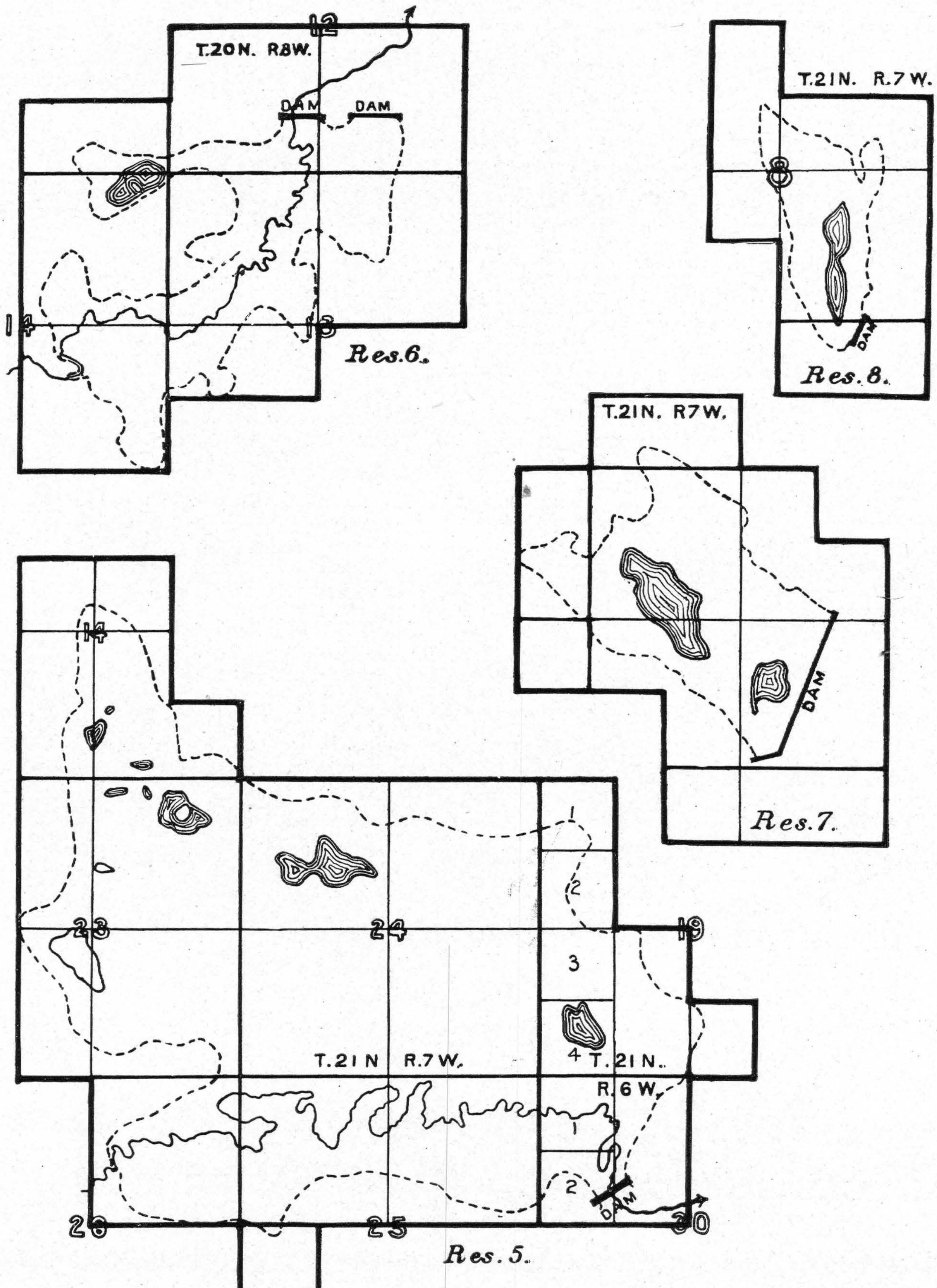
CANAL LINES.

As shown on Pl. LXXV, three canal lines were surveyed in connection with the Sun River Project. Canal No. 1, the longest of the three, is taken from the north side of the Sun River, in the NW. ¼ of Sec. 28, T. 22 N., R. 7 W., about a mile below reservoir No. 1. The river at this point is 160 feet wide and 4 feet deep, with gravel banks and small bowlder bottom, and will require a weir 10 feet high for diverting the water into the canal head. The first 41 miles of the canal can properly be considered a diversion line, as for that distance it is located along a slope varying in steepness from 1 to 4 in 10. There are, however, some good bottom lands lying below this line along the river that could be irrigated by this canal at the end of the forty-first mile, in Sec. 11, T. 21 N., R. 4 W., where the summit of the bench is reached, and from this point to the crossing of the Big Muddy Creek it traverses excellent agricultural land sloping eastward with an average fall of 13 feet per mile. This canal was given a grade of 2 feet per mile, except on the bench lands, when the grade was adapted to these lop of the country and given frequent drops of from 10 to 30 feet. This line was carried to the crossing of Big Muddy Creek in Secs. 11 and 12, T. 22 N., R. 1 W., a total distance of 66 miles, all of which will be earth excavations.

Canal No. 2 is taken from the top of reservoir No. 2, and will have its headworks in the waste weir of that reservoir. It is designed to carry the flood waters from reservoir No. 2 to supply reservoirs Nos. 5, 7, 8, and 9. The canal line is 13 miles in length and has a fall of 2½ feet per mile. With the exception of a few hundred feet it will be earth excavation. Reservoir No. 9 lies parallel to and 64 feet below mile 10 of this canal line, and is but a few hundred feet distant. This reservoir would be filled by a small lateral having a capacity of 20 second feet, which is sufficient to fill it in 21 days, the time required to fill Nos. 5, 7, and 8. Canal No. 2 empties into the north end of reservoir No. 8 in the NE. ¼ of Sec. 8, T. 21 N., R. 7 W., and from there the water will be carried in a natural water course through reservoir No. 7 to Willow Creek, thence to reservoir No. 5.

Canal No. 3 is taken from the bottom of reservoir No. 5 at the dam site, and will serve between 4,000 and 5,000 acres of good agricultural land lying below it and between the North and South Forks of the Sun River. The line surveyed was 11¼ miles long and was ended a half mile east of the town of Augusta. This distance can be shortened by carrying it across a 700-foot gap on a trestle 18 feet high. The first 3 miles of this canal will be considered as a diversion line and will be rather expensive work. The remainder will be comparatively easy, consisting only of earth excavation. It is the intention to carry this canal line across the South Fork and down the south side of Sun River to cover a large area of good land lying on that

MONTANA
RESERVOIR SITES SEGREGATED
H·M·WILSON Engineer.



side of the river. It was thought unnecessary to continue this survey, as the fact that such a canal is feasible has been demonstrated by the Florence Canal Company, which has constructed works in that locality.

Estimates have been made as to the cost of the canal line and reservoirs and their capacity under varying conditions, sufficient data being accumulated to demonstrate that the water of the Sun River project, as above utilized, will reclaim in all 96,200 acres above Benton Lake, 100,000 acres below that lake, 1,000 acres below reservoir No. 9, 5,000 acres near Augusta, and 32,800 acres below Fort Shaw, or a total of 235,600 acres of land.

On the following pages are given descriptions, by township, range, and section, of the sites of the above mentioned reservoirs.

Sun River reservoir system, Montana.

RESERVOIR SITE NO. 1.

T. 22 N., R. 7 W., Montana principal meridian.

		Acres.	Acres.
Section 19..	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
	E. ½ of the NW. ¼	80	
	SW. ¼ of the NW. ¼	44·20	
	N. ½ of the SW. ¼	84·27	
	SW. ¼ of the SW. ¼	45·14	
			533·61
Section 20..	SW. ¼ of the NW. ¼	40	
	W. ½ of the SW. ¼	80	
			120
Section 29	NW. ¼ of the NW. ¼		40
Section 30	NE. ¼ of the NE. ¼		40

T. 22 N., R. 8 W., Montana principal meridian.

		Acres.	Acres.
Section 24..	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120
Section 25..	NW. ¼ of the NE. ¼	40	
	E. ½ of the NW. ¼	80	
	SW. ¼ of the NW. ¼	40	
			160
Total area segregated			1,013·61

RESERVOIR SITE NO. 2.

T. 22 N., R. 8 W., Montana principal meridian.

		Acres.	Acres.
Section 28	S. ½ of the SW. ¼		80
Section 29	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	120
Section 31	E. ½ of the NE. ¼	80	
	SW. ¼ of the NE. ¼	40	
	E. ½ of the SE. ¼	80	
	NW. ¼ of the SE. ¼	40	
	SE. ¼ of the NW. ¼	40	
	All of the SW. ¼	160	440
Section 32	All of the NE. ¼	160	
	All of the NW. ¼	160	
	NW. ¼ of the SW. ¼	40	360
Section 33	All of the NW. ¼		160

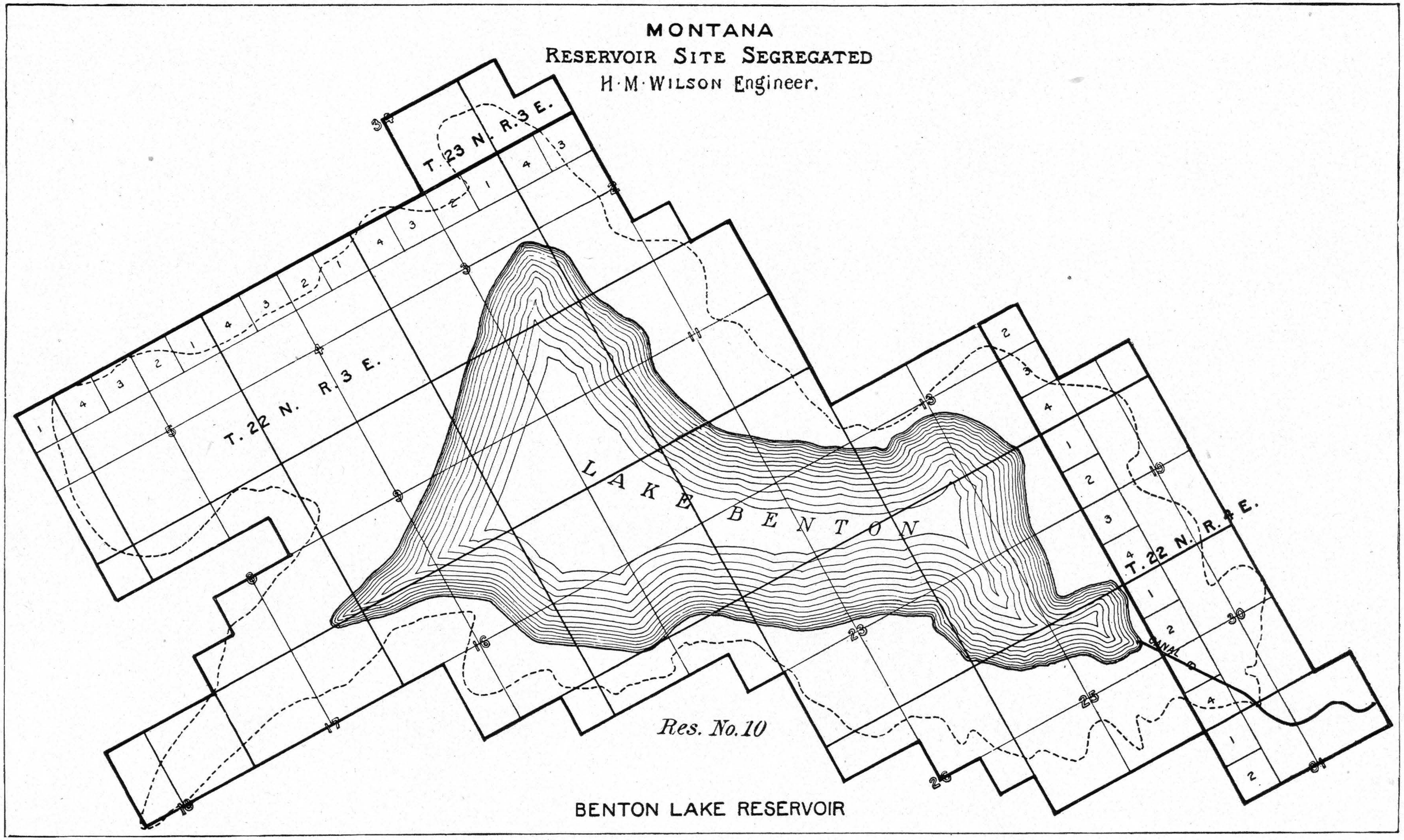
T. 22 N., R. 9 W., Montana principal meridian.

Section 36	E. ½ of the SE. ¼	80
Total area segregated		1, 240

RESERVOIR SITE NO. 3.

T. 22 N., R. 10 W., Montana principal meridian.

		Acres.	Acres.
Section 8	SE. ¼ of the SE. ¼		40
Section 9	S. ½ of the SW. ¼		80
Section 16	All of the NW. ¼	160	
	W. ½ of the NE. ¼	80	
	All of the SW. ¼	160	
	All of the SE. ¼	160	560
Section 17	All of the NE. ¼	160	
	E. ½ of the SE ¼	80	
	NW. ¼ of the SE. ¼	40	280
Section 21	All of the NE. ¼	160	
	All of the SE. ¼	160	
	E. ½ of the NW. ¼	80	400
Section 22	W. ½ of the NW. ¼	80	
	All of the SW. ¼	160	240



BENTON LAKE RESERVOIR

		Acres.	Acres.
Section 27	NW. ¼ of the NE. ¼	40	
	N. ½ of the NW. ¼	80	
			120
Section 28	NE. ¼ of the NE. ¼		40
Total area segregated			1, 760

RESERVOIR SITE NO. 4.

T. 21 N., R. 10 W., Montana principal meridian.

		Acres.	Acres.
Section 8	SE. ¼ of the SE. ¼		40
Section 9	SW. ¼ of the SW. ¼		40
Section 16	NW. ¼ of the NW. ¼		40
Section 17	All of the NE. ¼	160	
	All of the SE. ¼	160	
	SE. ¼ of the NW. ¼	40	
	E. ½ of the SW. ¼	80	
	SW. ¼ of the SW. ¼	40	
			480
Section 19	SE. ¼ of the SE. ¼		40
Section 20	W. ½ of the NE. ¼	80	
	NW. ¼ of the SE. ¼	40	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			440
Total area segregated			1,080

RESERVOIR SITE NO. 5.

T. 21 N., R. 7 W., Montana principal meridian.

		Acres.	Acres.
Section 14	E. ½ of the SW. ¼	80	
	SE. ¼ of the NW. ¼	40	
	SW. ¼ of the NE. ¼	40	
	W. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
			280
Section 23	E. ½ of the SW. ¼	80	
	E. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
			480
Section 24	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			640

		Acres.	Acres.
Section 25	All of the NE. ¼	160	
	All of the NW. ¼	160	
	NW. ¼ of the SW. ¼	40	
			360
Section 26	All of the NE. ¼		160

T. 21 N., R. 6 W.

Section 19	All of the SW. ¼	160	
	W. ½ of the NW. ¼	80	
	SW. ¼ of the SE. ¼	40	
			280
Section 30	All of the NW. ¼		160
	Total area segregated		2,360

RESERVOIR SITE No. 6.

T. 20 N., R. 8 W., Montana principal meridian.

		Acres.	Acres.
Section 11	S. ½ of the SE. ¼		80
Section 12	All of the SW. ¼	160	
	All of the SE. ¼	160	
			320
Section 13	All of the NE. ¼	160	
	All of the NW. ¼	160	
	N. ½ of the SW. ¼	80	
			400
Section 14	All of the NE. ¼	160	
	All of the SE. ¼	160	
			320
	Total area segregated		1, 120

RESERVOIR SITE No. 7.

T. 21 N., R. 7 W., Montana principal meridian.

		Acres.	Acres.
Section 16	S. ½ of the SW. ¼		80
Section 20	E. ½ of the NE. ¼	80	
	NE. ¼ of the SE. ¼	40	
			120
Section 21	All of the NW. ¼	160	
	S. ½ of the NE. ¼	80	
	NW. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
	N. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			560

		Acres.	Acres.
Section 28	N. ½ of the NE. ¼	80	
	NE. ¼ of the NW. ¼	40	
			120
Total area segregated			880

RESERVOIR SITE NO. 8.

T. 21 N., R. 7 W., Montana principal meridian.

		Acres.	Acres.
Section 8	E. ½ of the NW. ¼	80	
	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	NE. ¼ of the SW. ¼	40	
			360
Section 17	N. ½ of the NE. ¼		80
Total area segregated			440

RESERVOIR SITE NO. 9.

T. 22 N., R. 7 W., Montana principal meridian.

		Acres.	Acres.
Section 29	SW. ¼ of the SW. ¼		40
Section 30	W. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
	E. ½ of the SW. ¼	80	
			200
Section 31	N. ½ of the NE. ¼		80
Section 32	NW. ¼ of the NW. ¼		40
Total area segregated			360

BENTON LAKE.—RESERVOIR SITE NO. 10.

T. 22 N., R. 3 E., Montana principal meridian.

		Acres.	Acres.
Section 2	All of the NW. ¼	160	
	All of the SW. ¼	160	
	SW. ¼ of the SE. ¼	40	
			360
Section 3	Entire section		640
Section 4	Entire section		640
Section 5	Entire section		640
Section 6	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
			160

		Acres.	Acres.
Section 7	NE. ¼ of the NE. ¼		40
Section 8	N. ½ of the NW. ¼	80	
	N. ½ of the NE. ¼	80	
	SE. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
	SW. ¼ of the SW. ¼	40	
			480
Section 9	Entire section		640
Section 10	Entire section		640
Section 11	Entire section		640
Section 13	S. ½ of the NW. ¼	80	
	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	All of the SW. ¼	160	
			480
Section 14	Entire section		640
Section 15	Entire section		640
Section 16	All of the NE. ¼	160	
	All of the NW. ¼	160	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
			560
Section 17	All of the NE. ¼	160	
	All of the NW. ¼	160	
			320
Section 18	All of the NE. ¼	160	
	E. ½ of the NW. ¼	80	
			240
Section 21	NE. ¼ of the NE. ¼		40
Section 22	N. ½ of the NW. ¼	80	
	N. ½ of the NE. ¼	80	
	SE. ¼ of the NE. ¼	40	
			200
Section 23	Entire section		640
Section 24	Entire section		640
Section 25	Entire section		640
Section 26	All of the NE. ¼	160	
	N. ½ of the NW. ¼	80	
	NE. ¼ of the SE. ¼	40	
			280

T. 22 N., R. 4 E.

Section 18	W. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
	SW. ¼ of the NW. ¼	40	
	SW. ¼ of the SE. ¼	40	
			200

		Acres.	Acres.
Section 19..	All of the NW. ¼	153·16	
	All of the SW. ¼	154·72	
	W. ½ of the NE. ¼	80	
	W. ½ of the SE. ¼	80	
			467·88
Section 30..	All of the NW. ¼	155·54	
	All of the SW. ¼	157·08	
	W. ½ of the NE. ¼	80	
	W. ½ of the SE. ¼	80	
			472·62
Section 31..	All of the NW. ¼	156·39	
	All of the NE. ¼	160	
			316·39

T. 23 N., R. 3 E.

Section 35..	W. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			120
Section 34....	All of the SE. ¼		160
Total area segregated			11,936·89

ARKANSAS DIVISION.

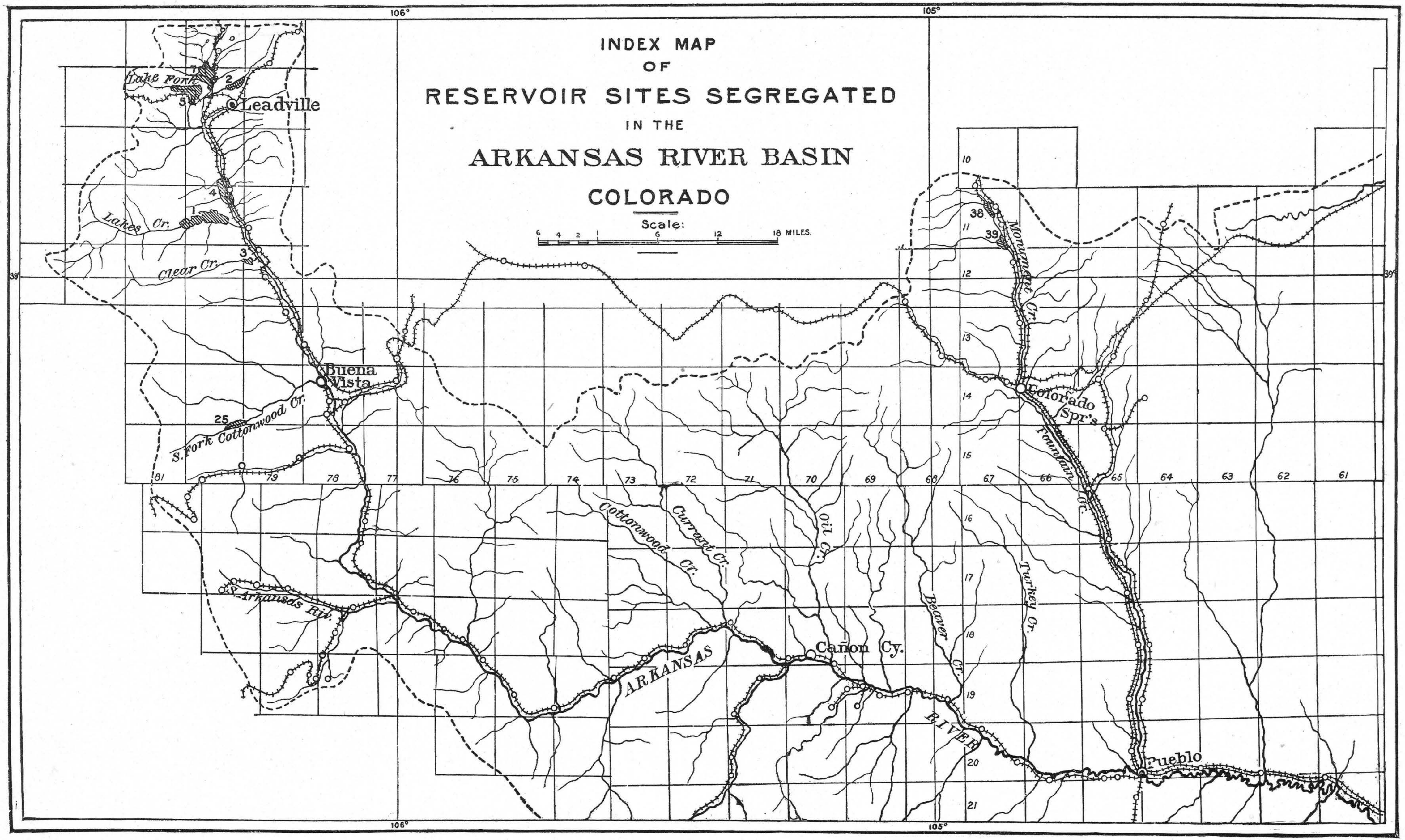
In June, 1889, Mr. Sumner H. Bodfish was assigned to the charge of this division, and after consultation with Mr. E. S. Nettleton, supervising engineer, a field party was organized under Mr. E. T. Vincent, assistant engineer, who made preliminary surveys, by means of the plane-table, transit, and level, of eight reservoir sites at the headwaters of the Arkansas, whose general locations are shown on Pl. LXXX. These were named either from the tributaries upon which they are located or from the nearest railway station or local topographic feature, and are as follows: Twin Lake, shown on Pl. LXXXI; Leadville, Clear Creek (2), and Hayden, on Pl. LXXXII; Sugar Loaf and Tennessee Fork, on Pl. LXXXIII; and Cottonwood, on Pl. LXXXIV.

Three very small sites were also examined with instruments by this party, one at Crane's Park on the Tennessee Fork, another on Lake Fork, and one on East Fork; but these have not been dignified with the names of reservoir sites because of their small capacity. The Hayden, Sugar Loaf, Twin Lake, Leadville, and Tennessee Fork sites are desirable, but the first four can with economy be replaced by the Twin Lake site, as will be explained elsewhere. The Cottonwood Lake is a small site and not a very economical one. The description in Land Office terms of these sites is given at the end of this section.

Early in August of the same year a second party was organized, under the charge of Mr. William Rist, for the purpose of surveying a preliminary or discovery line for a canal to be diverted from the Arkansas River at a point about 10 miles west of the Kansas and Colorado boundary. This line was run eastward to ascertain the possibility of irrigating the land north and northeast of Syracuse, Kansas. The land in this locality is of excellent quality, and the topography is such that it is well adapted to irrigation. From this survey information has been compiled which will in the future enable a very approximate estimate to be made of the cost of construction whenever the amount of water available has been determined.

Later in the season this party moved overland to Monument, Colorado, and began the survey of certain localities upon Monument Creek. The manner of survey was similar to that employed at the headwaters of the Arkansas. Reservoirs of doubtful value were surveyed, the best, however, that could be found on Monument Creek. Of these, two sites, known respectively as Monument and Pring, have been segregated, covering the areas shown on Pl. LXXXIV.

In the latter part of September Mr. W. W. Follet, division engineer, reported to Mr. Bodfish for the remainder of the season, and was assigned to the duty of making reconnaissance for the discovery of reservoir sites. He explored and found reservoirs on Oil or Four Mile Creek, and on the Wilson, Slate, West Oil, Six Mile, Eight Mile, Beaver, Middle Beaver, Seven Lakes, Oak, Big Turkey, Cottonwood, and Badger Creeks. He also explored the streams tributary to the Arkansas between Pueblo, Salida, and Texas Creek, and reported upon eighteen reservoir sites, giving for each the dimensions of dam required, the general character of abutments and foundation, capacity in acre feet, and the location by township, range, and section, together with remarks as to the limitations of the proposed reservoirs.


INDEX MAP
OF
RESERVOIR SITES SEGREGATED
IN THE
ARKANSAS RIVER BASIN
COLORADO
Scale:
18 MILES.
106°
105°
39°
Leadville
Lake Fork
Lakes Cr.
Clear Cr.
Buena Vista
S. Fork Cottonwood Cr.
S. Arkansas Riv.
ARKANSAS
RIVER
Cañon Cy.
Pueblo
Colorado Spr's
Monument Cr.
Fountain Cr.
Cottonwood Cr.
Currant Cr.
Oil Cr.
Beaver Cr.
Turkey Cr.
81
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
10
11
12
13
14
15
16
17
18
19
20
21
38
39
25

He thus obtained information which will be of much value in the subsequent survey of these localities.

In the case of the Twin Lake reservoir site, which can be made a substitute for four others, more careful detail surveys were made, and during the winter computations were attempted, using assumptions of discharge as far as the information at hand would justify. Owing, however, to the almost total absence of exact knowledge as to the flow of water at the reservoir sites, it was deemed unwise to attempt complete estimates until the hydrographic work should be brought nearer to completion.

TWIN LAKE RESERVOIR.

Lake Creek rises in the Sawatch Mountains a little to the northwest of Mount Elbert, in latitude 39° 10′ north, longitude 106° 32′ west, and flows south and southeasterly for about 10 miles, then eastward about 12 miles, and empties into the Arkansas River.

This creek drains 102 square miles of high mountain country, varying in altitude from 9,010 to 14,350 feet above sea level. This drainage basin has very precipitous sides, Mount Massive and Mount Elbert on the north of the basin attaining altitudes of 14,200 and 14,350 feet respectively; Grizzly Peak on the west being 13,956 feet in elevation and La Plata Mountain on the south side being 14,311 feet in altitude.

The glacier which once occupied the canyon now traversed by Lake Creek brought down from the mountain sides a great amount of débris, building for the last 4 miles of its course high lateral moraines upon either side and two terminal moraines across the valley, the lower about 1½ miles from the Arkansas River and the other 2½ miles from the lower, making two natural dams to the present creek and thereby forming two beautiful sheets of water called "Twin Lakes."

These lakes are situated in Lake County, Colorado, in T. 11 S., R. 80 W. of the sixth principal meridian, the upper lake occupying parts of secs. 17, 18, 19, 20, and the lower lake parts of secs. 15, 16, 17, 20, 21, and 22.

The surface of the lower and larger lake had an altitude on July 9, 1889, of 9,194 feet, the upper lake 9,200 feet; and from all information available in the vicinity it is not likely that their surfaces vary more than 2 feet in altitude during the year. A datum plane at mean sea level was assumed, and with the aid of the plane table and level a contour map at a scale of 500 feet to the inch was made of the lakes and adjacent country, showing 10-foot contours as high as 9,240 feet above datum, and 2-foot contours on and about the natural dam at the outlet of the lower lake. Eighty-six soundings were made of the lower and 44 of the upper lake, from which have been constructed extremely generalized contours of the lake bottoms with vertical intervals of 10 feet.

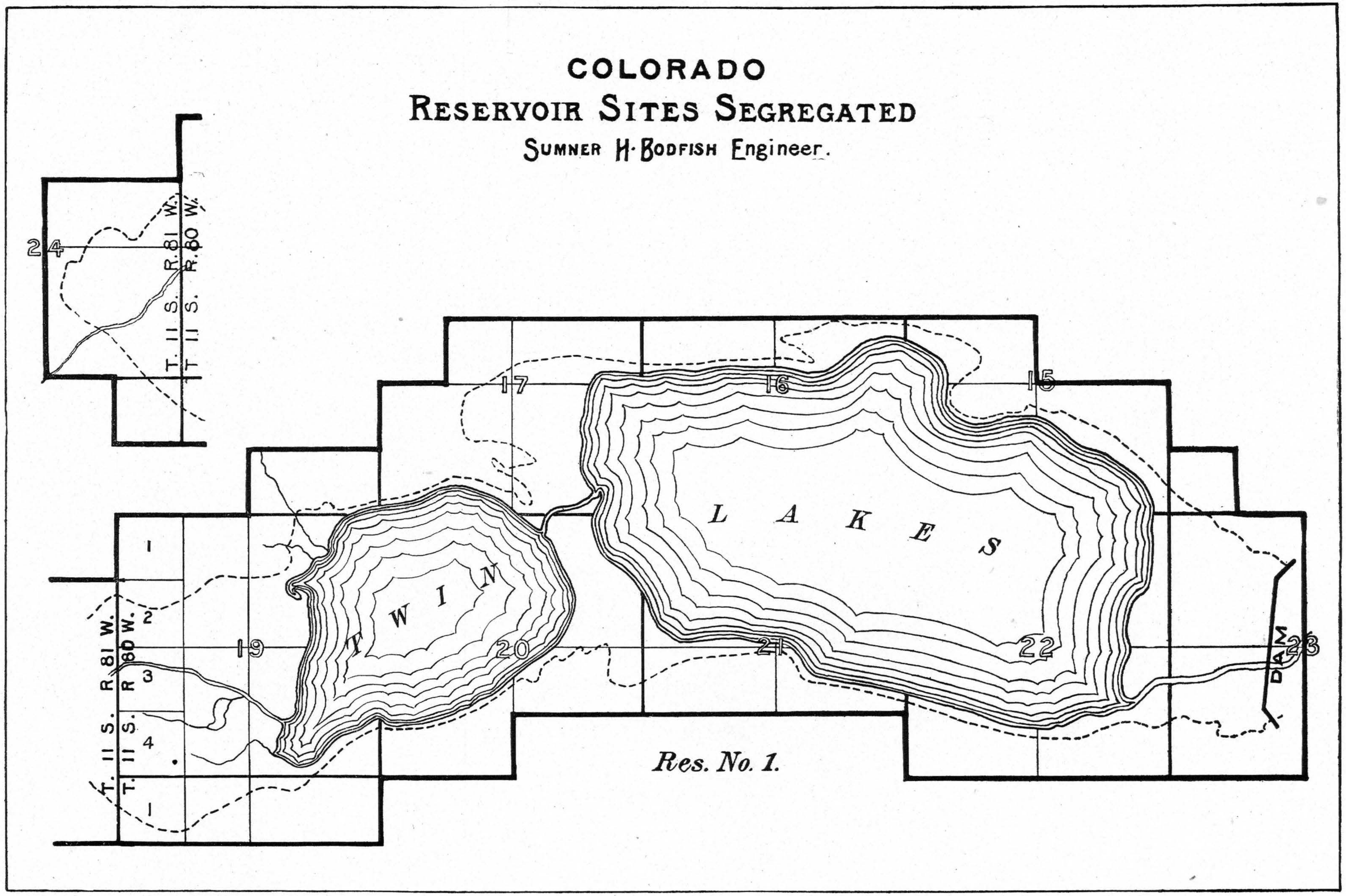
At the time this survey was made it was intended to store in these lakes only the water of Lake Creek at this point, and subsequent surveys were made of reservoir sites on Lake Fork, Tennessee, and East Forks of the Arkansas River, and on the river itself about 3 miles from Twin Lakes, with a view of storing the water of each stream within the area of its own basin.

Since the field season closed and after making a careful study of the subject, the conclusion has been reached that the water of the Arkansas River can be conducted from a point near Hayden Station, on the Denver and Rio Grande Railroad, by a canal to the lower Twin Lake, and stored there, thus obviating the necessity of constructing reservoirs on the Arkansas River and its tributaries.

The catchment area commanded by this canal comprises 285 square miles, which, added to that of Lake Creek, makes a total catch basin of 387 square miles, the water of which is available for storage in the Twin Lake reservoir.

No rainfall data exist at this time for this locality. The nearest station at which such observations have been recorded is Leadville, about 15 miles distant directly north, and at an altitude of 10,000 feet. These observations for the year from June, 1888, to May, 1889, inclusive, which was one of minimum precipitation, give a rainfall of only 10·93 inches.

The rim of the Twin Lake basin has an altitude varying from 10,500 to 14,000 feet, and as timber line is about 11,000 feet above sea level in this vicinity, this rim will average about


COLORADO
RESERVOIR SITES SEGREGATED
SUMNER H. BODFISH Engineer.
24
T. 11 S. R. 81 W.
T. 11 S. R. 80 W.
17
16
15
TWIN
LAKES
1
2
3
4
1
19
20
21
22
23
DAM
Res. No. 1.

2,000 feet above timber line. The precipitation on this ridge is principally in the form of snow, and is driven by the wind into immense drifts and piled to a great depth in the ravines, so that the flow of water caused by the melting of this snow under a summer sun is more uniform than among the lower tributaries of the Arkansas River.

The mean annual run-off of water from this district can be accurately determined only after a series of measurements extending over a period of several years. For the reason that the precipitation is much greater on the mountains than at Leadville, where the record was kept, and for want of controlling data, the arbitrary assumption has been made that the run-off of this basin will be equal to a depth of 10 inches over the entire area. This gives a total run-off of 206,400 acre-feet of water in one year, or water sufficient to cover 206,400 acres one foot in depth.

To store this water the crest of the dam has been assumed at 9,240 feet above datum, and the flood plane 9,232 feet. The elevation of the bottom of the lake at its outlet is 9,190 feet, and the content of the reservoir between the contour planes of 9,190 and 9,232 is 103,500 acre-feet. The assumption is also made that the reservoir will be emptied twice a year. If the dam at this height proves insufficient to hold the run-off from this drainage basin, the expenditure of a few hundred dollars will open a ditch between the two lakes and from the dam to the lower lake bed, so that the old lakes can be drawn to the level of the plane of 9,180. This would increase the capacity of the reservoir to 121,800 acre-feet. The estimate has been made in this way so as to obtain the maximum amount of probable future construction. The outlet should not be taken lower than 9,180, because it would necessitate considerable expense in excavating to draw off the existing lakes and also to get rid of the water below the dam.

The principal advantages to be gained by storing all of the water of these basins at Twin Lakes, rather than at two or more sites in other localities in the same basin, are many. These lakes are the property of the United States, and they furnish an extensive level plane upon which to store the water, and a comparatively small expenditure will be incurred in purchasing land to be flooded, for the flood plane of 9,232 does not cover much of the adjacent land.

The height of the dam in its highest part is no greater than would be required at other localities, except at the Hayden site, in which case the dam would necessarily be 120 feet high to impound 62,000 acre-feet of water. The length of the dam is greater than at the other sites, but for three-fourths of its length it has a height above the natural surface of less than 20 feet, and for over 300 feet of its length it has no inside slope. For 200 feet only does the embankment require building to the full height of the dam.

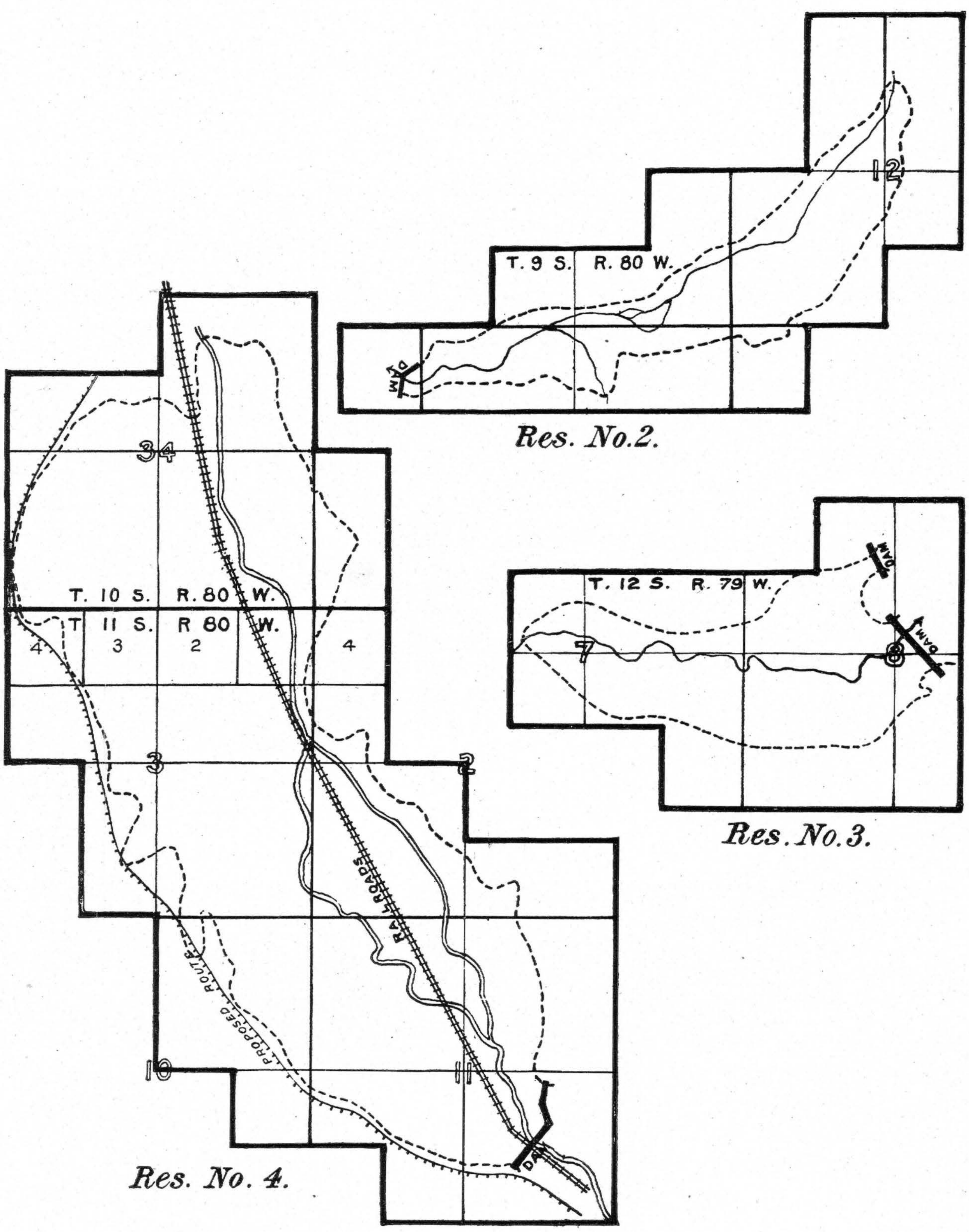
The material available for the construction of the embankment is of excellent quality, being a gravelly soil, grading from coarse gravel to sand and sandy loam. For masonry construction there is an abundance of large granite bowlders in the immediate vicinity; there is also a good quality of growing timber for temporary works; and for the transportation there are facilities both by rail and wagon road.

After mapping the reservoir and dam site, careful plans for the dam and all necessary accessories were made, together with estimates of the material required and of the water which would be impounded. This dam consists of an embankment 3,640 feet long, with a top width of 28 feet, inside slope of 1 on 3, and outside slope of 1 on 1½, with bermes 5 feet wide at intervals of 20 feet vertically.

Appreciating fully the necessity of good overflow facilities for a storage reservoir, and having in mind the many disasters that have followed the neglect to provide such facilities in the past, Mr. Bodfish does not see any great necessity for a large waste-weir at this dam, for the following reasons: The spring freshet begins to rise about May 1 and attains its maximum flow about May 30; then it falls rapidly to near the stage existing prior to the rise. In consequence of this, such water as has accumulated during the late fall and winter months should be discharged prior to May 1, thereby providing storage room for the spring freshet.

Should the water at any time reach the danger line, the head

COLORADO
RESERVOIR SITES SEGREGATED
SUMNER H. BODFISH Engineer.



gates of the feeding canal can be closed, thus turning away from the reservoir the water from the drainage area of the Arkansas River, the source of three-fourths of its supply. If the water still continues to rise, the outlet gates could be brought into use, and these, when in good order, should be capable of discharging the entire contents of the reservoir in 40 days.

When the large surface of the full reservoir, 3,475 acres, is taken into consideration, the above seems sufficient to prove that a waste-weir constructed to satisfy the conditions of twice the freshet flow of Lake Creek would be ample to protect the dam from injury by overflow.

The problem of discharging the water of this reservoir was also considered in detail, since the withdrawal of 121,800 acre-feet of water in 40 days, the period determined upon as necessary, requires construction of the strongest character. The absence of solid bedrock in the vicinity of the dam makes it necessary that the water shall be conducted through the embankment or through the solid ground near by. Mr. Bodfish favors placing the conduit in the embankment at the place where it can be done in the most economical manner. A masonry conduit, with wing walls, a gate tower, and apparatus, has been planned and estimates of quantities prepared.

The engineering work and preliminary calculations have been brought as near completion as the hydrographic data would permit, the only obstacle to an intelligent estimate of total quantities being the absence of information relating to the fluctuations and the mean annual discharge of the streams which should supply the water.

The descriptions of the reservoir site of this basin are given by township, range, and section in the following pages:

Arkansas River reservoir system, Colorado.

TWIN LAKES.—RESERVOIR NO. 1.

T. 11 S., R. 80 W., sixth principal meridian.

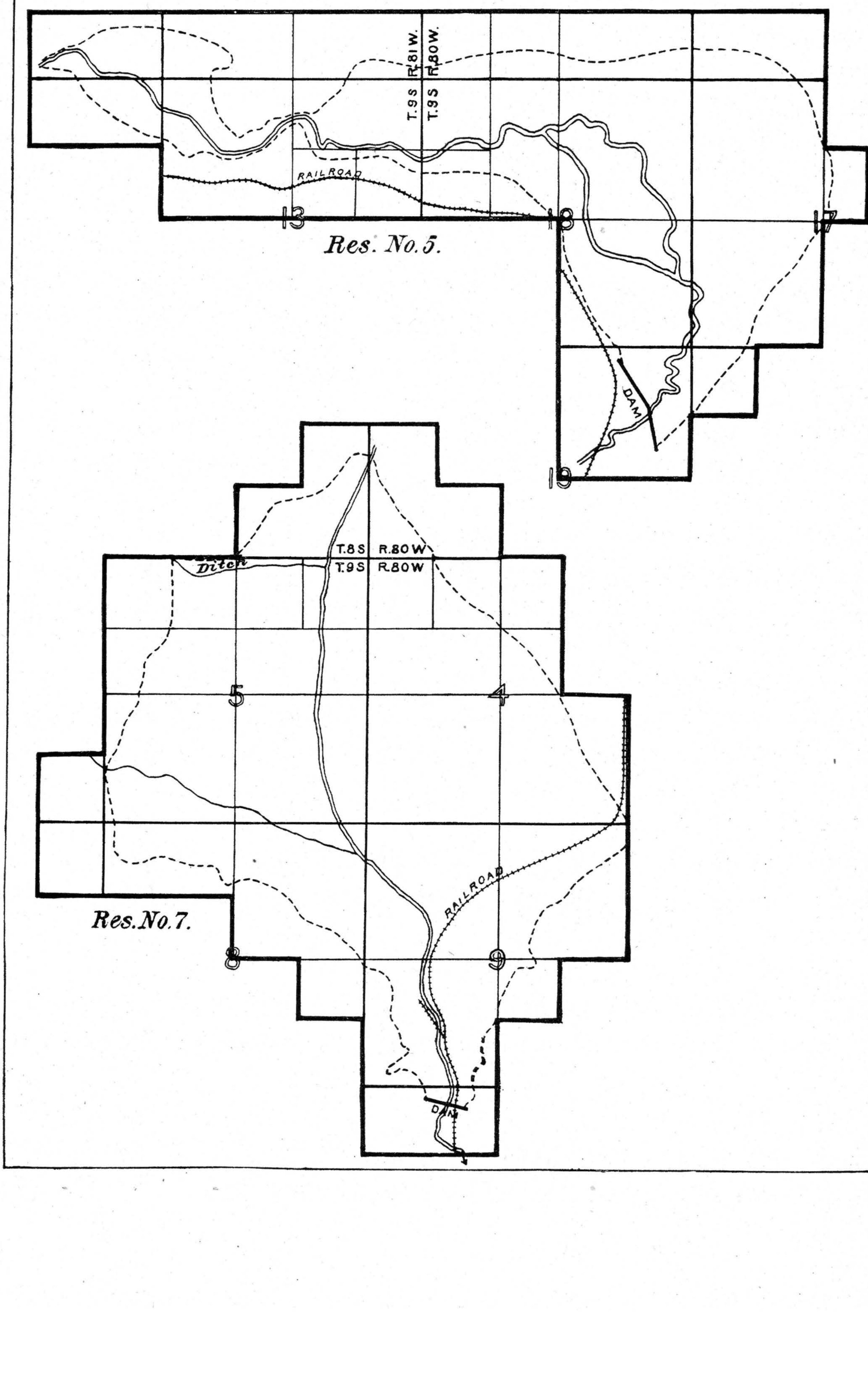
		Acres.	Acres.
Section 14	SW. ¼ of the SW. ¼		40
Section 15	All of the SE. ¼	160	
	S. ½ of the NW. ¼	80	
	All of the SW. ¼	160	
			400

		Acres.	Acres.
Section 16..	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	S. ½ of the NW. ¼	80	
	All of the SW. ¼	160	
			480
Section 17..	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	SE. ¼ of the NW. ¼	40	
	All of the SW. ¼	160	
			440
Section 18....	S. ½ of the SE. ¼		80
Section 19..	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the NW. ¼	157·71	
	All of the SW. ¼	158·31	
			636·02
Section 20..	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			560
Section 21..	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	All of the NW. ¼	160	
	N. ½ of the SW. ¼	80	
			480
Section 22..	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			640
Section 23..	All of the NW. ¼	160	
	All of the SW. ¼	160	
			320
Section 30..	N. ½ of the NE. ¼	80	
	All of the NW. ¼	160	
			240

T. 11 S., R. 81 W., sixth principal meridian.

Section 24..	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
			240
Section 25....	All of the NE. ¼		160
Total area segregated			4,716·02

COLORADO
RESERVOIR SITES SEGREGATED
SUMNER H. BODFISH Engineer.



Res. No. 5.

Res. No. 7.

LEADVILLE RESERVOIR SITE, NO. 2.

T. 9 S., R. 80 W., sixth principal meridian.

		Acres.	Acres.
Section 11	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
	SE. ¼ of the SW. ¼	40	
			160
Section 12	W. ½ of the NE. ¼	80	
	NW. ¼ of the SE. ¼	40	
	E. ½ of the NW. ¼	80	
	All of the SW. ¼	160	
			360
Section 13	NW. ¼ of the NW. ¼		40
Section 14	N. ½ of the NE. ¼	80	
	N. ½ of the NW. ¼	80	
			160
Section 15	NE. ¼ of the NE. ¼		40
Total area segregated			760

CLEAR CREEK.—RESERVOIR SITE, NO. 3.

T. 12 S., R. 79 W., sixth principal meridian.

		Acres.	Acres.
Section 7	S. ½ of the NE. ¼	80	
	N. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
	SE. ¼ of the NW. ¼	40	
	NW. ¼ of the SW. ¼	40	
			280
Section 8	W. ½ of the NE. ¼	80	
	W. ½ of the SE. ¼	80	
	E. ½ of the NW. ¼	80	
	SW. ¼ of the NW. ¼	40	
	All of the SW. ¼	160	
			440
Total area segregated			720

HAYDEN RESERVOIR SITE, NO. 4.

T. 10 S., R. 80 W., sixth principal meridian.

		Acres.	Acres.
Section 34	All of the NE. ¼	160	
	All of the SE. ¼	160	
	S. ½ of the NW. ¼	80	
	All of the SW. ¼	160	
			560
Section 35	W. ½ of the SW. ¼		80

T. 11 S., R. 80 W., sixth principal meridian.

		Acres.	Acres.
Section 2	W. ½ of the NW. ¼	74·35	
	All of the SW. ¼	160	
	S. ½ of the SE. ¼	80	
			314·35
Section 3	All of the NE. ¼	148·95	
	All of the SE. ¼	160	
	All of the NW. ¼	149·15	
	E. ½ of the SW. ¼	80	
			538·10
Section 10	All of the NE. ¼	160	
	NE. ¼ of the SE. ¼	40	
			200
Section 11	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the NW. ¼	160	
	E. ½ of the SW. ¼	80	
	NW. ¼ of the SW. ¼	40	
			600
Total area segregated			2,292·45

Sugar Loaf Reservoir Site, No. 5.

T. 9 S., R. 80 W., sixth principal meridian.

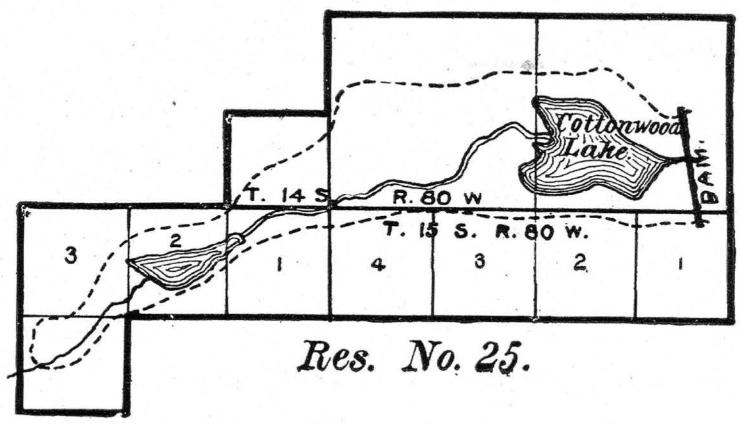
		Acres.	Acres.
Section 7	S. ½ of the SE. ¼	80	
	S. ½ of the SW. ¼	78·31	
			158·31
Section 8	S. ½ of the SW. ¼		80
Section 17	SW. ¼ of the NE. ¼	40	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			360
Section 18	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the NW. ¼	156·65	
			476·65
Section 19	All of the NE. ¼		160
Section 20	NW. ¼ of the NW. ¼		40

T. 9 S., R. 81 W., sixth principal meridian.

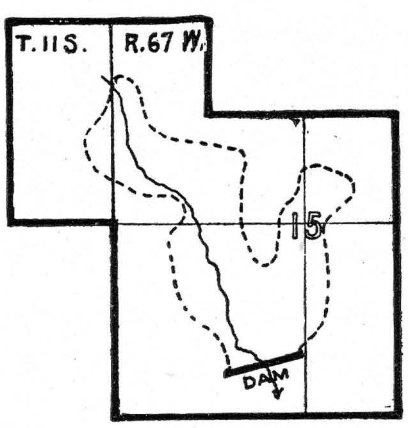
		Acres.	Acres.
Section 11	S. ½ of the SE. ¼		80
Section 12	S. ½ of the SE. ¼	80	
	S. ½ of the SW. ¼	80	
			160

COLORADO
RESERVOIR SITES SEGREGATED

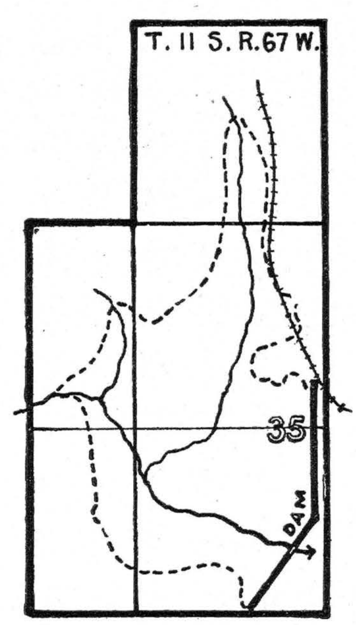
SUMNER H. BODFISH Engineer.



Res. No. 25.



Res. No. 38.



Res. No. 39.

		Acres.	Acres.
Section 13..	All of the NE. ¼	160	
	All of the NW. ¼	160	
			320
Section 14....	N. ½ of the NE. ¼		80
Total area segregated			1,914·96

TENNESSEE PARK RESERVOIR SITE, No. 7.

T. 8 S., R. 80 W., sixth principal meridian.

Section 32..	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120
Section 33..	W. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			120

T. 9 S., R. 80 W., sixth principal meridian.

Section 4...	W. ½ of the NE. ¼	79·57	
	All of the SE. ¼	160	
	All of the NW. ¼	159·05	
	All of the SW. ¼	160	
			558·62
Section 5...	All of the NE. ¼	158·72	
	All of the SE. ¼	160	
	All of the NW. ¼	158·60	
	All of the SW. ¼	160	
			637·32
Section 6.....	SE. ¼ of the SE. ¼		40
Section 7.....	NE. ¼ of the NE. ¼		40
Section 8...	All of the NE. ¼	160	
	NE. ¼ of the SE. ¼	40	
	N. ½ of the NW. ¼	80	
			280
Section 9..	All of the NE. ¼	160	
	NW. ¼ of the SE. ¼	40	
	All of the NW. ¼	160	
	All of the SW. ¼	160	
			520
Section 16....	N. ½ of the NW. ¼		80
Total area segregated			2,395·94

COTTONWOOD LAKE RESERVOIR SITE, NO. 25.

T. 14 S., R. 80 W., sixth principal meridian.

		Acres.	Acres.
Section 35	SE. ¼ of the SE. ¼		40
Section 36	All of the SE. ¼	160	
	All of the SW. ¼	160	
			320

T. 15 S., R. 80 W., sixth principal meridian.

		Acres.	Acres.
Section 1	N. ½ of the NE. ¼	80·52	
	N. ½ of the NW. ¼	81·52	
			162·04
Section 2	N. ½ of the NE. ¼	82·27	
	E. ½ of the NW. ¼	81·32	
			163·59
Total area segregated			685·63

MONUMENT CREEK RESERVOIR SITE, NO. 38.

T. 11 S., R. 67 W., sixth principal meridian.

		Acres.	Acres.
Section 15	SW. ¼ of the NE. ¼	40	
	W. ½ of the SE. ¼	80	
	S. ½ of the NW. ¼	80	
	NW. ¼ of the NW. ¼	40	
	All of the SW. ¼	160	
			400
Section 16	E. ½ of the NE. ¼		80
Total area segregated			480

PRING RESERVOIR SITE, NO. 39.

T. 11 S., R. 67 W., sixth principal meridian.

		Acres.	Acres.
Section 26	All of the SW. ¼		160
Section 34	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
			160
Section 35	All of the NW. ¼	160	
	All of the SW. ¼	160	
			320
Total area segregated			640

RIO GRANDE DIVISION.

The project of greatest interest in this division is that of the proposed reservoir above El Paso, Texas, named by Maj. Mills *Lake Constance.*

The general results of the engineering and hydrographic work at this point were stated in the first annual report, and details were given in the report of the Select Committee of the Senate, as well as in various official publications bearing upon the international features of the problem presented. It is therefore sufficient at this time to state briefly the conclusions.

A masonry dam at the pass 65 feet above the river bottom will create a lake 14½ miles long by 4 miles in maximum width, with a surface area of about 26,000 acres, an average depth of 23·6 feet, and a cubical content of 537,000 acre-feet. Of the two possible sites, which are 1¾ miles apart, the upper one was considered to be the more favorable. The estimated cost of a dam at this place is a little over $300,000, to which must be added the cost of removing the railroads, about $590,000, and the cost of the land overflowed, which is very nearly $69,000, making a total, including incidentals, of about $1,060,000. This cost, while large in itself, is small when taken in consideration with the probable returns, as at least 200,000 acre-feet of water per annum would be available.

Having completed the survey, maps, and calculations incident to this great project, Mr. Follett, the engineer of this division, was for a time transferred to the Arkansas division, but subsequently returned to make a reconnaissance of the headwaters of the Rio Grande for the purpose of discovering reservoir sites and obtaining other information regarding water storage and irrigable lands, preliminary to the surveys of the succeeding field season.

The principal localities examined were in and adjacent to the Mesilla, Albuquerque, Española, Taos, Puerco, San José, Chama, and Jemez Valleys in New Mexico and the San Luis in Colorado. Besides these, several great mesas containing many thousand acres of good land were traversed and the probabilities of supplying them with water carefully considered. Outside of these valleys and mesas there is a large percentage of the territory examined which is worthless for agricultural or pastoral purposes, hardly producing enough vegetation to support one sheep to 50 acres, the rainfall and snowfall being scanty over the whole of this area, except in the northern portion near the Colorado line.

The result of this examination brings out more strongly than ever before not only the great need of storing the flood waters of the Rio Grande, but also the many natural facilities which this basin possesses for this purpose.

For example, the following approximate estimate of the water needed will give some definite conception of the demand for water. In the San Luis Valley are five large canals with a combined carrying capacity of 8,000 second-feet. Probably none of them are now carrying over half their maximum flow, but even then 4,000 second-feet are being used in this valley. Of course, much of this water will find its way back into the river at or above the canyon, as irrigation is now conducted.

Between Embudo and San Marcial about 1,000 second-feet are used or needed. In the Mesilla Valley from Rincon to El Paso 900 second-feet are needed. The new El Paso ditch, which owns all the water rights of the old ditches below 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.

Thus there are needed below Embudo 3,100 second-feet to supply the demand. Of course, seepage will cause some water to be used two or three times over, but even then there will be a shortage of water except in years of maximum flow.

The country which suffers first, the Mesilla and Ysleta Valleys, is that the products of which are far more valuable per acre than those of the land on which the water has been used. With storage the Territory of New Mexico can support a much larger population in the Rio Grande Valley than at present; without it her progress will be slow.

It is to be noted that water is needed not only for land not yet under cultivation, but even for a large portion of the land which for years has been farmed, so that apparently New Mexico, or rather so much of it as depends upon the water of the Rio

Grande, can not grow or even hold its own until storage has been provided. That there are many natural advantages for this is shown by the fact that in New Mexico alone over fifty reservoir sites were discovered, besides ten in Colorado. For discussion the New Mexico sites are classified as A, B, C, D, and E. A tabulated statement of the capacity in acre feet of the reservoirs of these different classes is also given, with brief notes as to reason of assignment of all sites included in D and E.

The relative merits of these five classes are about as follows:

A.—Sites with abundant water supply, good dam site, good foundations, material handy for dam construction, and large storage capacity in proportion to size of the dam. These sites are all very valuable.

B.—Sites not quite so good in one or more respects as those classed A. Generally the storage capacity is not so great in proportion to the cost of the dam. These are all valuable sites.

C.—Sites where it is difficult to get foundations, or the water supply is somewhat doubtful, or storage capacity is small in proportion to the size of the dam.

D.—Sites where the water supply is doubtful, or where the dam is large and the foundation difficult, or where there is danger of the reservoir filling with sand.

E.—Small sites of little value, listed to show that they have been examined.

Of these different classes the number and storage capacity are as follows:

Class.	Sites.	Storage capacity.
		Acre-feet.
A	7	467,400
B	15	928,000
C	11	567,900
D	12	246,100
E	7	46,400
Total	52	2,209,400

Rejecting class E and two-thirds of D, it is safe to say that there has been found storage capacity for 2,000,000 acre-feet of water, and that there is in all probability a sufficient water supply available.

Mesas.—These reservoirs, if constructed, will add greatly to the agricultural area of the valleys along the Rio Grande and its tributaries, but on the mesas adjoining there appears to be little opportunity of reclaiming any considerable body of land on account of their elevation. They are briefly described as follows:

The high mesa west of Albuquerque, lying between the Rio Grande and the Puerco, is so high that it is above all possible water supply and is valueless, as but little grass grows on it.

East of Albuquerque there is a long mesa running from the Sandia Mountains on the north to Socorro on the south. It lies from 300 to 700 feet above the river. There is much fertile land on it, but it lies so high that water can only be gotten into it at enormous expense.

The Jornada del Muerto is the largest unbroken mesa in New Mexico, extending from Carthage to Las Cruces. The extreme length is about 120 miles and the extreme width 40 miles. It varies in elevation from 4,400 feet to 5,200 feet, possibly a little higher at the base of the San Andres Mountains. The soil at the southern end is a good loam, but the western portion of the plain west of the Santa Fé Railroad is somewhat broken and has a gravelly clay soil. In the central portion the soil is sandy, with much alkali and volcanic ash scattered over it. West of the Oscura Mountains is a large body of perfectly flat land with a fine alluvial soil.

A grave question to be considered in connection with any project looking to the watering of this plain is, can water be obtained? The only available source for water supply is the Rio Grande. From it must first be taken water sufficient to irrigate its arid valley lands. These extend from its source to somewhere in the neighborhood of Piedras Negras. It is not economy to carry water away from these valley lands for use on the mesas when the water can at a relatively small expense be taken on to the valley land, of which there is nearly if not quite enough to require the annual discharge of the river.

It is estimated that there are on the Jornada 1,500,000 acres, requiring at least twice the mean annual flow of the Rio Grande could it all be brought upon this land.

The mesa Cuchilla Negra embraces a large extent of country west of the Jornada del Muerto, along Alamosa Creek, Rio Cuchilla Negra, Rio Palomos, Rio Seco, Rio Animas, and Rio Perches. The valleys on these streams are all narrow and the bluffs high. Above the bluffs are mesas, the land of which is good.

As the fall of the streams is rapid, it is not impracticable to take water out of them onto the mesas, and as they all head on the Continental Divide, they furnish a spring flow, which if stored could be used on the mesas, but just what can be done here can be ascertained only after patient study and examination of the ground and the expenditure of much time.

A large level body of land lying almost on top of the Continental Divide, west of the Magdelena Mountains, is called the Plains of San Augustine. It has every appearance of having once been a lake bed. As it lies so high as to be above all possible water supply, it is valueless for agricultural purposes.

The Santa Fé Mesa is a tract of fertile land lying west and south of Santa Fé, which if a water supply could be assured would produce grain in abundance, but the possible source of water supply is still a problem.

The Questa Mesa includes the country east of the Rio Grande canyon from the San Luis hills as far south as Rio Colorado. With minor exceptions this is all good land and is well watered, being under the waters of the Rios Culebra, Costilla, Latir, Cabresto, and Colorado. With the storage possible on these streams all this area might be brought under cultivation.

The Tres Piedras Mesa includes all the country west of the river and east of the Vallecito Mountains, from the Rio San Antonio on the north to the Black Mesa just above Española on the south. This is a long stretch of country, and is all or nearly all underlain with lava. There are several townships of good land on top of the lava, but water could be brought onto it only at great expense, as a ditch from the Alamosa or San Antonio Rivers would have to be cut through lava rock for a large part of its length. The Taos Valley Ditch Company was organized to reclaim this land. They have 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, 1890, this ditch was carrying some 500 second-feet down a few miles to the end of the excavation, and there it was turned upon the country to find its way into the Rio Grande canyon as best it could. This mesa will probably be of use only as pasture land for many years to come.

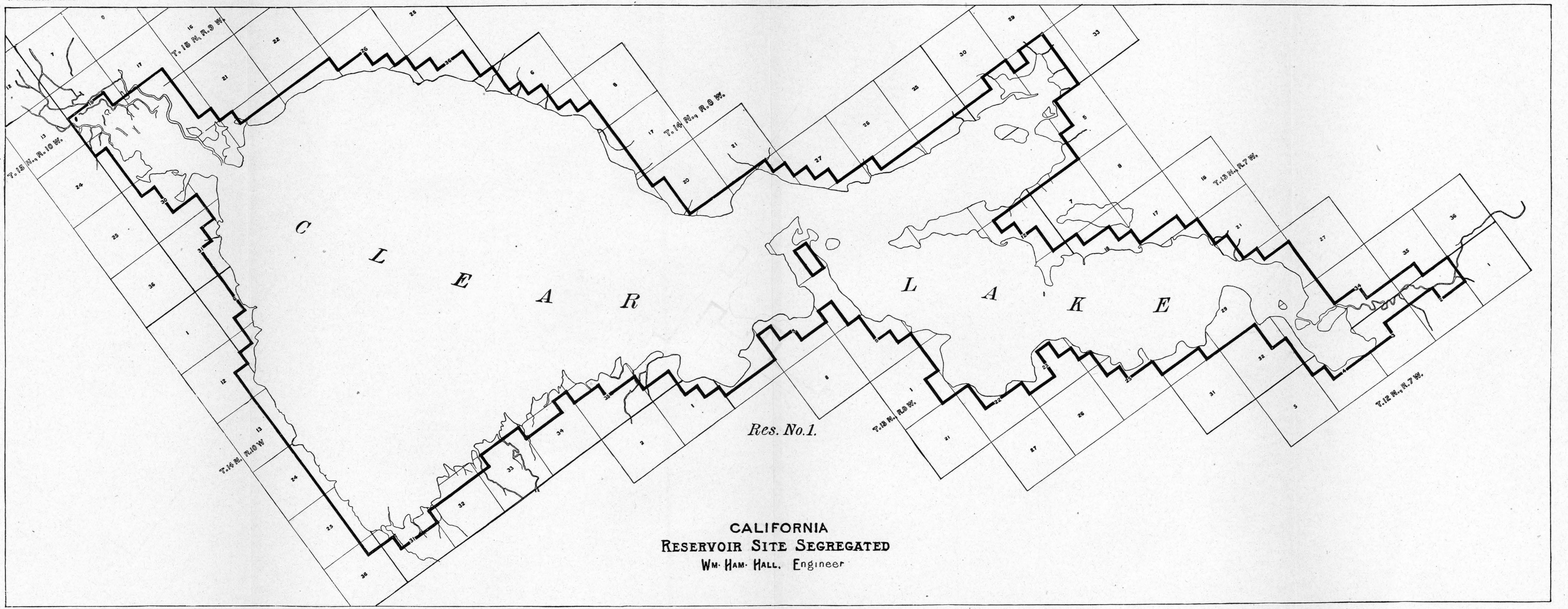
CALIFORNIA DIVISION.

In this division three field parties were organized by Mr. William H. Hall, the supervising engineer. The first of these, under Mr. Luther Wagoner, made a preliminary reconnaissance of the reservoir sites upon the headwaters of the Stanislaus, Tuolumne, and Merced Rivers. The second, under Mr. G. C. Rockwood, made a thorough survey of Clear Lake and its outlets, and the third undertook an examination of the country from the extreme north of the State down into the headwaters of the Sacramento.

THE CLEAR LAKE SURVEY.

The Clear Lake (See Pl. LXXXV) surveying party took the field July 23, 1889. The object of this party was to make a study of the utilization of the lake basin as a reservoir to conserve the waters of its drainage which are now usually wasted, and especially with a view to regulating the supply in its outlet stream for irrigation purposes, and in the hope of mitigating winter floods. The special work performed was essentially of a hydrographic and physiographic nature. On the 9th of August Mr. Josiah Pierce, topographer, commenced the topographic survey of the lake proper at Lakeport.

The topographic work was done in the most accurate manner by the plane-table method, supplemented by the use of the level for closely establishing elevations. The finished topographic sheets show the topography of the lake shore in considerable detail from the low-water plane to a contour several feet above it; they show the mean low water, the mean high water, and the highest known water line. On these sheets are also shown the various sloughs, marshes, meadow lands, cultivated



CALIFORNIA
RESERVOIR SITE SEGREGATED
WM. HAM. HALL, Engineer

lands, lands reclaimed, and works of reclamation, such as levees, etc.; they also show the property lines and the fences, roads, and other features of culture in addition to the 2-foot vertical-contour intervals of the ground surface.

On flat country, contours were accurately located for each 2 feet of elevation up to 10 feet above datum, and with a less degree of care to the 20-foot curve, but on a bold shore only the 10 and 20-foot curves were located. In the location of contours in flat country the Y level was used. In the projection of the first two sheets especially the 20-foot contour extended in many places to a distance 1½ miles back from the shore line, necessitating the placing of the plane-table at points removed from the traverse base. The plan usually followed was to project a plane-table traverse from some point on the base, using the stadia measurement, and finally closing again with the transit traverse on some far point, thus checking the accuracy of the work. Great difficulty was experienced in Big Valley on account of the high brush, weeds, and heavy timber. Level notes on work of this nature were not kept for record. The leveler would start from water surface as a base, checking upon it again at convenient points; the elevation of the water surface being deduced from day to day from a daily record of the fall of water.

In making the hydrographic survey, over 100 miles of traverse lines were run. Two base lines were measured for the triangulation work, one near each end of the lake, and these were afterward joined by triangulation with a check of a few feet, which was close enough for the purpose of this survey.

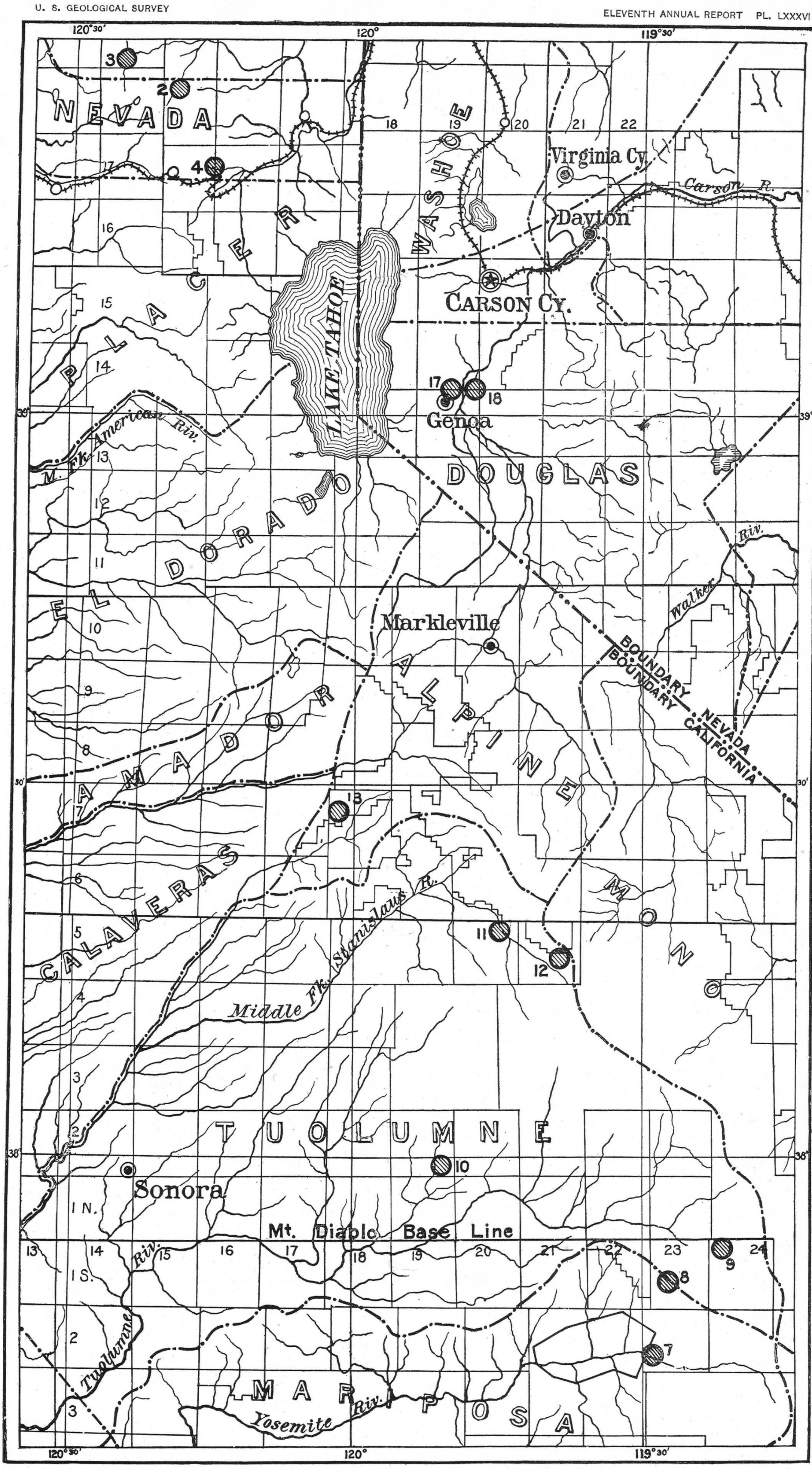
About 234 miles of sounding were run, occupying 26 working days, with an average daily progress of about 9 miles per day. The approximate length of the shore line is 74 miles, and the rate of progress along this line averaged about 2·8 miles per day.

A copy was secured of a very close record of the rise and fall of the waters of Clear Lake from 1873 to 1888, inclusive, kept under the direction of Capt. R. S. Floyd, of Kono Tayee Point. The levels of the survey were connected with the zero plane of this gauge. The low-water plane of Clear Lake, as established by this survey and connected with a checked line of railroad levels, is 1,325 feet above mean low tide in San Francisco Bay. Sounding lines were located by direction from point to point by compass bearings and double sextant angles, intermediate soundings being placed by time intervals. The soundings were accurately taken to a depth of 10 feet below mean low water, and with less care to a depth of 20 feet, and below this only sufficient soundings were taken to give a general idea of the depth of the lake and the topography of its bottom.

The special survey at the outlet of the lake was made in the most accurate manner as a transit, chain and level survey. Frequent traverse and cross-section lines were run, with levels taken along them, so as to afford data for estimating earthworks at any point. The detailed outlet survey extended over a distance of about 22,000 feet, covering the region of shoal water at the lower end of the lake, the adjacent marshes through which the outlet channel meandered, and that portion of Cache Creek flowing therefrom and extending down to a point where its bottom was 20 feet below the low-water plane of the lake. The map representing this work is projected on a scale of 500 feet to the inch, and delineates the surface topography in a very satisfactory manner.

On the 27th of July Mr. Rockwood commenced the meander line down the north bank of Cache Creek, taking elevations every 100 feet. The datum used was the mean low water (assumed from information given by Mr. Bowers) of the lower lake, this elevation being near 100 feet. The Cache Creek meander was carried down the stream 21,700 feet to a point where the creek bottom had an elevation of 79 feet. Cross-sections were run at intervals from the meander line and contours located on them a foot in elevation, up to 8 feet above the datum.

The following are some of the results obtained by a careful compilation of the data obtained by the hydrographic survey of the lake. The area of the surface of the lake at an elevation of 10 feet below mean low water is 56·85 square miles. At



INDEX MAP OF HIGH SIERRA RESERVOIR SITES.

Scale:
6 4 2 0 6 12 18 24 30 Miles.

low water (the assumed 100-foot contour) its area exposed to evaporation is 63·784 square miles, and the volume of water between these two planes is 385,300 acre-feet. The area of water surface of the lake at the 110 contour, which is 10 feet above mean low-water, is 72·08 square miles, and the volume contained between the low water mark and this plane is 435,300 acre-feet. These results would give an equivalent of about 19,330 second-feet of flow for 1 day for every 1 foot in depth of water in the lake in the lower 10-foot layer, and about 21,980 second-feet for 1 day for every 1 foot in depth of water in the layer above the mean low datum. The equivalent discharge during 30 days would average 645 second-feet for every 1 foot in depth of the lower layer, and 733 second-feet for every 1 foot of the upper 10-foot layer.

The mean monthly stand of the lake's surface, as shown on the Kono Tayee gauge rod and reduced to elevations above the assumed datum plane of 100 feet below low water, varied as follows: The observations extended for a period of years from 1874 to 1888, and the lowest mean during this period occurs in October, the reading being 100·574 feet, and increases slowly from that month until March, when the mean reading is 104·233 feet, after which it decreases again to October. The mean annual reading for that period of years was 102·585 feet, and ranged between 100·401 feet in 1883 and 104·663 feet in 1876. The monthly precipitation on the surface of the lake varied during the period of 15 years from a mean of 0 inches in the month of July to 4·67 as the mean for the month of January, and the annual mean is 20·21 inches.

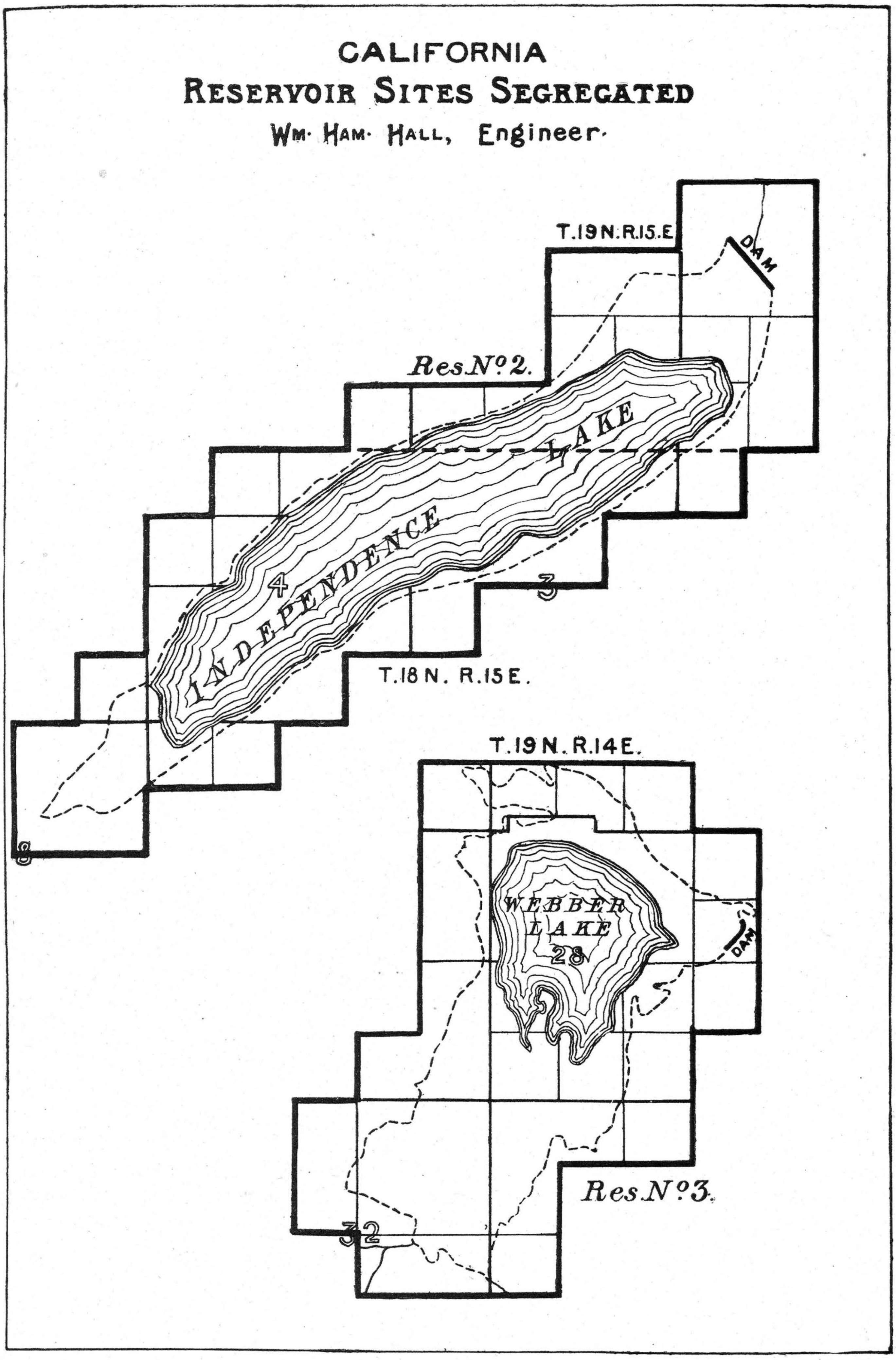
The probable loss by evaporation from the lake's surface, in inches, as compiled from observations made by the California State engineering department on water surface exposed to similar conditions, is: January, 1·1 inches; February, 1·6; March, 2·8; April, 3·1; May, 3·9; June, 6·4; July, 7·85; August, 9·65; September, 8·10; October, 5·2; November, 2·9; December, 1·4. Yearly, 54 inches. These rates give an annual evaporation from the surface exposed at the 92-foot plane of 168,000 acre-feet, and from the surface exposed by *the 100-foot plane of 184,700 acre-feet, and from the 110-foot* plane 298,400 acre feet.

As the result of the detailed survey for an artificial outlet to this lake and the study preliminary to any definite planning in this connection, estimates of the number of cubic yards of excavation are presented, being for a channel carrying 7,500 second-feet of water, 1,420,000 cubic yards, and for a channel to carry 5,000 second-feet, 921,000 cubic yards.

The general outlines of this lake are shown on Pl. LXXXV, and a description of the site is given by township, range, and section on page 159.

The field operations under Mr. Wagoner were, as before stated, confined to the upper portion of the watersheds of the several branches and tributaries of the Stanislaus, Tuolumne, and Merced Rivers, and were above a line drawn from the Big Tree Grove in Calaveras County to the Big Tree Grove in Mariposa County. The party engaged on this survey moved rapidly through this region, obtaining information as to the opportunities for storage, and definitely surveying and locating the sites which presented the most favorable conditions for this purpose. The work resulted in definite preliminary surveys of only the best storage sites, and a reconnaissance of the field for other sites, with recommendations as to their survey at a future time. In nearly every case the completed Land Office surveys did not extend to the sites discovered, but the positions of these have been closely determined by a projection of the land lines on the maps. The site for each dam completed was marked at each end by a large mound of stones.

The general route of the party was up the North Fork of the Stanislaus River to Hermit and Highland Valleys on the summit of the Sierras, thence southerly into the watershed of the Middle Fork of the Stanislaus and down that fork to a point south of Dardanelle Cone; from this point up Relief Valley Fork through Eureka and Relief Valleys to near the summit of the Sierra again, and crossing between Granite Dome and Crystal Lake down into the watershed of the South Fork of the Stanislaus, thence into the Big Canyon Creek, a tributary of


CALIFORNIA
RESERVOIR SITES SEGREGATED
WM. HAM. HALL, Engineer.
T.19 N. R.15 E.
DAM
Res. No. 2.
INDEPENDENCE LAKE
4
3
T.18 N. R.15 E.
8
T.19 N. R.14 E.
WEBBER LAKE
28
DAM
Res. No. 3.
32

the Tuolumne River, and around through Bell's Meadows, Bear and Cherry Valleys, to Lake Eleanor on Eleanor Creek. From this point the party moved into the Hetch-Hetchy Valley of the Tuolumne Canyon, thence out to Wade's Meadows on the south and over the divide to the Big Oak Flat road, thence south into Little Yosemite Valley on the watershed of the Merced River. From this point they moved up and above that valley to Lake Tenaiya and over into the headwaters of the Tuolumne above the Grand Canyon to the neighborhood of Tuolumne Meadows and Soda Springs Valley. Returning from this point through the Yosemite Valley, the party came back over the Big Oak Flat road and by a lower route across the Sierra back to Sonora and out to the point of departure at Stockton. In the course of this general route, with the many side trips that were made, the surveys and reconnaissances mentioned below were accomplished.

The work of this reconnaissance party has shown that the region of the High Sierras, within the watershed of the Tuolumne, Stanislaus, and Merced Rivers, is not especially favorable to the storage of water in large volumes. Very small reservoir sites exist, but comparatively few are found where storage can be effected with notable economy and in encouraging amount. The watershed of the Stanislaus is the least favorable in this regard, while that of the Merced is the most so of the three examined. It is to be remembered, however, that the work of the party was not intended to be complete throughout the region traversed.

There were made seven finished surveys at localities whose relative position is shown on Pl. LXXXVI; four instrumental reconnaissances accompanied by sketch maps; thirteen localities examined and recommended for survey; and thirty other localities recorded and recommended for definite reconnaissance preliminary to survey. Large-scale contour maps of the seven finished surveys have been completed from the notes and sketches collected.

The topography of the region examined by this mountain survey party is very similar throughout its various portions in general character, elevations, and in physiographic features.

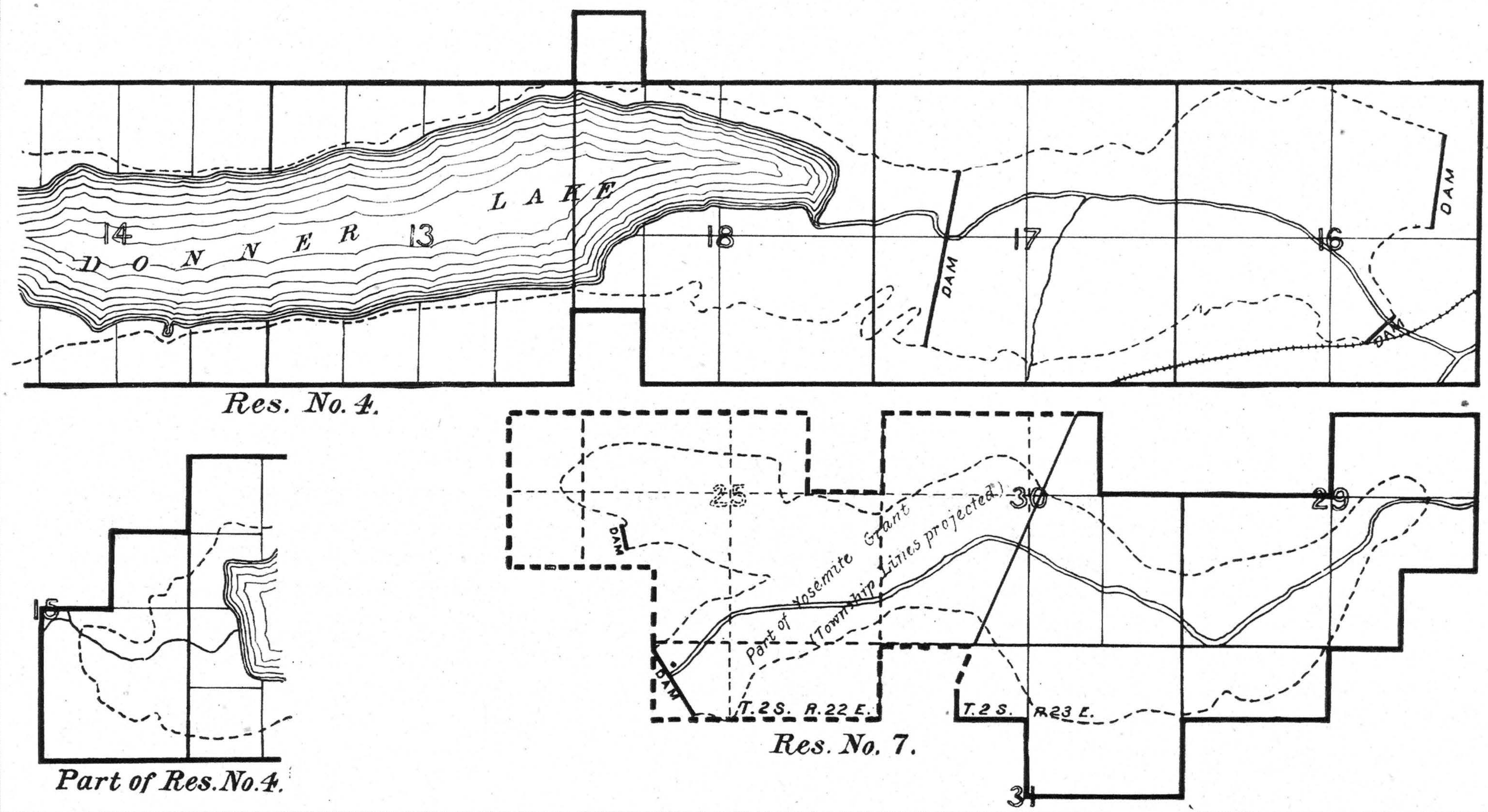
The total area to be affected by the investigations of this party, however, includes portions of the State differing largely in their topographic and hydrographic features.

The lands to be irrigated are of the greatest agricultural importance, lying on the western edge of the San Joaquin Valley, where the country is nearly level, while the storage sites are to be found high among the headwaters. The upper lines of drainage of this country are through easy slopes and valleys terminating in the deep and rugged canyons of the main rivers under discussion.

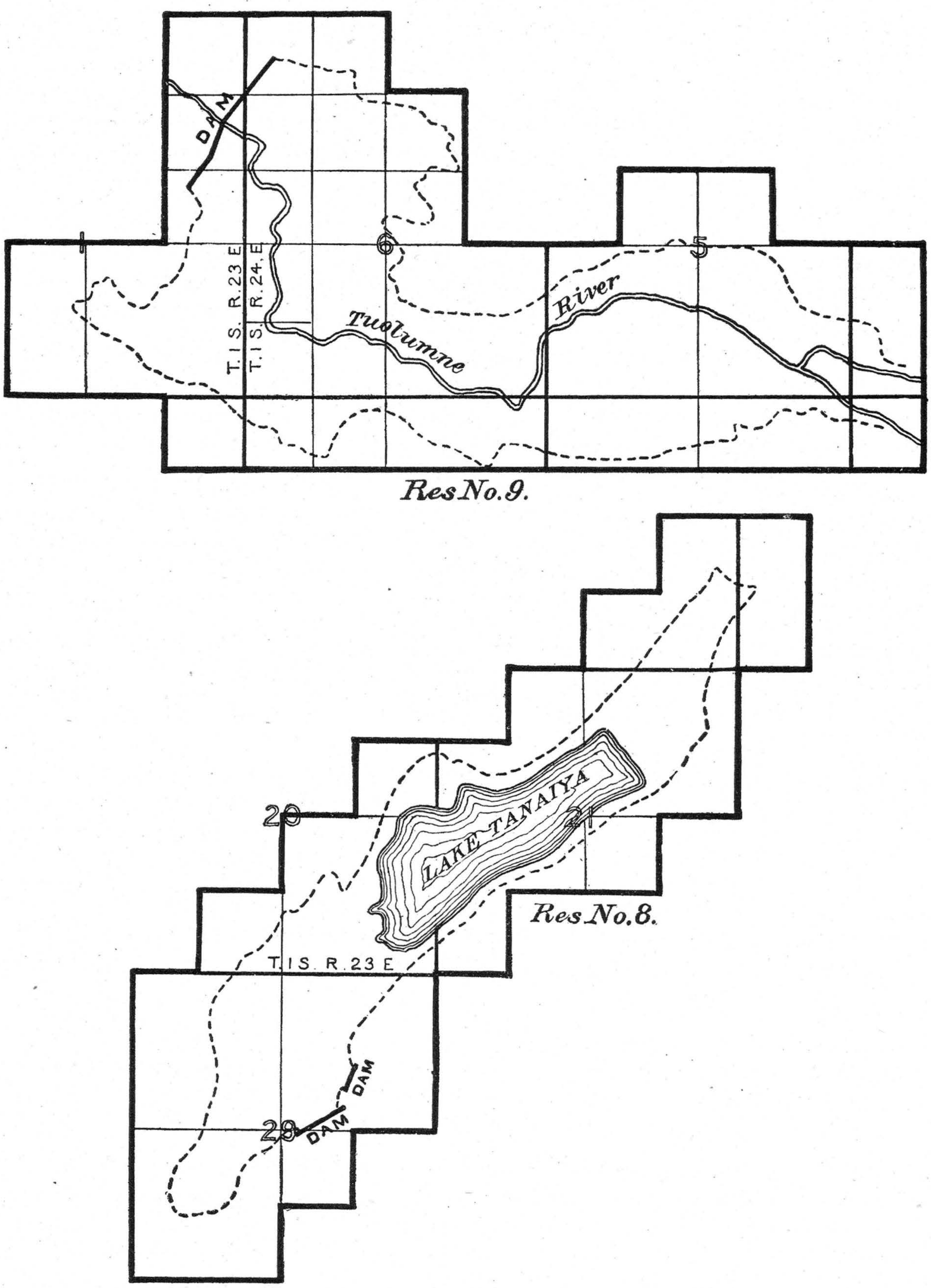
Eastward of this belt of country the second great topographic feature consists of a more regular and level sloping country, which extends from the foot of the great summit peaks of the High Sierra, with an easy incline to the west. This region has few prominent hills in it, and is practically a great flat tableland which has been cut and eroded by the innumerable streams draining it, which here flow far beneath the general surface level in deep and rugged canyons. In this region the canyons of the Stanislaus and Tuolumne Rivers reach a depth of several thousand feet. Yosemite Valley is at the western edge of this region, at the bottom of a broad expanse of the Merced Canyon. The soil throughout this portion of the Sierras is rather deep, and is a black and fruitful loam which produces an abundant and luxurious growth of tall, fine timber trees, the more prominent among which are the yellow and sugar pine, cedar, and firs. Few valleys or meadows of any kind are found in this region, and the opportunities for water storage are extremely limited.

It is in the upper portion and last belt of the Sierras that are found the many natural lakes, swamps, and open meadows which will furnish the sites for storage reservoirs. This country, extending from the upper edge of the level timber belt just described, at an elevation of about 5,000 feet, eastward to the crest of the High Sierras, consists of many high and imposing mountain masses separated by broad and picturesque valleys. Large portions of these mountain peaks are above the timber line, and some of the higher reach an elevation of 13,000 and 14,000 feet and are perpetually snow-clad. At the foot of

CALIFORNIA
RESERVOIR SITES SEGREGATED
WM. HAM. HALL, Engineer.



CALIFORNIA
RESERVOIR SITES SEGREGATED
WM. HAM. HALL, Engineer.



these are numerous glaciated valleys, terminating frequently in narrow canyon outlets and affording the reservoir sites which have been examined.

The water stored in the reservoirs of the High Sierras which were examined and surveyed in this division must all be returned to the main rivers, down which it will take its course, frequently from 150 to 200 miles, to the San Joaquin Valley before the irrigable lands will be reached.

Little Yosemite.—This site (see Pl. LXXXVIII, No. 7), is reached by trail 6 miles from Yosemite Valley or 8 miles from Glacier Point. Good timber is abundant, and sufficient loose rock can be had with about one-third of a mile haul to construct the main dam. There are two dams required, and estimates are given for heights of contour. The lower of these dams will be 115 feet in height and 915 feet long, making a lake of 862 acres, having a capacity of 45,000 acre-feet.

Lake Tenaiya.—This lake, shown on Pl. LXXXIX, No. 8, is situated on the Tioga toll road, distant 110 miles from Milton. The watershed is about 11 square miles. The dam site, is nearly all clean granite, with a foot or so of loam in places. Stone will be quarried from either end of the dam. Good loamy soil can be had with a haul of 1,000 feet. The main dam is 725 feet long; a lateral dam is 350 feet long and 35 feet high. The area of reservoir Pl. XC, will be 597 acres and the capacity 23,000 acre-feet.

Tuolumne Meadows.—This is a valley (see Pl. LXXXIX, No. 9), on the Upper Tuolumne River, about 15 miles from its headwaters. It is 116 miles from Milton, and is reached by the Tioga wagon-road, which passes through the valley. Stone can be had at each end of the main dam by quarrying; also from the sides, but below the level of the dam. Good loamy soil can be had with an average haul of 1,700 feet.

The main dam, is 870 feet long and 75 feet high. There are three lateral dams, whose dimensions are, respectively, 250 feet long and 18 feet high, 515 feet long and 65 feet high, and 710 feet long and 45 feet high. The area of the reservoir Pls. XCII and XCIII, is 1,081 acres and its capacity is 43,185 acre-feet.

Lake Eleanor.—Lake Eleanor (see Pl. XCI, No. 10), is one of the best reservoir sites in the region examined, the watershed being sufficient to fill the proposed reservoir to the height estimated about 70 feet above low water in the lake. The lake is reached by wagon road from Milton to Lord's ranch, via Bradford's sawmill, a distance of 62 miles, and thence by good trail for 15 miles farther. The trail could be changed into a passable wagon road at a trifling cost, thus affording direct communication with Milton by wagon road. The high-water mark of 1862 is still visible and indicates that an ample waste way must be provided.

At the lower dam site the foundation is all barren granite, but at the upper dam site the foundation is covered in many places with soil and trees to a depth of about 3 feet. At the upper dam site, by a haul of 1,000 feet from above it, a plentiful supply of soil, a sandy loam in character, can be had. Rock, which in all cases would have to be quarried, can be most easily obtained from the left bank of the creek at the upper dam site, and from the sides and ends of the dam at the lower site.

Estimates have been made for five types of dams to 150 and 170 foot contours (low water in the lake is 100 feet) at both the upper and lower dam site. Considering at this time but one of these types, it is estimated that a dam 65 feet high and 1,300 feet long will make a reservoir 1,127 acres in area and containing 45,770 acre-feet.

Kennedy's Meadow.—Kennedy's Meadow (Pl. XCI, No. 11), is situated on the upper waters of the Middle Fork of the Stanislaus River, is 60 miles east of Sonora and 2 miles from Baker's Station, on the Mono road. Stone can be had from each end of the dam, and can be easily quarried, and good loamy soil can be procured by a haul of about 1,200 feet. The 80-foot contour affords a natural spillway. The dam site is now inclosed, and is used as a pasture. A dam 102 feet high and 410 feet long will impound 7,408 acre-feet of water.

Kennedy's Lake.—This lake (Pl. XCI, No. 12), is 58 miles east from Sonora to Baker's Station (on Mono road) and thence 11 miles by trail over the mountain ridge. The foundation is detrital, probably a moraine. Earth, loose rock, brush, and bowlders are plentiful. The work consists of one dam 900 feet long on

LAKE TENAIYA RESERVOIR SITE, LOOKING SOUTHEAST.

the crest and 31 feet high, making a reservoir of the capacity of 2,000 acre-feet.

Bear Valley.—Blood's Station, near this site (Pl. XCIV, No. 13), is sixty-eight miles from Milton, on the Big Tree and Carson Valley Turnpike. The work proposed at this place consists of one main dam 1,670 feet long on the crest, with a maximum depth of 55 feet, and two side dams, one 300 feet long and 20 feet high, the other 240 feet long and 15 feet high. All of the foundations are of solid granite. The area of water surface will be 348 acres; capacity, 6,917 acre-feet; elevation above sea, 6,911 feet.

The areas reserved for the above-mentioned sites are described in full in the following pages.

High Sierra reservoir system, California.

CLEAR LAKE RESERVOIR SITE, NO. 1.

T. 15 N., R. 9 W., Mount Diablo meridian.

		Acres.	Acres.
Section 17..	S. ½ of the SW. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120
Section 18..	All of the SW. ¼	160	
	W. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
			280
Section 19..	All of the NE. ¼	160	
	All of the SE. ¼	160	
	N. ½ of the NW. ¼	80	
	SE. ¼ of the NW. ¼	40	
	E. ½ of the SW. ¼	80	
			520
Section 20..	All of the NW. ¼	160	
	All of the SW. ¼	160	
	W. ½ of the NE. ¼	80	
	W. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
			520
Section 26..	All of the SW. ¼	160	
	SW. ¼ of the SE. ¼	40	
			200
Section 27..	All of the SE. ¼	160	
	All of the SW. ¼	160	
	S. ½ of the NE. ¼	80	
	S. ½ of the NW. ¼	80	
			480

		Acres.	Acres.
Section 28..	All of the SE. ¼	160	
	All of the SW. ¼	160	
	S. ½ of the NE. ¼	80	
	S. ½ of the NW. ¼	80	
	NW. ¼ of the NW. ¼	40	
			520
Section 29....	The entire section		640
Section 30..	All of the NE. ¼	160	
	NE. ¼ of the NW. ¼	40	
	N. ½ of the SE. ¼	80	
	SE. ¼ of the NE. ¼	40	
			320
Section 31..	SE. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
			200
All of sections 32, 33, 34, and 35			2,560
Section 36..	All of the SW. ¼	160	
	SW. ¼ of the NW. ¼	40	
	W. ½ of the SE. ¼	80	
			280

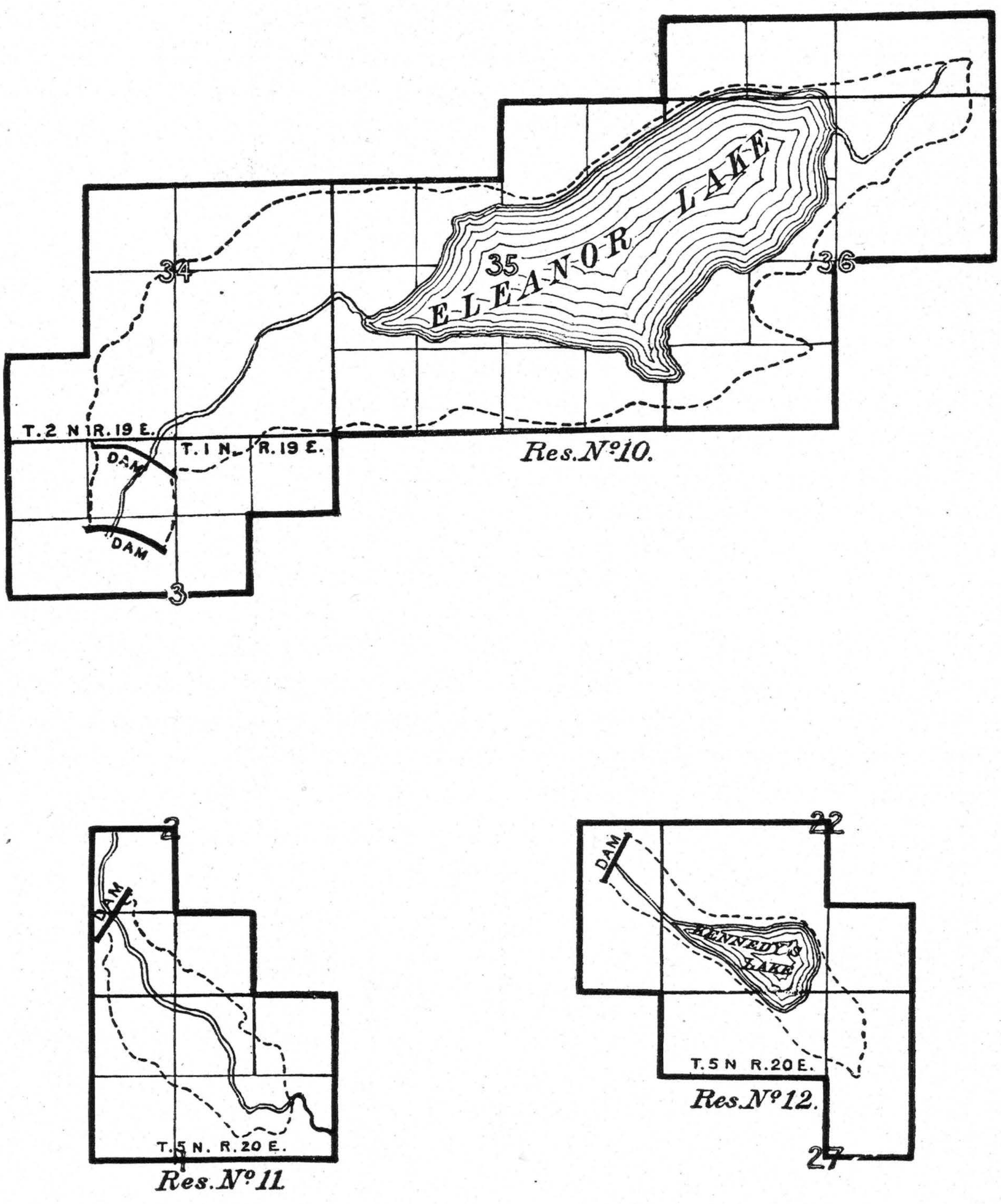
T. 14 N., R. 7 W., Mount Diablo meridian.

Section 31..	S. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the SW. ¼	160	
			560
Section 32..	S½ of the NW. ¼	80	
	NE. ¼ of the NW. ¼	40	
	W. ½ of the NE. ¼	80	
	W. ½ of the SE. ¼	80	
	All of the SW. ¼	160	
			440

T. 14 N., R. 8 W., Mount Diablo meridian.

Section 6..	W. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			120
Section 7..	All of the NW. ¼	160	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
	SW. ¼ of the NE. ¼	40	
			520
Section 18....	Entire section		640
Section 19....	Entire section		640

CALIFORNIA
RESERVOIR SITES SEGREGATED
Wm. Ham. Hall, Engineer.



		Acres.	Acres.
Section 20..	SW. ¼ of the NW. ¼	40	
	W. ½ of the SW. ¼	80	
			120
Section 27..	W. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			120
Section 28..	All of the NW. ¼	160	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
	W. ½ of the NE. ¼	80	
	SE. ¼ of the NE. ¼	40	
			600
All of sections 29, 30, 31, and 32			2,560
Section 33..	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	W. ½ of the SW. ¼	80	
			560
Section 34....	The entire section		640
Section 35..	S. ½ of the NW. ¼	80	
	NW. ¼ of the NW. ¼	40	
	S. ½ of the NE. ¼	80	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
			520
Section 36..	S. ½ of the NW. ¼	80	
	S. ½ of the NE. ¼	80	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
			480

T. 14 N., R. 9 W., Mount Diablo meridian.

All of sections 1, 2, 3, 4, and 5			3,200
Section 6...	All of the NE. ¼	160	
	All of the SE. ¼	160	
	SE. ¼ of the SW. ¼	40	
			360
Section 7...	S. ½ of the NW. ¼	80	
	NE. ¼ of the NW. ¼	40	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	All of the SW. ¼	160	
			600
All of sections 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, and 30			14,720

		Acres.	Acres.
Section 31..	N. ½ of the NW. ¼	80	
	SE. ¼ of the NW ¼	40	
	All of the NE. ¼	160	
			280
Section 32..	N. ½ of the NW. ¼	80	
	N. ½ of the NE. ¼	80	
			160
Section 33....	NW. ¼ of the NW. ¼		40
Section 34..	N. ½ of the NW. ¼	80	
	NW. ¼ of the NE. ¼	40	
			120
Section 35..	N. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
			240
Section 36..	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	N. ½ of the SW. ¼	80	
			560

T. 14 N., R. 10 W., Mount Diablo meridian.

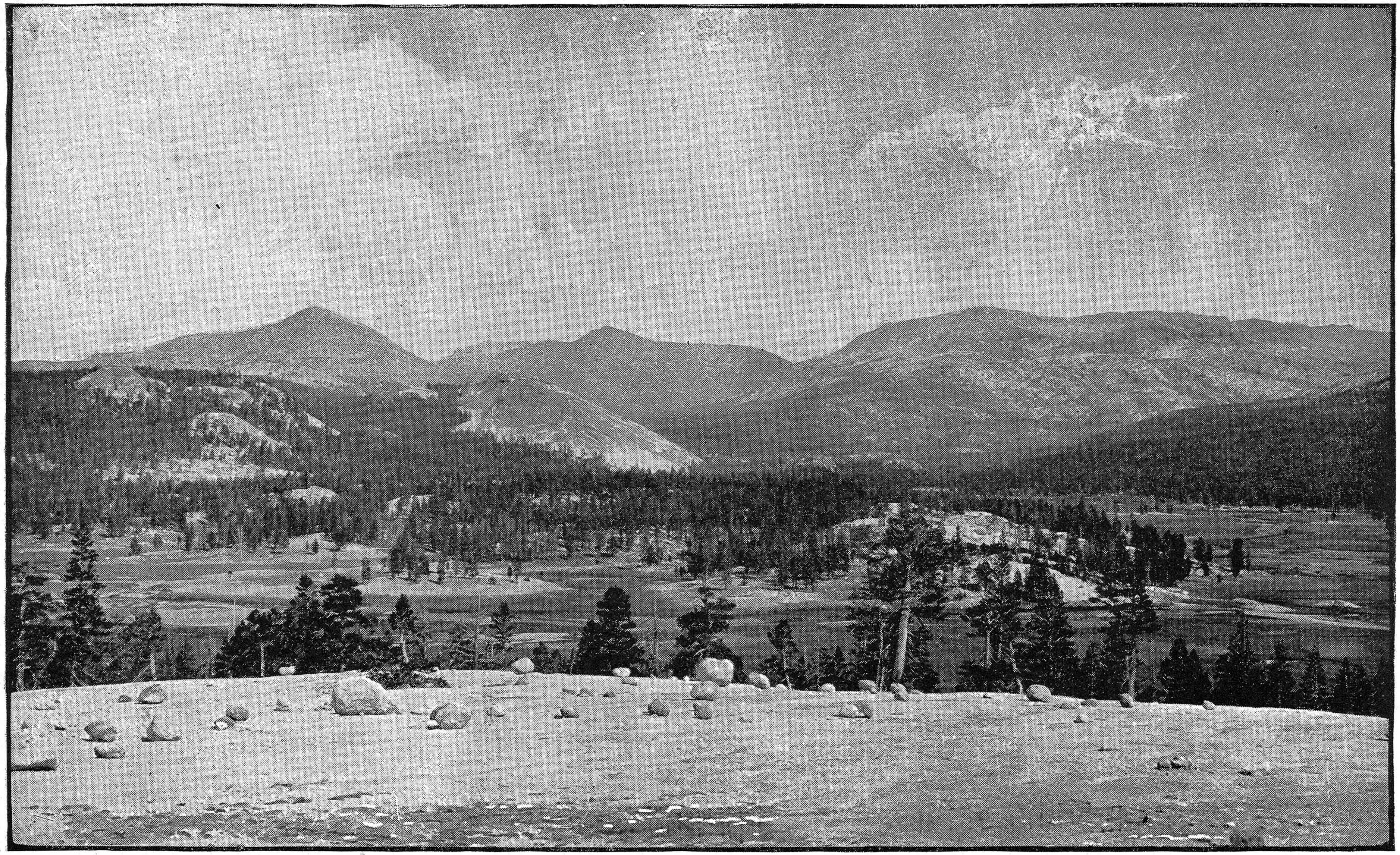
Section 12....	E. ½ of the SE. ¼		80
Section 13..	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
			160
Section 24..	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
			160
Section 25..	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
			160
Section 36....	NE. ¼ of the NE. ¼		39·72

T. 13. N., R. 9 W., Mount Diablo meridian.

Section 1...	E. ½ of the NE. ¼	80	
	NW. ¼ of the NE. ¼	40	
			120

T. 13 N., R. 8 W., Mount Diablo meridian.

Section 1	The entire section		640
Section 2	The entire section		640
Section 3	The entire section		640
Section 4 ...	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
			560



TUOLUMNE MEADOWS RESERVOIR SITE, LOOKING EAST.

		Acres.	Acres.
Section 5	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	E. ½ of the NW. ¼	80	
	NW. ¼ of the NW. ¼	40	
			360
Section 6	All of the NW. ¼	160	
	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	N. ½ of the SW. ¼	80	
			480
Section 9	All of the NE. ¼	160	
	NE. ¼ of the SE. ¼	39·93	
			199·93
Section 10	The entire section		640
Section 11	The entire section		640
Section 12	W. ½ of the NW. ¼	80	
	SE. ¼ of the NW. ¼	40	
	All of the SW. ¼	160	
	W. ½ of the SE. ¼	80	
			360
Section 13	The entire section		640
Section 14	The entire section		640
Section 15	The entire section		640
Section 16	E. ½ of the SE. ¼		80
Section 22	E. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
			240
Section 23	All of the NW. ¼	160	
	N. ½ of the NE. ¼	80	
	SE. ¼ of the NE. ¼	40	
	N. ½ of the SW. ¼	80	
			360
Section 24	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SE. ¼	160	
	N. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			600
Section 25	All of the NE. ¼	160	
	NE. ¼ of the NW. ¼	40	
			200
	T. 13 N., R. 7 W., Mount Diablo meridian.		
Section 5	W. ½ of the NW. ¼		80
Section 6	The entire section		640
Section 17	SW. ¼ of the SE. ¼	40	
	S. ½ of the SW. ¼	80	
	NW. ¼ of the SW. ¼	40	
			160

		Acres.	Acres.
Section 18..	W. ½ of the NW. ¼	80	
	SE. ¼ of the NW. ¼	40	
	SW. ¼ of the NE. ¼	40	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
			480
All of sections 19 and 20			1,280
Section 21....	W. ½ of the SW. ¼		80
Section 28..	All of the NW. ¼	160	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
	S. ½ of the NE. ¼	80	
			560
Section 29....	The entire section		640
Section 30..	All of the NW. ¼	160	
	All of the NE. ¼	160	
	N. ½ of the SW. ¼	80	
	N. ½ of the SE. ¼	80	
	SE. ¼ of the SE. ¼	40	
			520
Section 32....	E. ½ of the NE. ¼		80
Section 33....	The entire section		640
Section 34..	All of the SW. ¼	160	
	S. ½ of the SE. ¼	80	
			240
Section 35....	S. ½ of the SW. ¼		80

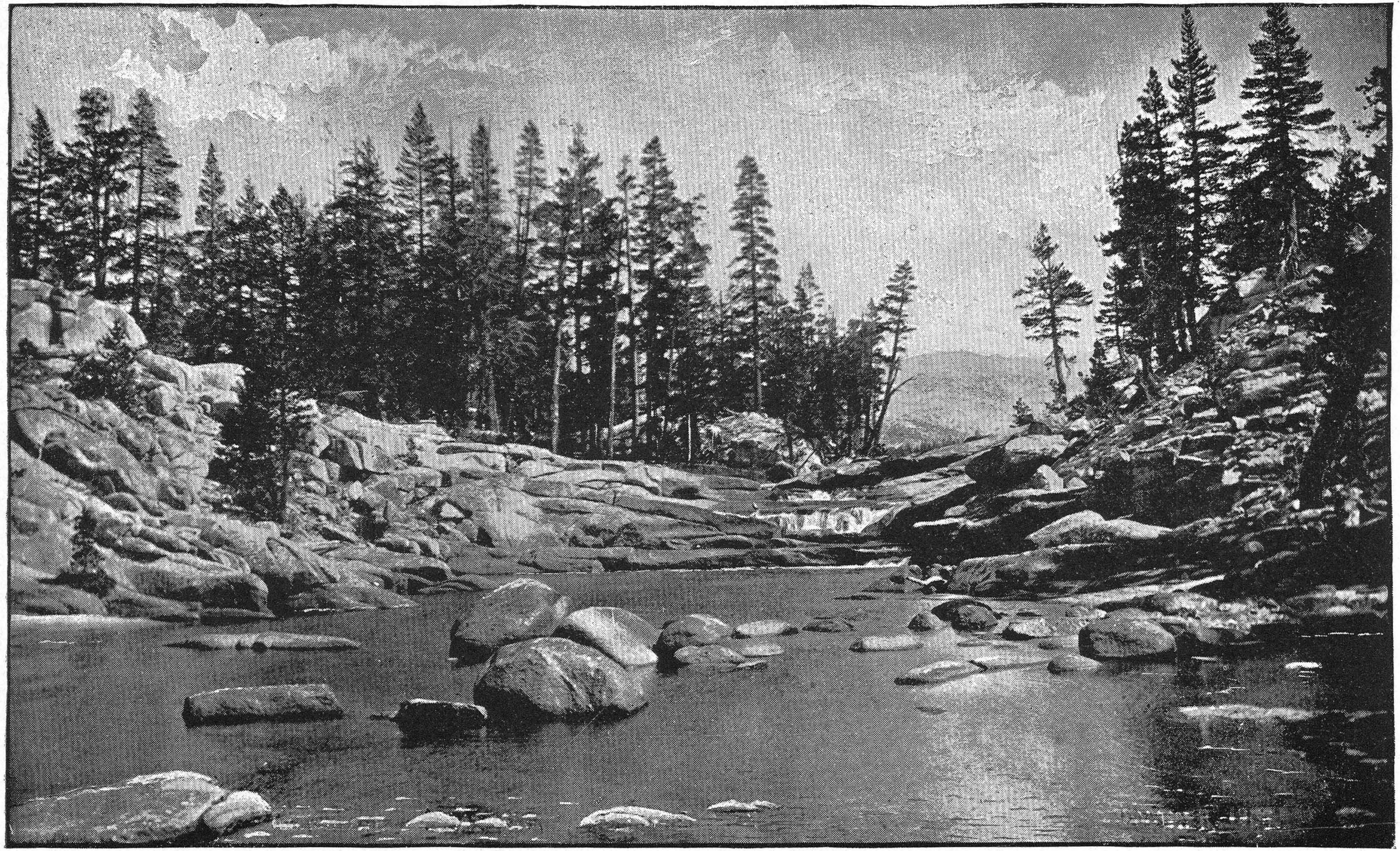
T. 12 N., R. 7 W., Mount Diablo meridian.

Section 2..	All of the NE. ¼	160	
	N. ½ of the NW. ¼	80	
			240
Section 3..	All of the NW. ¼	160	
	N. ½ of the NE. ¼	80	
			240
Section 4..	All of the NE. ¼	160	
	E. ½ of the NW. ¼	80	
	NW. ¼ of the NW. ¼	41·32	
			281·32
Total area segregated			50,920·97

LITTLE YOSEMITE.—RESERVOIR SITE NO. 7.

T. 2 S., R. 23 E., Mount Diablo meridian.

		Acres.	Acres.
Section 29..	S. ½ of the NE. ¼	80	
	N. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
	All of the SW. ¼	160	
			360



TUOLUMNE MEADOWS DAM SITE.

		Acres.	Acres.
Section 30..	SW. ¼ of the NE. ¼	24·48	
	E. ½ of the SE. ¼	80	
	NW. ¼ of the SE. ¼	38·83	
	SW. ¼ of the SE. ¼	54·79	
	E. ½ of the SW. ¼	24·27	
			222·37
Section 31..	All of the NE. ¼	160	
	NE. ¼ of the NW. ¼	36·98	
			196·98
Section 32....	N. ½ of the NW. ¼		80

PART OF RESERVOIR IN YOSEMITE GRANT.—LOT 37.

Projected T. 2 S., R. 23 E.

Section 30..	SW. ¼ of the NE. ¼, about	20	
	S½ of the NW. ½	80	
	All of the SW. ¼, about	135	
			235

Projected T. 2 S., R. 22 E.

		Acres.	Acres.
Section 25..	SW. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
	S. ½ of the NW. ¼	80	
	N. ½ of the SW. ¼	80	
	SE. ¼ of the SW. ¼	40	
			400
Section 26..	SE. ¼ of the NE. ¼	40	
	NE. ¼ of the SE. ¼	40	
			80
Section 36..	N. ½ of the NE. ¼	80	
	NE. ¼ of the NW. ¼	40	
			120
Total area segregated			1,694·35

TANAIYA LAKE.—RESERVOIR SITE NO. 8.

T. 1 S., R. 23 E., Mount Diablo meridian.

		Acres.	Acres.
Section 15....	W. ½ of the SW. ¼	80	
Section 16..	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120
Section 20..	SE. ¼ of the SW. ¼	40	
	All of the SE. ¼	160	
	SE. ¼ of the NE. ¼	40	
			240

		Acres.	Acres.
Section 21..	All of the NE. ¼	160	
	S. ½ of the NW. ¼	80	
	NE. ¼ of the NW. ¼	40	
	NW. ¼ of the SE. ¼	40	
	W. ½ of the SW. ¼	80	
	NE. ¼ of the SW. ¼	40	
			440
Section 29..	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SW. ¼	160	
	NW. ¼ of the SE. ¼	40	
			520
Total area segregated			1,400

TUOLUMNE MEADOWS.—RESERVOIR SITE NO. 9.

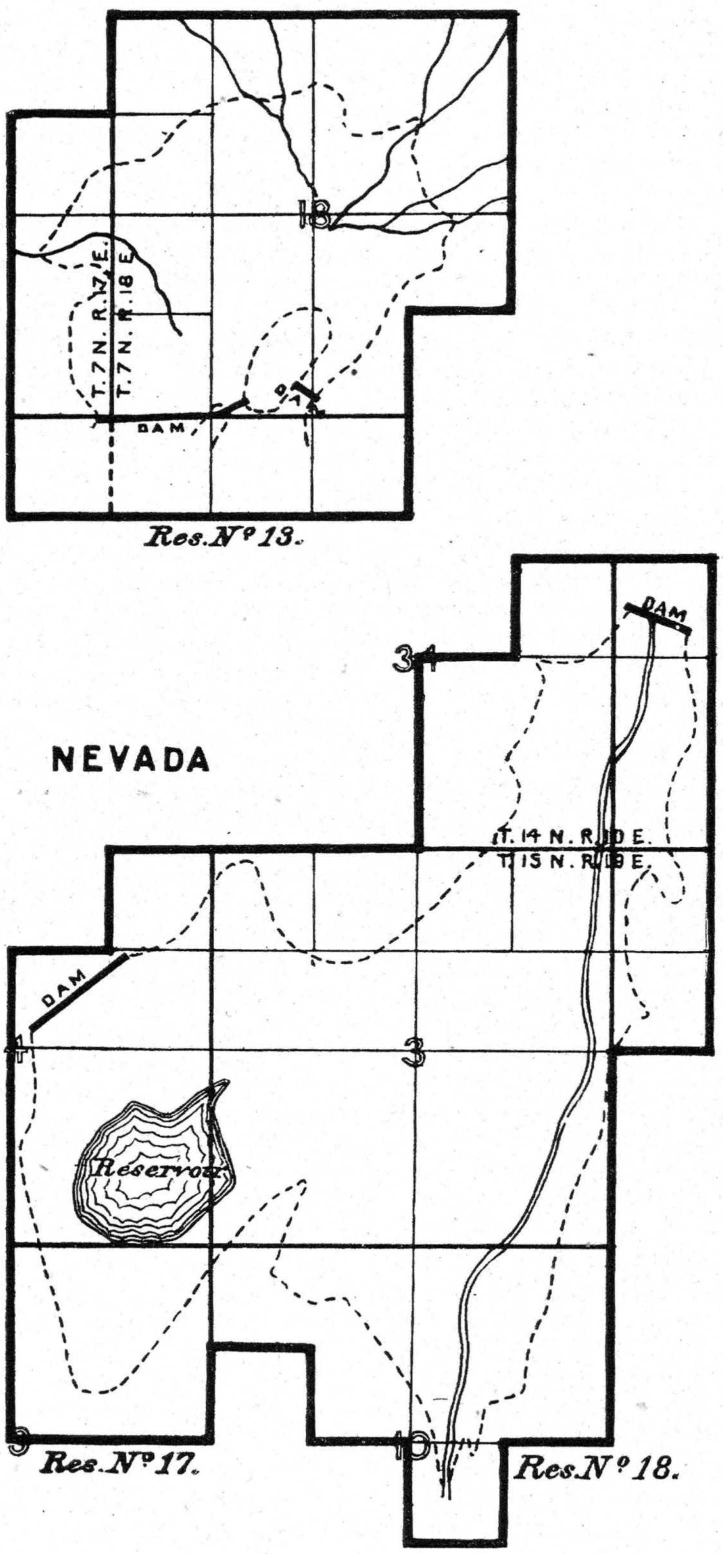
T. 1 S., R. 24 E., Mount Diablo meridian.

		Acres.	Acres.
Section 4....	W. ½ of the SW. ¼		80
Section 5..	Lot No. 19 of the NW. ¼	40	
	Lot No. 18 of the NE. ¼	40	
	All of the SE. ¼	160	
	All of the SW. ¼	160	
			400
Section 6..	Lots No. 11, 12, 13, 14, 19, and 20 of the NW. ¼	240	
	Lots No. 15 and 18 of the NE ¼	80	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
			640
Section 7..	N. ½ of the NW. ¼	80	
	N. ½ of the NE. ¼	80	
			160
Section 8..	N. ½ of the NW. ¼	80	
	N. ½ of the NE. ¼	80	
			160
Section 9....	NW. ¼ of the NW. ¼		40

T. 1 S., R. 23 E., Mount Diablo meridian.

		Acres.	Acres.
Section 1..	Lots 9, 16, and 17 of the NE. ¼	120	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
			360
Section 12..	NE. ¼ of the NE. ¼		40
Total area segregated			1,880

CALIFORNIA
RESERVOIR SITES SEGREGATED
WM. HAM HALL, Engineer.



Eleanor Lake.—Reservoir Site No. 10.

T. 2 N., R. 19 E., Mount Diablo meridian.

		Acres.	Acres.
Section 25..	S. ½ of the SW. ¼	80	
	S. ½ of the SE. ¼	80	
			160
Section 34..	SE. ¼ of the NW. ¼	80	
	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
	SW. ¼ of the SW. ¼	40	
			440
Section 35..	S. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
	All of the SW. ¼	160	
	All of the SE. ¼	160	
			560
Section 36..	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SW. ¼	160	
			480

T. 1 N., R. 19 E., Mount Diablo meridian.

		Acres.	Acres.
Section 3..	All of the NW. ¼	157·52	
	N. ½ of the NE. ¼	73·22	
	SW. ¼ of the NE ¼	40·	
			270·84
Total area segregated			1,910·84

Kennedy's Meadows.—Reservoir Site No. 11.

T. 5 N., R. 20 E., Mount Diablo meridian.

		Acres.	Acres.
Section 2..	E. ½ of the SW. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120
Section 11..	All of the NE. ¼	160	
	E. ½ of the NW. ¼	80	
			240
Total area segregated			360

Kennedy's Lake.—Reservoir Site No. 12.

T. 5 N., R. 20 E., Mount Diablo meridian.

		Acres.	Acres.
Section 21	E. ½ of the SE. ¼		80
Section 22	All of the SW ¼	160	
	SW. ¼ of the SE. ¼	40	
			200
Section 27	N. ½ of the NW. ¼	80	
	W. ½ of the NE. ¼	80	
			160
Total area segregated			440

Bear Valley.—Reservoir Site No. 13.

T. 7 N. R. 18 E., Mount Diablo meridian.

		Acres.	Acres.
Section 18	All of the NW. ¼	160·12	
	All of the NE. ¼	160	
	All of the SW. ¼	160·36	
	W. ½ of the SE. ¼	80	
	NE. ¼ of the SE. ¼	40	
			600·48
Section 19	N. ½ of the NW. ¼	80·24	
	NW. ¼ of the NE. ¼	40	
			120·24

T. 7 N., R. 17 E., Mount Diablo meridian.

		Acres.	Acres.
Section 13	E. ½ of the SE. ¼	80	
	SE. ¼ of the NE. ¼	40	
			120
Section 24	NE. ¼ of the NE. ¼		40
Total area segregated			880·72

LAHONTAN DIVISION.

The three surveying parties organized for field work in June, 1889, by Mr. Lyman Bridges were disposed as follows: The first, under the charge of Mr. Francis Bridges, assistant engineer, prosecuted the topographic survey of Independence reservoir site; the second party, under the charge of Mr. L. H. Shortt, assistant engineer, made preliminary surveys for canal lines from the lower Truckee River, in the neighborhood of Wadsworth; and the third party, in charge of Mr.

George A. Brown, assistant engineer, was engaged upon the topographic and engineering survey of the Hope Valley reservoir site, within the Carson River watershed.

In the following pages is given a brief description of the surveys which have been completed and for which the computations, maps, and estimates have been prepared. The statements of capacities of the reservoirs definitely surveyed and of the length and heights of dams are to be considered as preliminary merely, as in order to reach definite conclusions regarding the most feasible and economical sites it will be necessary to complete the hydrographic survey. Until this is done a knowledge of the quantities of water available for storage and of capacity and economy of construction can not be reached.

Tahoe Tunnel.—Lake Tahoe is the greatest natural lake basin of the Sierra Nevada range, and one of the largest lakes held within mountain walls at a high altitude on the American continent. Its maximum length is 22½ miles and its greatest width 13 miles. Its area is about 195 square miles, and it is at an altitude of about 6,225 feet. Its greatest depth is said to be 1,500 feet. This lake has a tributary watershed of over 500 square miles (inclusive of its own surface), constituting the upper portion of the drainage basin of the Truckee, which river is its outlet channel.

Lying parallel to and east of the Tahoe Basin, and separated from it by an arm of the Sierra known as the Tahoe Range, is the main upper valley of the Carson River. The elevation of this plain varies between 4,600 and 4,850 feet above sea level, or is from 1,350 to 1,600 feet lower than the plane of Tahoe's water surface.

The Tahoe tunnel line survey was made for the purpose of testing the feasibility and estimating the cost of piercing the Tahoe Range by a tunnel through which to draw water from the lake for use in Carson and other valleys through which the Carson River runs.

By the contour work of the Topographic Section of the Geological Survey the range was found to be narrowest opposite the southeast quarter of the lake. To definitely determine the best location here for a tunnel line two trial meander lines were run over the mountain from the lake to the contour 20 feet below the elevation of the lake's low-water plane, on the east face of the range. These lines determine the shortest direct distance through from Boundary Bay to Haines Creek Canyon to be 17,331 feet, or 759 feet less than from Zephyr Cove to Genoa Canyon. This difference in favor of the former route, together with other advantages as to outcome, led to its adoption for further examination. Accordingly, a direct line was run between the two first-named points, and by leveling a ground profile was made thereon. The following are the data for these lines:

The Boundary Bay line commenced at a point on the shore of Lake Tahoe in the cove known as Boundary Bay, at the mouth of Small's Creek, and 3,169 feet north of the California-Nevada boundary monument (Von Schmidt Survey), on Nevada territory. The project was to start the tunnel grade at a plane 20 feet below the lake's surface as found at that time, which was nearly the lowest water ever known. A fall of 4 feet was allowed for in the full length of the proposed work. The open cutting, 4,200 feet long, was projected to a depth of 57 feet at its heading, before the tunnel was to be entered. Taking the surface of the lake at 6,225 feet elevation, the summit of the range to be cut under was found to be 7,698 feet above sea level. The tunnel grade would be 1,275 feet below this ridge line. The open-cut work, it was anticipated, would be chiefly in soil, the tunnel work altogether in rock, for the most part probably granite. As projected, this work would debouch into Haines Canyon at a point about 3 miles from and about 1,500 feet above its opening into Carson Valley.

Tahoe outlet regulation dam.—As the survey first mentioned was made for the purpose of studying a scheme for drawing the water of Lake Tahoe to a lower level than the present, through a tunnel into Carson Valley, so the Tahoe outlet regulation dam survey was made to acquire data on which to estimate the cost of holding the water to a higher level than the normal, with the view of drawing down the surplus thus impounded, through the natural outlet, for irrigation of the valleys along the Truckee River.

The intake of Truckee River from Lake Tahoe is about a quarter of a mile from Tahoe City. There already exists a framed timber dam in this channel at a point about 500 feet back from the lake shore line, which is owned by a company claiming the right to use waters of the lake for flushing logs down Truckee River and for other purposes. This dam has three open ways, closable by gates and flash boards, with a floor nearly on a level with the channel grade, and with 11, 12, and 10 feet clear width, respectively. It has a waste way with a crest 75 feet in clear length and 6 feet above the floor grade of the open ways.

The survey was made July 19, 1889. As subsequently found, the waters of the lake afterward fell during that summer about 1·2 feet, to an extreme low water in that autumn. At the time of survey the waste-way crest of the existing dam was 5·05 feet above the water surface of the lake. The survey section was made across the river channel, a few feet above the existing dam. The average height of the banks of the lake and river adjoining this section was found to be 8·5 feet above the lake's surface at the time of the survey, and the general elevation of the channel bed was 2·8 feet below the same water plane. To close the outlet to an elevation equal to that of the banks would require, it was found, a dam about 400 feet long.

As afterward ascertained by Mr. Hall, the lowest known water plane of Tahoe was in October, 1889, when, as above mentioned, the surface was about 1·2 feet lower than at the time of the survey in July of that year. The highest elevation of the lake's waters, as observed at Tahoe City, occurred in the spring of 1886, and was 5·3 to 5·5 feet above the extreme low water of 1889. The high water of 1888 was observed on September 8 at 1·85 feet, and that of 1889 was observed in the early spring of that year at 1·55 feet above the same datum. The high water of the spring of 1890 has been very nearly up to that of 1886, notwithstanding the fact that the outlet gates of the dam remained open during the rising period. These data are grouped here to afford some idea of the problem in part examined by this survey. No survey was attempted of the Truckee River bed as the outlet channel of the lake with a view of commanding the lake's waters to a lower depth than the natural low-water plane.

Truckee reservoir site.—The water-storage scheme, known as the Truckee reservoir project, contemplated a dam across the Truckee River at a point less than a mile above the town of Truckee, and about a quarter of a mile below the outlet of Donner Lake and Cold Creek into the river.

The survey consisted of meandering a level contour around the proposed reservoir space in the Truckee River canyon, and making a cross-section of the canyon at the proposed dam site. The contour was at a level 46 feet below the high-water plane of Donner Lake, as established by the reservoir survey next described. The dam section extended up to the plane of the contour only.

As surveyed, the dam for this reservoir to the height of the contour would be 1,131 feet in length and 70 feet in height above the bed of the Truckee River where crossed. The surveyed contour line was 30,290 feet in length. As demonstrated by this survey, water would be backed by this dam up Truckee Canyon about 2¾ miles to a maximum width of 1,500 feet, and would cover 206 acres in area. The chief waters which it would impound would be those discharged by the main Truckee River. Its utility is a little doubtful, as the work performed by it may be done by the utilization of Lake Tahoe as a storage basin. The Truckee reservoir site, however, has a great advantage over Lake Tahoe, in that it exposes to evaporation an infinitely smaller surface, and if it is shown by further investigation to be necessary to conserve the waters of the main Truckee, this will probably prove the most economical reservoir site for that purpose.

Truckee canal line.—Commencing at the dam site for the proposed Truckee reservoir as last above described, the Truckee canal line survey was carried out on the south side of the river to command the lands of Martis Valley, situated there, and commencing immediately below the town of Truckee. This canal line commenced at an elevation 20 feet below the top of the proposed high-water plane of the reservoir. It was given a fall of 0·4 per 1,000, and was extended to a length of 74,400 feet.

Donner Lake reservoir sites.—Donner Lake, whose outlines are shown on Pl. LXXXVIII, No. 4, occupies a glacial basin lying close under the main crest of the Sierra Nevada range, and lengthwise between two spurs which jut eastward therefrom. Its ordinary water surface is nearly 3 miles long, has a nearly uniform width of a little more than half a mile, and is about 6,095 feet above sea level. It is about 3 miles west of the town of Truckee, and immediately north of and below the line of the Central Pacific Railroad where the ascent of the Sierra is made from the east.

The old glacial basin of Donner Lake extends away eastward beyond the limits of the lake, as a valley, and joins the Truckee River valley near the town of Truckee. Cold Creek Canyon enters the Donner Valley three-fourths of a mile east of the east end of the lake, and joins Donner Creek, the lake's overflow channel, which, flowing east through the valley, turns abruptly to the south, through a gap in one of the ancient moraines, to join the river.

One project for the utilization of Donner Basin contemplated the closing of this outlet gap by a high dam, and of the main valley opening, between the intermediate morainal ridge and the northern mountain spur, by another dam, thus forming a reservoir covering the entire Donner Valley and lake, and at the same time the opening of Cold Creek Valley.

Another project contemplated the construction of a long, low dam across the entire valley, following the location of a later terminal moraine situated about half a mile from the lower end of the present lake.

The total length of the upper contour surveyed was 61,190 feet; the length of the basin thus inclosed was found to be about 5¼ miles, and the width generally about 3,500 feet. The total area inclosed was 2,006 acres. The storage space, without allowance for lowering the lake's surface (which might be effected to decided advantage), has, from the data of this survey, been estimated at 42,827 acre-feet.

Taking the Donner Lake basin alone, without the lower part of Donner and Cold Creek Valley, the length of the 120-foot contour (20 feet above the lake surface) was found to be 40,574 feet; the length of the reservoir space about 3¾ miles; and the width, about 3,250 feet. The area thus inclosed was 1,337 acres, and the storage capacity above the lake's surface is found to be 22,205 acre-feet.

Donner reservoir canal line.—A canal line survey was next made, commencing in the former main opening of the Donner Basin, north of the intermediate morainal ridge mentioned, at the site of the proposed dam No. 2 of the Donner Basin reservoir scheme, and extending around north of the town of Truckee to command lands lying between Truckee River and Prosser Creek.

The grade elevation of the head of this canal line was 30 feet below the proposed high-water plane of the projected reservoir. The grade slope allowed for in the survey was 0·2 per thousand. The line was run as a preliminary to Prosser Creek, a distance of about 29,000 feet.

Independence Lake reservoir.—Independence Lake (see Pl. LXXXVII, No. 2), is a counterpart of Donner, of glacial origin, immediately under the Sierra's crest and held lengthwise between high mountain spurs jut ing out at right angles thereto. The natural dam between these spurs, which forms the lake, is plainly an old moraine. It lies 9 miles in a direct line a little north of west from Donner.

Its ordinary water surface is about 2½ miles in length, somewhat less than half a mile wide, and covers an area of about 709 acres. It is about 7,000 feet above sea level. Its waters escape by Independence Creek, turn northward, and become tributary to the Little Truckee, a main branch of the Truckee River.

In making the survey of this reservoir site, the elevation of the water plane of the lake was taken at 15 feet, because, it would seem, it was proposed to cut through the natural dam and draw the water down to a depth much lower than the natural outlet. The dam section was chosen at a comparatively narrow part of the outlet valley, 1,800 feet beyond the end of the lake, and where the bed of the outlet creek was 12 feet below the water plane of reference.

The margin of the lake and a contour 25 feet above its plane were meandered, and a number of cross-sections of the valley were measured. The lake contour was found to be 29,652 feet in length, and the upper contour 38,061 feet. The reservoir space inclosed by this upper contour was found to be about 3¼ miles long and 2,500 feet in ordinary width, embracing an area of 984 acres. From the base of the dam to the highest contour (not allowing for lowering the lake) the storage space thus held is 23,707 acre-feet in volume.

Webber Lake reservoir, (see Pl. LXXXVII, No. 3).—About 7 miles north of west from Independence Lake, in the summit valley of the famous Henness Pass over the Sierra Nevada range, at an elevation about 6,769 feet above the sea, lies Webber Lake, bordered by a flat, grass-grown meadow. The Little Truckee River rises west of the main range behind Independence Lake, flows north about 10 miles into Webber Lake, and then turning eastward, breaks through the main range.

The lake is nearly round, and covers an area of about 233 acres. A short distance below the canyon narrows. Surveys were made to study this location for reservoir purposes.

The margin of the lake and a contour 20 feet above it were meandered and a number of cross-sections surveyed between these meanders. The upper contour was 39,706 feet in length; the space inclosed by it was about 9,000 feet long, ordinarily 4,000 feet wide, and contained 778 acres. The total capacity for storage (not allowing for lowering the lake) has been estimated at 11,152 acre-feet.

Lower Truckee reservoir No. 1.—The proposition calling for this survey was to store water in the canyon of the lower Truckee River, to be diverted for irrigation on the mesas about and below the town of Wadsworth.

The proposed dam site was 4¾ miles above Wadsworth, on the Big Bend of the Truckee River, and the line extended across from the grade of the Central Pacific Railroad to a point of rocks opposite O'Brien's. The survey was never finished, but afforded the following information.

The proposed dam would be about 1,000 feet long on top, and would have a maximum height of 60 feet above the bed of the river where crossed. Thus projected, the dam's crest would be 86 feet above the plane of the railway track at Wadsworth, 4·6 feet below the rails at the site of the dam, and would back water up the canyon a distance of about 3 miles. The reservoir space would be long and narrow, like that of the upper Truckee, already described.

Lower Truckee reservoir No. 2.—This project is similar to that last above described, the dam site being 5¾ miles above that at O'Brien's, and 3¾ miles below Clark's station on the Central Pacific Railroad. The length of the dam was 870 feet; the height above the river bed, 50 feet; its distance below the plane of the railroad track, 5 feet; and above the top of the projected dam at site No. 1, 90 feet. The length of reservoir space was approximately 3½ miles. This reservoir would also be narrow, and not of large capacity.

Lower Truckee canal lines No. 1, *A and B.*—For the purpose of studying the delivery of water out from the projected Lower Truckee reservoir No. 1, a trial line for a canal was run from its dam on each side of the river, to certain irrigable plains and mesas below.

The north side line, A, commenced at an elevation 15 feet below the top of the dam, and was run on a grade of 2 feet in the mile for a length of 30,800 feet. It was then found that this would not reach the larger body of the lands desired to be commanded.

The south side line, B, also began at an elevation 15 feet below the top of the dam. It was given a grade of 0·2 per 1,000 and was extended to a total length of 50,700 feet. This line was located along the mountain face which comes abruptly to the river on the south side. The design was to reach the lands of Warm Spring Valley, 5½ miles below Wadsworth, and the survey ceased at the commencement of that valley.

Lower Truckee canal lines No. 2, *A and B.*—These lines were run for the study of canal routes for the delivery of water out of Lower Truckee reservoir No. 2. The main line, A, commenced from the Clark's site dam, on a plane a few feet below its crest, and followed the mountain side south of the river to a point just above Wadsworth, and thence swung around to the south, commanding a wide valley and mesa country east of the town above named. It was laid on grades of 1 and 1·5 feet per mile, and was surveyed, as a preliminary, for a distance of 90,000 feet—sufficiently far to establish the fact that it could be carried over a divide known as Ragtown Pass, to deliver water in an arm of Lower Carson Valley. From the main line the branch B was taken off just below the O'Brien dam site. The project was to cross the river by pressure pipes. This line was carried thence a distance of 45,000 feet on a grade of 1 foot per mile, to command lands on the high plateau north of Wadsworth.

Long Valley reservoir (Pl. CXIV, No. 18).—The Upper Carson Valley extends, in a north and south direction, along the eastern base of the Tahoe ridge of the Sierra Nevada Mountains. The main valley is about 14 miles long and 8 miles in width. Joining it at the southern end are, respectively, the valley of the West Carson and the canyon of the East Carson; and these are separated by a plateau tongue of land about 4 miles in width. Lengthwise through this plateau is a decided depression, alternately closing to the form of a canyon and thrice widening into well formed valleys with fine expanses of tillable lands. These openings are known successively as Diamond, Dutch, and Long Valleys. Through them and the joining canyons flows a creek which heads in the east slope of the mountain range south of the main canyon of the West Fork of Carson River. This creek escapes from Long Valley, the lower of the trio, into the East Fork of the Carson. Waters are brought into it from the West Fork of the Carson, over a low divide 11 miles above, for purposes of irrigation in Diamond and Dutch Valleys. Long Valley was thought to present a favorable location for storage, even though it would have to be supplied with water from a canal out of one of the forks of the Carson. Accordingly, it was surveyed as a reservoir site.

This site consists of two valleys side by side and separated by a low ridge. A canyon holding a stream bed escapes from each, consequently it would be necessary to build two dams, one to close each canyon opening. The easternmost of these twin valleys is Long Valley proper; the westernmost, Springmeyer's Valley. Cross-sections of the canyons at the proposed dam sites were surveyed; the top contour of the proposed reservoir space was meandered, and the valleys cross-sectioned.

The office-results for the survey of this reservoir site consist of a plat drawn to a scale of 2,000 feet to the inch, showing a contour plan of the site surveyed for reservoir purposes, including the site already occupied by the Springmeyer reservoir, together with the locations of proposed dams to effect the water storage.

The main dam at Long Valley canyon is 794 feet long and 100 feet maximum height, while the subsidiary dam at Springmeyer's Canyon is 1,510 feet long and 60 feet high in one place. At the full-water plane the Long Valley portion of the site is about 12,000 feet long and 2,200 feet wide; the Springmeyer Valley 7,000 feet long and 2,300 feet wide. The top contour around both valleys was found to measure 43,159 feet, embracing an area of 1,086 acres. The total capacity of the site as a whole was determined to be 34,425 acre-feet.

The diverting weir on the East Fork of the Carson River is 431 feet long and 98 feet high. The canal to deliver water thence into Long Valley has its bed at a place 5 feet below the full-water plane of the reservoir. The total length of the canal is 6,300 feet, 1,100 feet of which would be a tunnel through soft rock. The total grade slope is 5 feet.

Long Valley irrigation-canal lines.—For study of the delivery of waters stored in Long Valley to the lands of Carson Valley two canal surveys were made from the Long Valley dam site. The west side line commenced at a plane 50 feet below the top of the dam. The grade was 0·5 per 1,000, and the length surveyed 8,352 feet. The east side line commenced at a plane 50 feet below the top of the dam. The grade was 0·5 per 1,000, and the length surveyed 10,397 feet. The crossing of the East Carson River was 1,080 feet long and the head of pressure 160 feet.

The west side project was for the delivery of water on the mesa between the East and West Carson channels. The east side project was for the delivery of water to command the highest parts of the "Twelve Mile Desert," lying on the east side of the main valley. This latter project involved a crossing of the East Carson River canyon by pressure pipes under the 160-foot head, as shown above.

East Carson canal lines.—For the purpose of ascertaining the feasibility of commanding the Carson Valley "Twelve Mile Desert" above referred to by a work taking its supply immediately from the East Carson River, a canal-line survey was made.

A diverting dam was projected at a point about 3,300 feet by the river's course below the location of the tunnel through to Long Valley reservoir from the canyon described above. Apparently this dam was intended also to store water in the canyon. As surveyed, its length on top is recorded at 1,180 feet; its height is 134 feet.

Commencing on the west bank at this dam, at a plane 50 feet below the dam crest, a canal grade line was carried down the canyon 9,300 feet; then across the canyon by pipes 480 feet under 115 feet of pressure; then to a total length of 12,593 feet, making one other canyon crossing of 290 feet in length and 85 feet in depth. This line joined the Long Valley reservoir east side canal line at a point just east of its crossing of the East Carson; and its continuation thence was evidently intended to follow the former described line, commanding the desert lands above referred to.

Long Valley supply-canal line, West Carson.—A special survey was made for a site at which to locate a dam for the diversion of water from the West Carson River, with the view to delivery thence by canals, as follows: The site was chosen at a point about a mile above Woodford's, and the dam was to be 458 feet long and 20 feet in height above the river bed. Commencing at this site, the line extended around the south bank of the river over a low divide and across the head of Diamond Valley to the creek heretofore spoken of as flowing through Long Valley. The intention of the projected canal was to supply water to the Long Valley reservoir.

Long Valley reservoir supply-canal, East Carson.—For the purpose of studying the matter of diverting water, first, for the supply of the Long Valley reservoir, and second, for irrigation of the east side of the main Carson Valley, a chain and level survey was made of the East Fork of Carson River for a length of several miles. With a view to supplying water for storage in Long Valley a canal line survey was made out of the East Fork of Carson River to the head of that valley. This canal line commenced at an elevation 5 feet below the top of the diversion weir. The grade was 0·5 per 1,000 and the length of the line 10,400 feet.

West Carson canal line.—This survey was made for the purpose of taking the waters of the West Carson around the base of the mountain northward, to command the lands on the western side of the Upper Carson Valley. Diversion was to be made at the diversion weir above spoken of. The line commenced on a plane 5 feet below the top of the diverting weir; the grade thence was 0·5 per 1,000 and the length 26,300 feet.

Hope Valley reservoir survey.—Lying in a north and south direction, between two parallel ridges of the Sierras, just about at the junction of the Tahoe range with the main range ot the Sierras, is one of the largest summit valleys of the Sierra Nevadas. It commences about 10 miles from the southern end of Lake Tahoe at an elevation of 7,050 feet above the sea, or 850 feet above the lake, and extends southerly nearly 10 miles. It is separated into two somewhat distinct parts by a low rocky ridge, lying across the general direction of the valley.

The lower division of this great depression is known as Hope Valley; the upper division, as Faith Valley. The waters of the West Carson River drain the mountain slopes above and around these valleys; the main channel winds northerly and longitudinally through them, and near the north end of Hope Valley turns abruptly to the east and plunges headlong through a deep rock-bound canyon down to the main valley, already described.

At first glance Hope Valley seems to present an exceptionally favorable opportunity for water storage; so a survey was made to test its capacity and the question of cost of dam. As projected to a height of 153 feet above the bed of the creek in the line of the site, the dam would be 1,560 feet in length. The top contour was meandered and the valley cross-sectioned, the total length of the meander being 62,762 feet. The length of the reservoir space thus inclosed is 4½ miles; ordinary width, 3,500 feet; area, 1,803 acres; and holding capacity, 4,129,923,600 cubic feet, or 94,810 acre-feet.

Lahontan system.

INDEPENDENCE LAKE.—RESERVOIR SITE No. 2.

T. 19 N., R. 15 E., Mount Diablo meridian, California.

		Acres.	Acres.
Section 33	SE. ¼ of the SE. ¼		40
Section 34	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
	S. ½ of the SW. ¼	80	
			320
Section 35	All of the NW. ¼	160	
	All of the SW. ¼	160	
			320

T. 18 N., R. 15 E., Mount Diablo meridian.

Section 2	NW. ¼ of the NW. ¼		40·31
Section 3	N. ½ of the NE. ¼	80	
	SW. ¼ of the NE. ¼	40	
	All of the NW. ¼	160	
	NW. ¼ of the SW. ¼	40	
			320
Section 4	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
	S. ½ of the NW. ¼	80	
	NE. ¼ of the NW. ¼	40·50	
	All of the SW. ¼	160	
			560·50
Section 5	SE. ¼ of the SE. ¼		40
Section 8	All of the NE. ¼		160
Section 9	N. ½ of the NW. ¼		80
Total area segregated			1,880·81

WEBBER LAKE.—RESERVOIR SITE No. 3.

T. 19 N., R. 14 E., Mount Diablo meridian.

		Acres.	Acres.
Section 20	SE. ¼ of the SE. ¼		40
Section 21	S. ½ of the SW. ¼	80	
	SW. ¼ of the SE. ¼	40	
			120

		Acres.	Acres.
Section 28	All of the NW. ¼	160	
	All of the NE. ¼	160	
	All of the SW. ¼	160	
	W. ½ of the SE. ¼	80	
	NE. ¼ of the SE. ¼	40	
			600
Section 29	E. ½ of the NE. ¼	80	
	E. ½ of the SE. ¼	80	
	SW. ¼ of the SE. ¼	40	
			200
Section 32	E. ½ of the NW. ¼	80	
	All of the NE. ¼	160	
	N. ½ of the SE. ¼	80	
			320
Section 33	W. ½ of the NW. ¼	80	
	NE. ¼ of the NW. ¼	40	
	NW. ¼ of the SW. ¼	40	
	NW. ¼ of the NE. ¼	40	
			200
Total area segregated			1,480

DONNER LAKE.—RESERVOIR SITE NO. 4.

T. 17 N., R. 16 E., Mount Diablo meridian.

		Acres.	Acres.
Section 7	SW. ¼ of the SW. ¼		34·75
Section 16	Entire section		640
Section 17	Entire section		640
Section 18	All of the NE. ¼	160	
	All of the NW. ¼	160	
	All of the SE. ¼	160	
	E. ½ of the SW. ¼	80	
	NW. ¼ of the SW. ¼	40	
			600

T. 17 N., R. 15 E.

Section 13	Entire section		640
Section 14	Entire section		640
Section 15	SE. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
			200
Total area segregated			3,394·75

SPRINGMEYER RESERVOIRS NOS. 3 OR 17.—LONG VALLEY RESERVOIR NO. 18.

T. 12 N., R. 20 E., Mount Diablo meridian.

Section 34	SE. ¼ of the NE. ¼	40	
	All of the SE. ¼	160	
			200

		Acres.	Acres.
Section 35..	SW. ¼ of the NW. ¼	40	
	W. ½ of the SW. ¼	80	
			120

T. 11 N., R. 20 E., Mount Diablo meridian.

Section 2....	W. ½ of the NW. ¼		80·20
Section 3..	All of the NE. ¼	159·74	
	All of the SE. ¼	160	
	All of the NW. ¼	158·58	
	All of the SE. ¼	160	
			638·32
Section 4..	NE. ¼ of the NE. ¼	39·15	
	S. ½ of the NE. ¼	80	
	All of the SE. ¼	160	
			279·15
Section 9....	All of the NE. ¼		160
Section 10..	All of the NE. ¼	160	
	NW. ¼ of the SE. ¼	40	
	N. ½ of the NW. ¼	80	
	SE. ¼ of the NW. ¼	40	
			320
Total area segregated			1,797·67

UTAH.

In Utah, in addition to the general reconnaissance of the storage facilities at the headwaters of the Sevier River and other streams, a careful survey was made of Utah Lake. This survey, run by level and transit around the lake, was for the purpose of determining the area which would be covered by damming or holding back the flood water. A description of the location and physical features of this body of water is to be found in this report under the head of Hydrography, and it will suffice to state here that after a careful study it was found that, on account of the excessive evaporation from such an enormous surface, the lake was too large to act in an economical manner as a storage reservoir. On the other hand, while it may not be advisable to hold back the water to a point above that of the average height, yet there is sufficient evidence to show that natural forces at times may raise the water level and increase the area to abnormal proportions by backing water over the great fringing marshes on the east and south. This land being, therefore, the natural flood ground of the lake, should be reserved up to the high-water line. Accordingly, the segregation, as shown on Pl. xcv and given in the following lists, was made to include not only the bed but the lowlands up to mean high water.

Utah Lake Reservoir System.

T. 5 S., R. 1 W., Salt Lake meridian.

			Acres.
Section 23	All of the E. ½		320
Section 24	Entire section		640
Section 25	Entire section		640
Section 35	All of the E. ½		320
Section 36	Entire section		640

T. 6 S., R. 1 W.

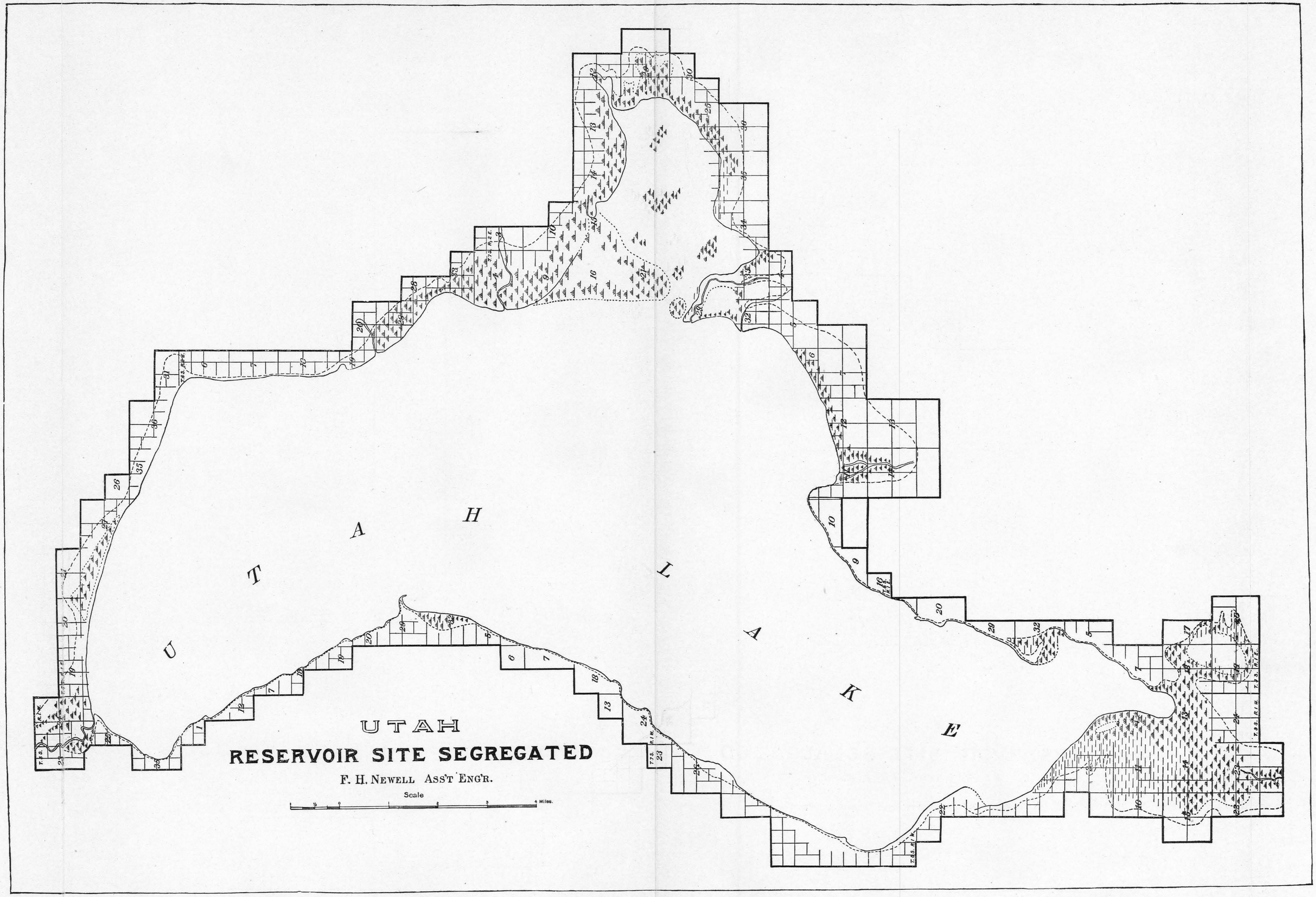
Section 1	All of the NW. ¼	160	
	All of the E. ½	320	
			480
Section 12	All of the NE. ¼		160

T. 7 S., R. 1 W.

Section 13	All of the SE. ¼	160
Section 23	All of the SE. ¼	160
Section 24	Entire section	640
Section 25	Entire section	640
Section 26	Entire section	640
Section 34	All of the E. ½	320
Section 35	Entire section	640
Section 36	Entire section	640

T. 8 S., R. 1 W.

Section 1	Entire section	640
Section 2	Entire section	640
Section 3	Entire section	640
Section 4	All of the E. ½	320
Section 9	All of the E. ½	320
Section 10	Entire section	640
Section 11	Entire section	640
Section 12	Entire section	640
Section 13	Entire section	640
Section 14	Entire section	640
Section 15	Entire section	640


UTAH LAKE
UTAH
RESERVOIR SITE SEGREGATED
F. H. NEWELL ASS'T ENG'R.
Scale
4 Miles

			Acres.
Section 16	All of the E. ½		320
Section 22	All of the NW. ¼	160	
	All of the E. ½	320	
			480
Section 23	Entire section		640
Section 24	Entire section		640
Section 25	Entire section		640
Section 26	Entire section		640
Section 27	All of the E. ½		320
Section 34	All of the E. ½		320
Section 35	Entire section		640
Section 36	Entire section		640

T. 9 S., R. 1 W.

Section 1	Entire section	640
Section 2	Entire section	640
Section 3	All of the SE. ¼	160
Section 10	All of the E. ½	320
Section 11	Entire section	640
Section 12	Entire section	640
Section 13	Entire section	640
Section 14	Entire section	640
Section 15	Entire section	640
Section 22	All of the E. ½	320
Section 23	Entire section	640
Section 24	Entire section	640
Section 26	All of the N. ½	320
Section 27	All of the NE. ¼	160

T. 5 S., R. 1 E.

Section 19	All of the S. ½	320
Section 20	All of the S. ½	320
Section 21	All of the S. ½	320
Section 26	All of the SW. ¼	160
Section 27	Entire section	640
Section 28	Entire section	640
Section 29	Entire section	640
Section 30	Entire section	640
Section 31	Entire section	640
Section 32	Entire section	640
Section 33	Entire section	640
Section 34	Entire section	640
Section 35	Entire section	640
Section 36	Entire section	640

T. 6 S., R. 1 E.

			Acres.
Section 1	Entire section		640
Section 2	Entire section		640
Section 3	Entire section		640
Section 4	Entire section		640
Section 5	Entire section		640
Section 6	Entire section		640
Section 7	Entire section		640
Section 8	Entire section		640
Section 9	Entire section		640
Section 10	Entire section		640
Section 11	Entire section		640
Section 12	Entire section		640
Section 13	Entire section		640
Section 14	Entire section		640
Section 15	Entire section		640
Section 16	Entire section		640
Section 17	Entire section		640
Section 18	All of the NW. ¼	160	
	All of the E. ½	320	
			480
Section 19	All of the NE. ¼		160
Section 20	Entire section		640
Section 21	Entire section		640
Section 22	Entire section		640
Section 23	Entire section		640
Section 24	Entire section		640
Section 25	Entire section		640
Section 26	Entire section		640
Section 27	Entire section		640
Section 28	Entire section		640
Section 29	Entire section		640
Section 32	Entire section		640
Section 33	Entire section		640
Section 34	Entire section		640
Section 35	Entire section		640
Section 36	Entire section		640

T. 7 S., R. 1 E.

Section 1	Entire section	640
Section 2	Entire section	640
Section 3	Entire section	640
Section 4	Entire section	640
Section 5	Entire section	640
Section 6	All of the SE. ¼	160

		Acres.
Section 7	All of the E. ½	320
Section 8	Entire section	640
Section 9	Entire section	640
Section 10	Entire section	640
Section 11	Entire section	640
Section 12	Entire section	640
Section 13	Entire section	640
Section 14	Entire section	640
Section 15	Entire section	640
Section 16	Entire section	640
Section 17	Entire section	640
Section 18	Entire section	640
Section 19	Entire section	640
Section 20	Entire section	640
Section 21	Entire section	640
Section 22	Entire section	640
Section 23	Entire section	640
Section 24	Entire section	640
Section 25	Entire section	640
Section 26	Entire section	640
Section 27	Entire section	640
Section 28	Entire section	640
Section 29	Entire section	640
Section 30	Entire section	640
Section 31	Entire section	640
Section 32	Entire section	640
Section 33	Entire section	640
Section 34	Entire section	640
Section 35	Entire section	640
Section 36	Entire section	640

T. 8 S., R. 1 E.

Section 1	Entire section	640
Section 2	Entire section	640
Section 3	Entire section	640
Section 4	Entire section	640
Section 5	Entire section	640
Section 6	Entire section	640
Section 7	Entire section	640
Section 8	Entire section	640
Section 9	Entire section	640
Section 10	All of the N. ½	320
Section 11	Entire section	640
Section 12	Entire section	640
Section 13	Entire section	640
Section 14	Entire section	640

		Acres.
Section 16	All of the NW. ¼	160
Section 17	Entire section	640
Section 18	Entire section	640
Section 19	Entire section	640
Section 20	Entire section	640
Section 23	All of the N. ½	320
Section 24	All of the N. ½	320
Section 29	All of the W. ½	320
Section 30	Entire section	640
Section 31	Entire section	640
Section 32	All of the W. ½	320

T. 9 S., R. 1 E.

Section 5	All of the W. ½	320
Section 6	Entire section	640
Section 7	Entire section	640
Section 17	All of the W. ½	320
Section 18	Entire section	640
Section 19	Entire section	640
Section 20	Entire section	640

T. 5 S., R. 2 E.

Section 31	All of the S. ½	320

T. 6 S., R. 2 E.

Section 6	Entire section		640
Section 7	Entire section		640
Section 18	Entire section		640
Section 19	Entire section		640
Section 20	All of the S. ½		320
Section 28	All of the SW. ¼		160
Section 29	Entire section		640
Section 30	Entire section		640
Section 31	Entire section		640
Section 32	Entire section		640
Section 33	All of the NW. ¼	160	
	All of the S. ½	320	
			480

T. 7 S., R. 2 E.

Section 3	All of the W. ½	320
Section 4	Entire section	640
Section 5	Entire section	640
Section 6	Entire section	640
Section 7	Entire section	640

			Acres.
Section 8	Entire section		640
Section 9	Entire section		640
Section 10	All of the NW. ¼	160	
	All of the S. ½	320	
			480
Section 13	Entire section		640
Section 14	Entire section		640
Section 15	Entire section		640
Section 16	Entire section		640
Section 17	Entire section		640
Section 18	Entire section		640
Section 19	Entire section		640
Section 20	Entire section		640
Section 21	Entire section		640
Section 22	Entire section		640
Section 23	Entire section		640
Section 24	Entire section		640
Section 25	Entire section		640
Section 26	Entire section		640
Section 27	Entire section		640
Section 28	Entire section		640
Section 29	Entire section		640
Section 30	Entire section		640
Section 31	Entire section		640
Section 32	Entire section		640
Section 33	Entire section		640
Section 34	Entire section		640
Section 35	Entire section		640
Section 36	Entire section		640

T. 8 S., R. 2 E.

Section 4	All of the N. ½	320
Section 5	Entire section	640
Section 6	Entire section	640
Section 7	Entire section	640
Section 8	All of the W. ½	320

T. 7 S., R. 3 E.

Section 18	Entire section		640
Section 19	Entire section		640
Section 20	All of the W. ½		320
Section 30	All of the NE. ¼	160	
	All of the W. ½	320	
			480

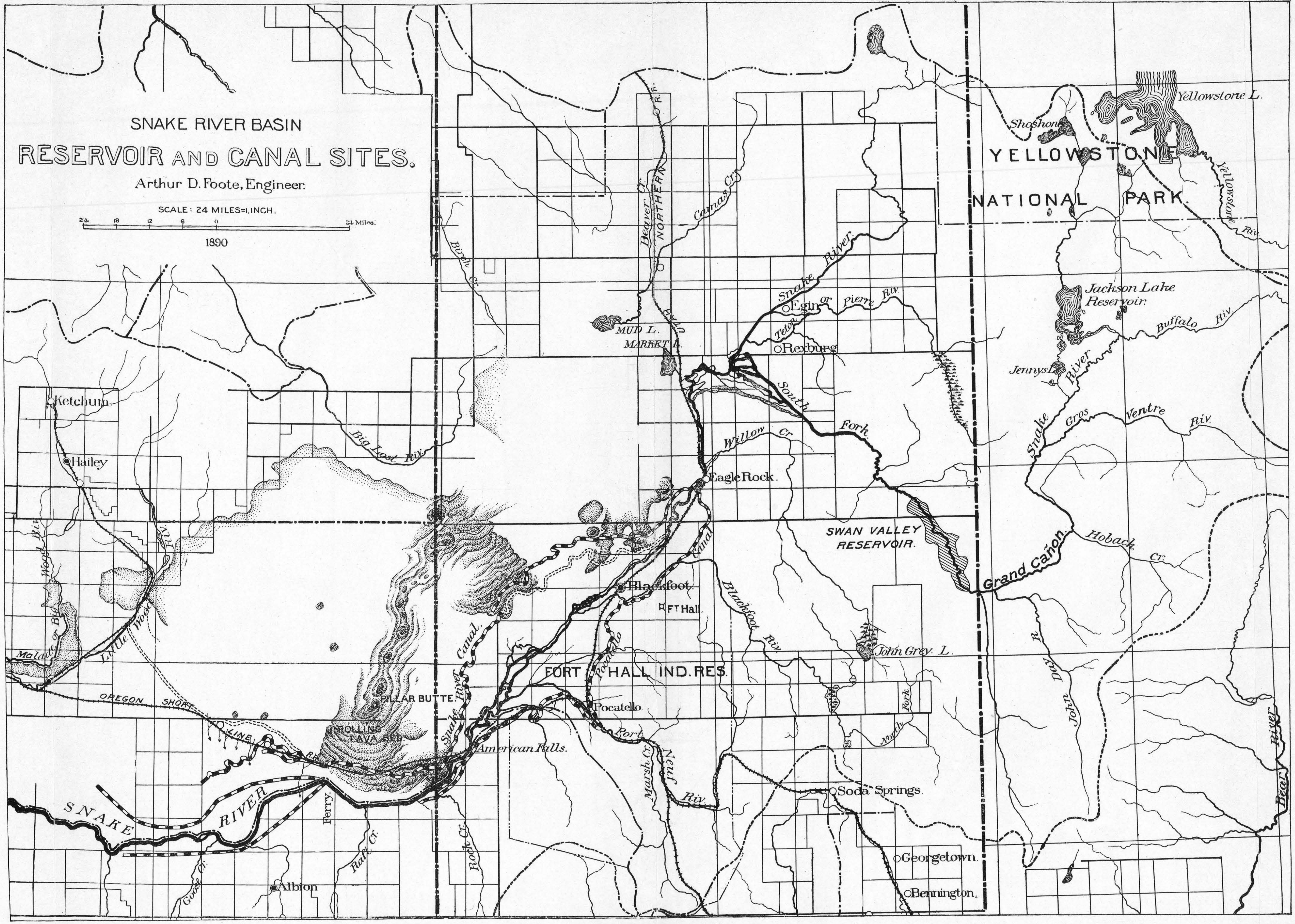
Total area segregated, 125, 440 acres.

SNAKE RIVER DIVISION.

Mr. A. D. Foote, division engineer, was assigned to the charge of this division, and commenced field work in June, 1889. He immediately organized a party under the charge of Mr. A. W. Wiley, assistant engineer, and began the work of surveying canal lines to be diverted from the Snake River below Eagle Rock. Mr. Wiley was engaged on the field and office work connected with these surveys until March 14, 1890, when he resigned. On the same day Mr. F. J. Mills was engaged as assistant engineer, and continued the survey of the Snake River canal lines until the end of August, 1890, at the close of the irrigation surveys.

After starting Mr. Wiley's party in July, 1889, Mr. Foote undertook a personal reconnaissance on the headwaters of the Snake in search of reservoir sites. (See Pl. XCVI.) In the performance of this work he examined the South Fork of the Snake River, on which he found the Swan Valley reservoir site, which has a storage capacity of about 1,500,000 acre-feet. Higher up, near the head of the same fork, at Jackson's Lake, a second reservoir site with a capacity of 500,000 acre-feet was discovered. On the Falls River branch of the North Fork, the Falls River reservoir site, with a capacity of 500,000 acre-feet, was discovered, and a preliminary examination of it made. Mr. Foote reports that there is a possibility of finding one or two other reservoir sites on the South Fork or its tributaries, but that in all probability these will be unnecessary, since the large sites just described will doubtless prove capable of storing all the water available.

Swan Valley is of dimensions so enormous that it can probably be made into one of the largest reservoirs in the United States. It is about 8 miles long by 4 miles wide, and very level. Through the center of it the Snake River winds with a slow velocity and very slight fall. The walls bounding it are steep and high, and the outlet is a narrow gorge with perpendicular rock sides and a rock bottom. A dam can easily be constructed across it 100 feet in height if necessary. Into this valley the drainage of nearly the entire South Fork of the


SNAKE RIVER BASIN
RESERVOIR AND CANAL SITES.
Arthur D. Foote, Engineer.
SCALE: 24 MILES=1 INCH.
24 18 12 6 0 24 Miles.
1890
YELLOWSTONE
NATIONAL PARK.
Yellowstone L.
Shoshone
Yellowstone Riv.
Jackson Lake Reservoir.
Buffalo Riv.
Jennys L.
Snake River
Gros Ventre Riv.
Grand Cañon
Hoback Cr.
John Day R.
Bear River
SWAN VALLEY RESERVOIR.
South Fork
Snake River
Egin
Teton or Pierre Riv.
Rexburg
Camas Cr.
Beaver Cr.
NORTHERN
UTAH
R.R.
MUD L.
MARKET L.
Birch Cr.
Big Lost Riv.
Willow Cr.
Eagle Rock.
Canal
Blackfoot
Ft Hall
Blackfoot Riv.
John Grey L.
FORT HALL IND. RES.
Pocatello
Pocatello
Port Neuf Riv.
Marsh Cr.
North Fork
Soda Springs
Georgetown
Bennington
Ketchum
Hailey
Big Wood Riv.
Little Wood Riv.
Malade or Big
OREGON SHORT LINE R.R.
PILLAR BUTTE
ROLLING LAVA BED
Snake River Canal.
American Falls.
SNAKE RIVER
Ferry
Raft Cr.
Rock Cr.
Goose Cr.
Albion

Snake River passes. From the reconnaissance it is found that the area of this valley averages 32 square miles, in which water can be impounded to a depth of 100 feet, and about 25 square miles to a depth of 50 feet. A loose rock dam 125 feet in height will store all the water entering this valley, thus avoiding the expense of constructing a masonry dam. Immediately above Swan Valley is another reservoir site of nearly equal capacity; and without examining in detail Mr. Foote is of opinion that several good sites can be found on this river between Swan Valley and Jackson's Lake.

The Swan Valley dam, for holding back a million and a half acre-feet, is in such a position as to avoid the necessity of building a waste weir. Raising the water will cause the surplus to flow over a low granite-bound gap to one side of the present channel, thus affording a natural waste weir. By this favorable location the cost of the dam, although large, will not exceed 33⅓ cents per acre-foot. This valley has a watershed of about 5,365 square miles, the run-off of which is at least 4,000,000 acre-feet.

Jackson's Lake, with a watershed of about 840 square miles, the run-off of which is not less than 9,000,000 acre-feet, would need a dam only about 20 feet in height to impound 500,000 acre-feet. Such a dam will not cost more than 20 cents per acre-foot. The Falls River reservoir site is also favorable, and the dam should not cost over 20 cents per acre-foot.

The surveys for the Pocatello Canal line include a canal to be diverted from the Snake River at Eagle Rock. This was surveyed for a distance of 100 miles, in the course of which it crossed the Blackfoot River, and farther on the Portneuf River at Pocatello, finally terminating and tailing into the Snake River above American Falls. It was intended that this canal should have at its head a bed width of 50 feet, with a depth of 7½ feet of water. At this point its calculated velocity of flow was 3·46 second-feet, and its discharge was estimated to be 1,492 second-feet. This canal, if built, will command 216,400 acres of arable land, all of which has excellent soil.

Two canal lines were surveyed from the American Falls, on the Snake River, the first or lower one having a total length of 13 miles of surveyed line, after which it was abandoned as impracticable, owing to the difficulties of construction encountered. The object of both these canals was to irrigate the plains and valleys adjacent to Raft River and Goose Creek. The arbitrary size assumed for the lower canal was 60 feet bed width and 10 feet depth of water, with a slope of 0·3 of a foot per 1,000.

After the abandonment of this line the upper American Falls survey was commenced at a point 15 miles east of the falls, on Bannock Creek. This canal was to catch the tail water of Pocatello Canal, thus obtaining a higher line in hopes that it would reach the lands above referred to. After 17 miles of this canal had been surveyed it was discontinued because of the difficulties of construction encountered.

Toward the close of the same year Mr. Wiley commenced the survey of a canal to be diverted from the north side of the Snake River, heading a little below Eagle Rock. Owing to the lateness of the season, this canal survey was made for a short distance only, and work was discontinued for the year. Early in 1890 the work was again taken up by Mr. Mills, and main and trial lines run with a view to carrying the water onto the Snake River desert, north and west of the Snake River. It was hoped to cross a ridge extending between Big and Pillar Buttes, but this proved impracticable. This line as ultimately designed will cover an area of at least 600,000 acres of good arable land.

During the spring and summer of 1890 Mr. Mills also made surveys for two canals from Minidoka Ferry, one to irrigate the lands on the south side of the river in the neighborhood of Goose Creek and Bruneau Plains, and the other from the north side with the intention of commanding the country around Shoshone. Surveys were also made for a canal diverted from the Snake River at Salmon Falls, and one to utilize the water of the Big Springs for the purpose of irrigating the tract of land in the neighborhood of Mountain Home. These latter surveys, however, produced only negative results, as they showed the canals contemplated to be too expensive construction.

The topography of this great valley, from the mouth of the

Weiser River to the confluence of the Teton, some 500 miles, presents three great plains of inclination. The upper one, from the Teton to the American Falls, descends at an average rate of 6 feet per mile, the second from the American Falls to Glenn's Ferry at an average of 14 feet, and the third to the Weiser at the average fall of 4 feet per mile. Across the whole valley, from foothill to foothill, at the American Falls, there is a dike of very hard volcanic rock, over which the river has cut for itself a weir, and at once descends with a drop of about 50 feet, again dropping at the Twin Falls 90 feet, and at the great Shoshone Falls, 3 miles below Twin Falls, it leaps over a cascade of 310 feet in height.

It is the surface of the river and not the valley that shows the break of grade at these points. Above the American Falls the valley lands are not much higher than the river. Below the American Falls the river runs continuously in a canyon of variable depth, but always too deep to be tapped for irrigating the high plains of Cassia, Owyhee, Elmore, and Logan Counties. Thus it is seen that any canal for purposes of irrigating this plain must be diverted from the river before it enters the deeper portions of this canyon.

The bottom of the basin or valley proper has an area of about 15,000,000 acres. This valley, once a lake, is now covered with one vast sheet of lava, great fields of which are still as black and rugged as when first cooled, while other portions have by decomposition changed into smooth fertile lands. So strong and persistent is this lava field that for 400 miles along the valley not a stream of any kind has been able to force its way across it into the Snake River.

The Snake River, heading in the Teton, Wind River, and Green River Mountains, at the eastern end of the basin, flows westward on top of the lava for the first 100 miles after entering the valley, and then at the American Falls has cut a deep channel into the lava and continues like a mighty canal for the greater part of its course to the Columbia River. The Snake River forms the central axis of the whole drainage system of the valley, and into it all the waters from the surrounding mountains eventually find their way.

CANAL SURVEYS.

At the beginning of the season there were few or no data obtainable to guide Mr. Foote in the solution of the irrigation problems presented by the Snake River Valley. It was evident that the greatest economy in the use of the water, as well as the cheapest system of canals, required that the water should be diverted first by canals heading at or near the entrance of the river into the plains, and be afterward again diverted lower down at such points as would make no canal too long, and would, at the same time, make each canal supplement the canal above and catch the drainage from it.

Realizing also that there was probably much more land in the valley than the uncontrolled flow of the Snake River would irrigate, rapid reconnaissances of the headwaters of the river were made for the purpose of locating and describing such sites as appeared favorable for the economical storage of water.

The examination of the valley with reference to irrigated and irrigable lands was also necessary in order to locate the canal lines, considering the main valley as beginning where the South Fork enters it. The Eagle Rock and Willow Creek Canal Company have their headworks at the ideal point for the complete and proper irrigation of their portion of the valley, and it is hoped that this canal may be enlarged and so managed as to carry out its proper mission.

With this view a canal line, called the Pocatello line, was run from a point on the river favorable for diversion, 2 miles below Eagle Rock, which would supplement the above-named canal and cover all the lands in the valley on the south and east side of the river above the American Falls, diverting on its way the waters of the Blackfoot and Portneuf Rivers. The Idaho Canal Company is now practically carrying out this plan by constructing a canal to embrace the same area, though it takes its water from the river a few miles above.

The object of the survey of the Pocatello canal line was to determine the feasibility of irrigating certain desert lands on the south side of the Snake River, in the southern half of Bingham County, Idaho.

As the large tract of desert land south of the junction of the North and South Forks of the Snake River is already irrigated or capable of irrigation as far south as the town of Eagle Rock by canals already completed or in process of construction, the survey was started at a point on the Snake River about 1½ miles south of the town of Eagle Rock, in the southeast quarter of the southwest quarter of Sec. 25, T. 2 N., R. 37 E. of Boisé meridian, at an exceptionally favorable site for the location of headworks for the diversion of the waters of the Snake River.

These headworks, as at present planned, will consist of a rock-fill dam, 185 feet long, with a maximum height above the bed of the river of 55 feet, and a waste weir of masonry about 900 feet in length, with a maximum height of 15 feet. The cross-section adopted for the first section canal, on the south side of the river, has a bottom width of 50 feet, side slopes of 1 to 1, and a water depth of 7½ feet.

The elevation of the bottom of the canal at the headgates is 4,717 feet. The grade rate is 0·3 of a foot per 1,000 feet. This gives a calculated velocity of 3·46 feet per second, and a discharge of 1,492 second-feet. For the first mile of its course the canal will follow the bank of the river closely, with a cut about 12 feet in depth. From there on it continues very nearly at grade to the crossing of the Utah and Northern Railway, whence it continues through a very level country until the Blackfoot River is reached, at the twentieth mile.

The Blackfoot River, which the canal line follows for the next 16 miles of its course, has an average width of 50 feet, with banks 8 feet high, and an average fall of 5·6 feet per mile.

No improvements will be needed in the river bed to make it capable of carrying the water of the canal. The velocity of flow due to the fall of 5·6 feet per mile will be checked by the very crooked channel, while the banks are protected from erosion by a dense growth of willows, and the river bed is formed of a very stiff clay.

The canal leaves the river at a point about 3 miles southeast of the town of Blackfoot and 38½ miles by the line from the head of the canal on Snake River. The diversion of the canal from the Blackfoot will be effected by a masonry weir across the river, connected by earth dikes with the high ground on each side of the river.

The line now follows the base of the Portneuf Range upon a favorable grade, crossing Ross Creek without much difficulty, whence it continues on an almost perfect grade line through a part of the cultivated lands of the Fort Hall Indian Reservation. This favorable country continues, with only occasional trifling excavations or fills, until it finally reaches the town site of Pocatello, where it drops over a lava bench into the Portneuf River, making a fall of 14 feet between the bottom of the canal and the river bed. The Portneuf River at this point is a stream about 50 feet wide, with banks 8 feet in height. The canal will follow the Portneuf River, and so avoid an independent crossing of the Oregon Short Line Railway, which bridges the river, and will then be diverted from the Portneuf by a masonry weir across the river. The last section of the canal is in favorable country, encountering little or no heavy earthwork.

The line from Pocatello to Dry Gulch is not high enough to follow the base of the foothills, and leaves uncovered a strip of land between the canal and the foothills amounting to about 18,000 acres. This land can be covered only by a small canal taken out of the Portneuf River some miles above the point where the present line leaves it.

Between the head of the canal and the Blackfoot River are 74,480 acres of land beneath the canal; between the Blackfoot and the Portneuf Rivers are 107,200 acres, and between the Portneuf and the American Falls there are 34,720 acres, making a total of 216,400 acres of reclaimable land, all of which has an exceptionally fine soil.

Of this land, about 141,000 acres are on the Fort Hall Indian Reservation, and the remaining 75,400 only are open to settlement.

It was very important to continue this system, if possible, by diverting the water again at the American Falls. After the two surveys above referred to were made, it was found that the cost would be prohibitory, and the plan of irrigating the rich lands of Marsh and Goose Creek Valleys with water derived from this source was reluctantly abandoned.

A point half a mile above the Minnidoka Ferry was next selected as a canal head, and a line run on the south side of the river as far as Cottonwood Creek. This line was run for a distance of 35 miles, crossing Goose Creek Valley. The object of running this canal was to ascertain if it were feasible to cross a high sand ridge on the west side of Marsh Creek near the river. As this was found possible, there will be no difficulty in covering a tract of half a million acres, and possibly more than that, on the south side of the valley. With this line completed, the south side of the main river has been thoroughly explored, as there is no further opportunity for diversion lower down the river.

On the north side of the main river a canal line was run from an excellent weir site 2 miles below Eagle Rock, by means of which water could be diverted to supply this and the Pocatello Canal. This canal line covers about 250,000 acres of good land above the American Falls. When projected it was hoped that it might be run farther to the northward and thus cover much more land before getting opposite the falls; but it was found that a range of extinct volcanoes extended between Pillar and Big Buttes, thus barring its progress in a westerly direction. These cones, which are not shown on the maps of the country, rise from 5,000 to 7,000 feet, with extremely flat slopes, and are the center from which extended the great lava flow covering the Snake River plains. They form a mass of rugged, undecomposed lava, which is utterly sterile.

The canal line skirts the edge of this lava field, crossing the Oregon Short Line Railway about 4 miles west of American Falls, and recrossing it about 10 miles farther on, turning to the northward and reaching the Little Wood River about 15 miles north of Shoshone. The country covered by this canal line consists almost entirely of excellent land. The area covered above the American Falls amounts to about 250,000 acres; that below the American Falls amounts to nearly 1,000,000 acres, of which 600,000 acres are of excellent quality for cultivation. The great length of the canal lines to cover this lower land (about 220 miles) is the *most serious objection* to this line.

A line was run from the north side of Minnidoka Ferry, heading at the same point as the South Minnidoka Canal, with the intention of covering a great portion of the land below the lower end of the Snake River Canal, thus doing away with the great length of that line and permitting its cross-section to be reduced. It was expected that this canal could be extended to cover the land as far as Shoshone and Mountain House. Unfortunately this line was found impracticable, owing to the great expense which would be incurred in its construction.

The line left the river most favorably, but was not high enough to keep far away from it. It worked to the northward and commanded about 100,000 acres of good land above Starrh's Ferry. But at 4 miles below this point the line returned to the river bank and extended along the lava wall of the canyon for nearly 4 miles, involving work that would cost as much as $150,000 per mile. After 4 miles of this canyon work the line again left the river and extended toward Shoshone in a reasonably direct manner, but the country encountered was rolling lava, with little earth over it, thus making a necessarily expensive line. After running some 35 miles through this country the line was decided to be impossible and was abandoned.

A short distance above the Salmon Falls of the Snake River a mass of water bursts from the canyon wall on the north side and falls 150 feet into the river. These "Big Springs," as they are called, issue from a horizontal fissure between two layers of lava about 150 feet below the crest of the wall. The aggregate amount of water thus discharged into the river within a distance of one-fourth of a mile is about 4,000 second-feet. The different outlets through which this water issues are scattered irregularly along the bluff, but on the same level, for a distance of about one-fourth of a mile, though smaller jets issue from the bluff at intervals for several miles.

By aneroid connected with the railroad elevations at Bliss, the elevation of the outlet appeared to be about 3,000 feet, while the railroad station at Mountain Home is 3,145 feet in elevation. As about 75 miles of canal would be required to conduct this water to the neighborhood of Mountain Home, it was considered, provided the aneroid elevations were correct, that the source of supply was not sufficiently high for the purpose desired.

In order to verify these observations, the party which had been conducting the Minnidoka Canal surveys under Mr. Mills was moved early in August, 1890, to this point, with the intention of making a canal survey. The line was run from the Big Outlet down the river, with the hope of getting it back over the bluffs within a reasonable distance. About 25 miles of line were run to a point opposite Bliss, and a connection was made with railroad levels. This showed that line to be 231½ feet below the track at Bliss, thus proving beyond a doubt that a continuation of the line was useless.

It is possible that a method of pumping a portion of this water by the aid of the power obtained by the 150 feet of fall which it has may at some time be devised, thus providing a supply for a portion of the land adjacent to it. The water issuing from these springs is wonderfully clear and pure, and is reported to be of a uniform temperature throughout the year. It is evident that these great springs are the outlet of a system of under-laval channels and lakes, formed by drainage of that vast tract of desert and mountain country to the north and east, which for thousands of miles along the river shows no signs of water. In the survey of the canal line, a small hole or lake of pure living water was discovered near Wapi and within 100 feet of the canal line level. It is reported by the stockmen as being of enormous depth and having an unchanging surface level. It is not impossible that this lake forms a portion of the underground reservoir system which supplies the Big Springs.

The water supply for all the foregoing main Snake River system is as follows:

	Acre-feet.
Jackson Lake reservoir site, capacity	500, 000
Swan Valley reservoir site, capacity	1, 500, 000
South Fork and Main Snake Rivers, capacity for 100 days.	850, 000
Total	2, 850, 000

The area to be irrigated in this system, not including the Mountain Home tract, is about 1,730,000 acres, which would thus have a water supply sufficient for nearly 18 inches in depth over its entire surface in 100 days.

The accompanying map gives an idea of the amount of land developed by Irrigation Surveys only in the main system, and does not include the Mountain Home tract or the area covered by private surveys.

THE ARID LANDS.

THE ARID LANDS.

Statement before the Committee on Irrigation of the House of Representatives.

COMMITTEE ON IRRIGATION, *February* 27, 1890.

The committee met pursuant to adjournment.

STATEMENT OF MAJ. J. W. POWELL, DIRECTOR OF THE U. S. GEOLOGICAL SURVEY.

Maj. POWELL addressed the committee as follows:

Mr. Chairman and gentlemen of the committee, I have on the wall before you a map (see Pl. LXVII) of the western portion of the United States, on which is exhibited an outline of the area in which irrigation is necessary. The eastern border of the region is marked by a red line, as you see, which runs across the country near the 100th meridian, but is irregular. The western boundary is still more irregular. The mountains are so formed and the currents of the Pacific are of such a nature that much moisture is drifted into this northern country and the boundary is pushed farther eastward. Within the lines on the map there is a total area of 1,340,000 square miles, but that does not include all the area where irrigation is or should be used, and where it must be practiced in the near future. There is a doubtful belt of 2 or 3 degrees in width on the east side of the line, which I have heretofore in my writings called the subhumid region, where irrigation is practiced to some extent. In some years there is sufficient rainfall to warrant the planting of crops and agriculture is successful, but from time to time seasons come in which there is no rainfall, and crops are cut off and disaster comes to the people; so they are beginning now to resort to irrigation 100 or 200 miles beyond or east of this line.

The two lines include a region where, except little places on the mountains, agriculture is practically impossible year by year without irrigation. Then there is a subhumid region on the west where agriculture is sustained without artificial means some seasons and other seasons not. If we include all the area where agriculture is dependent in whole or in part on irrigation one-half the area of the United States, exclusive of Alaska, would be embraced therein. The map further shows the extent to which irrigation has been practiced. Such areas are colored blue, and are scattered about the map, so that it will be seen that the question of irrigation is no longer one of uncertainty—it is no longer a theory; but large areas are irrigated, aggregating in all about 8,000,000 acres, scattered variously throughout the States and Territories embraced in these lines. The larger part of that irrigation is dependent upon the utilization of the small streams—creeks and small rivers—and to some slight extent upon artesian waters and to a very small extent upon pumps taking the water from wells which do not overflow and are not artesian wells in the proper sense; but in the main the agriculture is dependent upon the flowing waters, the exceptions being so trivial as scarcely to be worthy of mention.

There are a few places where water is stored, as in California; but in the main no attempt has yet been made to create reservoirs, and the waters from fifty to eighty days only are used for irrigation, while the remainder are allowed to run to waste.

Mr. HERBERT. If the waters in that area which you have marked off were all scientifically utilized, what portion of that area would be rendered productive—as much as one-tenth or one-twentieth?

Maj. POWELL. I have made a pretty careful estimate; three of us have been engaged on it for several years, from time to time, attacking the problem by different methods and coming substantially to the same conclusion, that we have about 100,000,000 acres of land which can be redeemed between those lines by the use of the streams.

Mr. HERBERT. How many million acres are between those lines?

Major POWELL. There are nearly 900,000,000 acres. I believe about 100,000,000 acres can be redeemed by the utilization of streams.

The CHAIRMAN. Storage and so on?

Maj. POWELL. Storage and so on. But there will be in addition to this three other sources which will increase the area to an extent of which we are not willing to make predictions; the investigations are not sufficient to warrant it. But I will indicate the three sources. The first is the utilization of the storm waters—waters which are not perennial. To a large extent the storm waters will be used in detail on small tracts of land, where they do not contribute to the flow of perennial streams. Where they do they are better used with the streams, and are included with them in my estimate. Then there are the "sand reservoirs," as I shall call them, where the water accumulates in valley sands and does not appear as artesian waters; and finally, there are the artesian waters. From these three sources considerable areas in addition to what I have estimated will ultimately be redeemed. Of the three additional sources the storm waters constitute the chief.

The CHAIRMAN. Do I understand you to say there are 100,000,000 of acres of land between these two lines which will be cultivable if they had water put on them?

Maj. POWELL. No, sir; one-half the area, if you had water, would be cultivable.

The CHAIRMAN. And of that half 100,000,000 acres would be cultivable?

Maj. POWELL. There are probably 500,000,000 acres of land which would be arable if there were sufficient water.

The CHAIRMAN. Then your idea is that of this, 100,000,000 acres of land are cultivable by the use of all the water?

Maj. POWELL. Yes; from perennial streams.

The CHAIRMAN. That is, that 100,000,000 acres of land could be cultivated including the estimate of storm waters?

Maj. POWELL. No, sir; that has to be added. The amount to be irrigated from the use of the three sources--storm waters, sand-reservoir waters, and artesian waters—is to be added to the 100,000,000 acres.

The CHAIRMAN. Then to give importance to that problem you must have some sort of an estimate of the amount of storm water?

Maj. POWELL. Yes, sir. In the regions where the streams are perennial the cutting off of the storm waters will, to a large extent, cut off the supply from permanent streams and reservoirs, and such cutting would be injurious, for it is better to handle them with the permanent streams. There are other regions where the storm waters can be used as such, and must be used as such if used at all, for they do not feed perennial streams. Let me make myself understood. All the waters are primarily storm waters. They all come from the heavens. Some are gathered into perennial streams, and then I call them *stream* waters, and such waters constitute the chief body to be used in irrigation. A small amount of the waters coming from the storms sink into the rocks, and when they can be recovered by overflowing wells they are called *artesian* waters. Another small amount of original storm waters are accumulated in *sand* valleys, and are called sand-reservoir waters. They are to be recovered in part by pumps and in part by gravity—that is, by drawing them off onto lower lands. Now, there are regions of country where the rain does not gather into permanent streams, but where storm streams that soon go dry are abundant, and these we call storm waters.

The CHAIRMAN. If there is no other point just there, perhaps it might be desirous to get at some information on the different precipitations of the mountains and in the valleys.

Maj. POWELL. I shall come to that.

The CHAIRMAN. This whole region is traversed by mountains.

Maj. POWELL. The rainfall of the arid region is very irregularly distributed, as it is concentrated on the mountains. In the great valleys and plains there is comparatively little. Now, the storm waters of the mountains feed the streams and become *stream* waters, and are used in irrigation in the valleys below, and it is through the use of these mountain-born streams that 100,000,000 acres of land can be redeemed. The rain that falls on the arid plains does not give rise to perennial streams; only storm-water streams are formed, and largely these waters coming down from the hills sink into the valley sands and are evaporated. Ultimately large tracts of land on the plains will be irrigated by catching these storm waters and holding them in tanks or ponds to be used in irrigation. This is the chief resource of water for the plains.

Mr. Chairman, I have prepared a table by States and Territories of the land irrigated. I will not read that table to the committee, as it is statistical, but I wish to incorporate it, if I may be permitted, in my remarks, to show how much land is irrigated in each State and Territory.

Irrigated areas--Totals.

States.	Acreage.		Percentage irrigated to total area of States.
	Under ditches constructed or projected.	Irrigated (and under ditch).	
	Acres.	*Acres.*	
Arizona	455,600	175,000	.2
California	6,000,000	3,000,000	3
Colorado		2,000,000	3
Idaho	740,000	400,000	.7
Montana		*348,000	.3
Nevada		75,000	.1
New Mexico	1,360,000	638,000	.8
Oregon	191,000	119,000	.2
Utah		802,000	1.5
Wyoming	1,227,819	*500,000	.8
Total		8,057,000	

NOTE.—The figures above are not comparable among themselves as they are derived from many sources and by various persons, each having different purposes and ideas as to what constitutes irrigation.

* Including large areas of hay lands; in Wyoming probably 90 per cent. is meadow.

It will be seen from the map before you that irrigation is widely distributed; so there is no great district of country where irrigation is possible that does not present examples of what has been accomplished. I think I should have stated further, while there are about 8,000,000 acres now actually under cultivation, there are probably 2,000,000 to 4,000,000 more under canals; the works are already constructed, and it is estimated that from 2,000,000 to 4,000,000 acres more will be cultivated. That is because a man often has only a portion of his farm irrigated, but will irrigate more in time from the works already constructed.

The map (see Pl. LXVIII) which I now place before you exhibits the distribution of the forests. The same lines indicating the borders of the arid lands are seen here, and within that area we have a map of the forests. Over almost all the region surveys have been carried on; so the forests are mapped with a fair degree of accuracy. They are of two characters. First, on the high mountains and plateaus we have forests of commercial value, forests of pine, fir, spruce, and sequoia. They are colored in dark green. The area covered by forests of this class is not one-tenth of the whole; it is about 125,000 square miles. But all of these forests are on high plateaus and mountains. Now, it must be understood that the forests of which I am speaking, although they cover a considerable area, are not dense. On this map here we have had to represent them in large bodies; and for that reason they are apparently exaggerated. There are fine open prairies and glades intermingled among the forests; there are mountains covered here and there by forests, but having great spaces of naked rock, and there are other regions of country where the trees are far apart. It will be safe to say that all the forests of this 125,000 square miles of which I make mention could stand on one-fourth of the space.

In addition to these there are forests of some value covering a somewhat larger area than that of the heavy forests of commercial value. These consist of piñon or nut pine, cedars, and in some places dwarf oaks. They are available for firewood, fences, and for minor domestic purposes, but they are very scant—everywhere there is but a small amount of wood to the acre. Along the streams we find cottonwood trees that are of some value for firewood and fences, but it is not generally dense. The cottonwood forests, the cedar forests, the piñon forests, and the dwarf-oak forests are all colored in light green. The area covered in this manner is a little over 130,000 square miles, so that within the arid area the extent of forest is about one-fifth, and it is scattered.

The distribution of forests is otherwise shown by this table:

Approximate area in square miles of timbered lands in the arid region.

State.	Firewood.	Merchantable timber.
	Square miles.	*Square miles.*
Washington	1,050	1,080
Idaho	8,600	9,800
Montana	6,500	21,000
Oregon	3,500	8,700
Wyoming	7,300	15,700
South Dakota	2,400	400
North Dakota (river bottoms)	200	....
California	20,300	11,000
Nevada	5,400	700
Arizona	26,510	11,700
New Mexico	21,540	14,490
Colorado	15,000	23,500
Utah	14,000	7,700
Total	132,300 125,770	125,770
Grand total	258,070	

Total area of arid lands, 1,340,000 square miles.

Now, some important facts must be brought out, showing where these forests are and their relation to agriculture and other industries of the country. Where the forests of commercial value grow, as a general thing, agriculture can not be practiced. They grow high on the mountains and plateaus.

The CHAIRMAN. Not over 5,000 feet elevation?

Maj. POWELL. It varies from north to south. The lower limit of the commercial forests varies from 4,500 feet above the level of the sea at the north to about

6,000, or 7,000 feet at the south, and from this lower limit the timber belt rises 4,000 feet into the region above. Where these forests of commercial value are situate great snows fall during the winter, and during the summer frosts may be expected; so that by reason of climatic conditions in part the region covered by commercial forests is not agricultural. There are still other reasons why in these high mountains agriculture would not be productive. In the rough mountains there will be no agriculture except in little spots—gardens where the people cultivate potatoes and such things about the mining camps. In general it is not an agricultural region where forests of commercial value are found. The area colored in dark green is not an agricultural region. The area colored in light green is in part agricultural, and will in part fall within the irrigation districts which must ultimately be established in the country and which practically they are beginning to establish all over the land.

The forests are being rapidly destroyed, and it is of their protection that I wish to speak now, and to show their relation to the agriculture. The forests are utilized by the people who are engaged in agriculture in the valleys far away—5, 10, 20, 50, or 100 miles from the forests—and they are also utilized for mining purposes, and they are burned in the towns and cities as firewood.

Mr. HERBERT. And the railroad companies also use them largely for cross-ties.

Maj. POWELL. Yes, sir; but ordinarily that is not a very great use. The mining use is great, the domestic use is very great, and the use for railroad purposes is of little importance. It will be understood, then, that the man who cultivates a farm in this region of the country usually has no timber on his tract of land. The timber with which he builds his house, with which he builds his fences, and which he uses for firewood grows many miles away. Hence they build roads into the canyons and bring the timber down, and they construct tramways to some extent, and slides down the mountain sides, and flumes taking it out on streams of water and floating it down; so that the timber industry is away in another region from the farming industry—it is segregated to itself. But the timber is being very rapidly destroyed by fire. That which men use is insignificant. Man himself, taking the grand aggregate, has made no impression on the forests of that country. They grow faster than man has heretofore cut them, and if they could be protected from devastation by fire the use made by man would never injure the forests—not until a vastly denser population is gathered. These forests are composed of coniferous trees that are rich in inflammable resinous substances, the bark of the trees is exceedingly inflammable, and the pine needles which fall upon the ground are inflammable and all give rise to great fires, and vast areas of forest have thus been destroyed.

A little more than 10 years ago I mapped the Territory of Utah, and in making that map I delineated not only the existing forests, but the burned forests, and found that at that time one-half of the forests of the Territory had been burned. I have seen one fire in Colorado destroy more timber than has been used by man from the migration to Pike's Peak up to the present time; and I have seen several such fires in Colorado. This past season, as an attaché to the Senatorial committee investigating the questions relating to the arid lands, I passed through South Dakota, North Dakota, Montana, Washington, Oregon, and Idaho by train. Among the valleys, with mountains on every side, during all that trip a mountain was never seen. This was because the fires in the mountains created such a smoke that the whole country was enveloped by it and hidden from view. That has been the experience for twenty-odd years, year by year, in this region. The geographical work of our Survey is cut off during the very dry months by the smoke; the men can not get lines of sight from height to height through that country because of the fires produced in the mountains and the smoke settling down over the land. In the last 20 years one-half of the timber has been burned. Where timber burns in this manner it springs up again; the lands as forest lands are not destroyed by these fires, but the timber itself is destroyed, and it is of slow growth.

Mr. HERBERT. Can you suggest any method of preventing the fires?

Maj. POWELL. Yes, sir; I am just coming to that. In the first place, let me make it plain that the character of the forests themselves is such that it makes these fires exceedingly destructive. In lands where trees are not coniferous, but ordinary deciduous trees, the fires are not so destructive. The coniferous trees, pines, firs, hemlocks, spruces, and so on, are very easily burned. In an ordinary year fire is not destructive; fire in an ordinary year passes over the ground and burns the leaves and cones, etc., only. But there come critical years, five, ten, fifteen, or twenty years apart, critical seasons of great drought, when there is no rain for several months, and the fire starts and sweeps everything away. Now, the settlement of the country conduces to this. If the forests' grounds were perenially burned—burned every year, as by the Indians in the olden times—these great fires would not prevail. But protected from annual burning as they are now, the cones, leaves, and twigs accumulate for six, eight, ten, or twelve years, as the case may be, until there is a heavy mat of this inflammable material, and when a dry season comes and the fire starts it sweeps over the country in one big conflagration. The real protection is to come ultimately in two ways. It will come in part by pasturing the lands. The pasturing of the lands will destroy the younger growth and consume the grass, and stock will make trails and roads by which the fires will be cut off and not spread widely. Then, by annual burning, at times properly selected, when not too dry, the trees can be protected.

The points of importance in connection with matters relating to irrigation are, the people who are engaged in irrigation have their timber land far away. The timber lands that are far away are subject to fires. Now, how is the General Government to protect them from these fires? They are asking that the Government establish a forestry commission for this purpose. It will be noticed that the area drained by a river like the Platte, or the Arkansas, or the Rio Grande, has its source in the mountains, the timber lands. The people in the valleys who are cultivating the soil by irrigation are interested in the forests above, in the mountains, where the sources of water supply are found. They are interested in it in a double manner. They want the wood for their use below, and, further, they want to protect these forests which stand about the sources of their water supply; so the people have a double interest in the mountain lands. They need that timber and need to protect the sources of their water supply.

Mr. HERBERT. What will be the fuel of the future in that country; is there coal enough to supply the future population you anticipate?

Maj. POWELL. The geology of the arid region is not so fully known that we can state that all of the coal has been discovered. But, Mr. Chairman, I now place before you a map of the same region showing the distribution of the known coal fields. In Dakota, as you see, we have a very large body of coal. While coal is probably found throughout the greater part of that area, in much of the region it lies so deep as to be unavailable for working economically. We have here in Utah and Colorado a very large area with which I am personally acquainted, as I have examined it myself. We have smaller ones lying around here, as you will see. There is one in Washington, and so on. There are two or three small places that have been found in Nevada, but the great body of the coal lies in the Rocky Mountains and to the east of the Rocky Mountains. Altogether there are very great coal fields. Compared with the coal fields of the eastern portion of the United States they are far superior in area.

The CHAIRMAN. There is a coal field down here [marking on the map].

Maj. POWELL. Yes, sir; in Texas.

Mr. LANHAM. There are coal fields east of that line.

Maj. POWELL. There are coal fields down in here [indicating]. I have only put in the coal fields within these two lines. There are coal fields west of the arid region and others east of it. But there are coal fields between the two lines enough to supply all practical purposes. You will see little dots over the areas, red dots in the blue areas, representing places where they are mining considerable quantities. In the main the coal is very accessible. It has been so placed by geological agencies that it can be reached with comparatively little expense. It is not very ancient coal—not so ancient as that in the eastern portion of the United States. It is in part Cretaceons and in part Tertiary. It exists in large quantity, and the quality is good enough for all domestic purposes and for making steam, and the people are gradually learning to coke it. It was difficult to use in the metallurgical processes for a long time, but the difficulties are being surmounted as experimentation goes on. Now, the sources of fuel for the people are in part the forests represented on the map before you and in part the coal fields represented on this map. There may be discovered ultimately other coal fields than those already known.

Climatic temperature decreases from the level of the sea to the summit of the mountains, but it also grows colder from the equator to the poles. Now, the lowest lands of the arid country are farthest south. In Arizona and southern California the uninhabitable deserts of America are found; there are districts of country below the level of the sea and other stretches just above it. There are other stretches where billows of sand drift across the desert with the prevailing winds. Still other areas are covered with sand and stony fragments and strewn rocks, where vegetation gains little foothold. All these lands are worthless. In passing from the Mexican to the British line, where conditions of altitude are the same, the grasses steadily improve, and those of the northern half are comparatively rich. But even here there are waste places, for lava fields abound that are virtually desert. And there are "bad lands" that yield little vegetation—hills of clay and sand that are washed by the storms and baked by the sun. When the rains come the hillsides are sloughs, and when the winds come the dried surfaces crack and crumble. Then there are cañon lands that are carved by many winding, branching gorges, and are thus rendered worthless. Then there are alcove lands where every rill of the rainy season heads in a precipitous, rocky gulch. These are also barren. Then buttes are scattered over the mesas and plateaus—fragments of formations left by the destroying storms for their future employment. Then there are cinder cones, naked and desolate. Often lines of cliff stretch athwart the country—the margins of mesas and plateaus. These cliffs are worthy of further mention. When the winds drift the clouds along the lowlands, such a cliff, a few hundred or a few thousand feet in height, obstructs their way. So the clouds rise and discharge their moisture, and floods are speedily born. In regions of cliff a large portion of the precipitation is along these lines, and yet with this increased precipitation they are not favored with great vegetation, for the water glides away on the steep declivities, and a zone of low lands near by receives it, and here the most valuable forests of piñon and cedar are often found. Then the mountains are not all grassy slopes, for they are often interrupted with rocks and ledges and cliffs that are naked.

Though the grasses of the pasturage lands of the West are nutritious, they are not as abundant as in the humid valleys of the East. Yet they have an important value. These grasses are easily destroyed by improvident pasturage, and they are then replaced by noxious weeds. To be utilized they must be carefully protected, and grazed only in proper seasons and within prescribed limits. But they cannot be inclosed by fences in small fields. Ten, twenty, fifty acres are necessary for the pasturage of a steer. So the grasses can be utilized only in large bodies, and be fenced only by townships or tens of townships. Yet they must have protection or be ruined, and they should be preserved as one great resource of food for the people. When the valleys below are irrigated, so that flocks and herds may be fed when the snows and frosts of winter come, the hills and mountains of the arid region will support great numbers of horses, cattle, and sheep.

The mountains of the far West are full of gold. Ores of this metal are found in fissures that seam the rock and fill spaces between barren formations and lie in bodies where lavas have cooled in hill-bound basins. Then the whole mountain region has been plowed with glaciers and swept by storms or buried by river floods, and in these glacial gravels and storm gravels and river gravels the gold has been carried, and here the placer mines are found. In other hills and mountains there are stores of silver and copper, while lead and iron abound. Then asphalt, oil, and gas are found, and the hills are often filled with coal. With slight exception all of these minerals are found in lands which can not be redeemed for agriculture. The coal lands are chiefly pasturage lands, and the gold and silver mines are under the forests. The coal and iron have been and can be discovered by science; but gold and silver are discovered by prospectors, and revealed only by the pick and shovel. These mines of gold and silver furnish the basis of our monetary system, and are the source of vast wealth. During the last calendar year $32,816,500 in gold and $59,118,000 in silver were taken from these regions, and this supply is to be continued through an indefinite future.

Mr. Chairman, I have thus presented a general outline of the arid lands and certain facts connected with the agriculture of the country, the present distribution of irrigation, the forests, the distribution of coal, a description of the pasturage lands, and have made mention of the mineral lands.

I propose now to present an outline of some of the more important problems relating to irrigation, and in order to do this to the best advantage I have prepared a series of maps (condensed on Pl. LXIV), each one representing some great river valley and all the areas drained by the river within the arid region. I now place before you a map of the Arkansas basin, so much of it as is in the arid region. The Arkansas heads in central Colorado, in high mountains, about 14,000 feet above the level of the sea, and it flows eastward across the Kansas line at this point. It has many important tributaries, and they all head in the high mountains. You will see that I have divided the Arkansas drainage into districts, and each one represents a natural irrigation district—a region of country that must be considered as a unit. I shall first call attention to the head waters of the Arkansas itself. You will see that west, north, and south from Canyon City there is a great mountain area. This is the catchment region of the waters of the upper Arkansas.

Below Canyon City you will see that the district connected with the mountain catchment area narrows greatly down to Pueblo, and continues a comparatively narrow strip down the Arkansas many miles, and then leaves the Arkansas to the north and extends to the State line. This narrow district below is the farming region, which must depend for its waters upon the catchment district above. The mountains above furnish the water to the plains. This great fact is important, for it illustrates a general condition in all regions of agriculture by irrigation. The farming area below depends on a catchment area above, and this dependence is vital. Let us call the whole the upper Arkansas district, extending from Leadville to the Kansas line. The farming must chiefly be below Canyon City, and the water must chiefly come from above Canyon City, and Canyon City marks approximately the critical point in the valley. Above it most of the waters are to be stored when storage is resorted to, though a part can be stored below, but those stored below should be diverted from the river near Canyon City. The surveys have progressed far enough for us to state that the waters of the Arkansas coming down to Canyon City can be taken out in that neighborhood and carried by high-line canals over the lands below lying within the district as outlined. A part of the waters can be taken out on the north side by high-line canals; another part of the waters can be taken out by a high-line canal starting a little below Canyon City and running on the south side of the river. The irrigable lands therefore lie chiefly below Canyon City on both sides of the river, and extend on the south side half way to the Colorado-Kansas line and on the north side entirely to the Kansas line. But not all the lands in the lower part of the district can be irrigated; the water is insufficient for that purpose. At the present time in critical years—and I mean by that in dry years—all the waters of the Arkansas are used that flow during the season of irrigation. All additional development of agriculture along the region therefore depends upon the storage of water. In years of great precipitation much larger areas can be cultivated without storage, but in years of drought waste water must be used, and this demands storage.

Permanent, prosperous agriculture, therefore, if it is to be enlarged in this district, will have its enlargement depend upon storage. We already know of fine storage basins in the upper region and others in the lower region, and know that the waters which now run to waste for ten months can be stored. Now I wish to make it clear that the entire district of which I make mention is an interdependent district; that the interests of the people throughout the district are common interests, and that one man's interest can not be affected without at the same time affecting another man's interest; that there are certain great common problems in which all of the people of the district are involved and about which they must be all consulted and in the determination of which they should all have a voice.

First, then, is the catchment area above Canyon City, where the chief body of water falls. Now this water can not be divided among the farmers below until it reaches Canyon City; it must be divided there; and farther down a common body of water flows by, from which every farmer must take his quota. If the water is to be stored above, the farmers below who are to store it must go to the upper districts, away from their homes one or two hundred miles, and construct reservoirs; when the waters of these reservoirs are needed they must be discharged into the natural channels, to be taken out again by diverting dams; the people must also go away from their homes many miles to construct the diverting dams where the waters are taken out from the natural channels and turned into canals. In like manner the canals must be constructed on lands above them, 5, 10, 20, 50, 100, or 200 miles, as the case may be. The last farmer near the Kansas line is as much interested in the storage reservoir at Twin Lakes, high in the mountains 300 miles away, as the man living at Pueblo below Canyon City.

This upper region is mountainous, and the mountains are largely covered with forests. But the forests themselves are being destroyed by fire. This destruction of the forests is exceedingly injurious to the reservoirs. Forests should be managed in the interest of agriculture, that the water supply of the people may have protection in the mountains where it is caught. All the people of the district, therefore, to the Kansas line are alike interested in the mountain slopes and the forests which they carry, and they are the only people directly interested in them, for they are the people who wish to use the timber which these forests will afford. Their homes are to be made, their farms are to be fenced, and their firewood is to be obtained from them; though their fuel will, perhaps, be derived in part from the coal which the region affords.

But not all of the land can be irrigated. The mountain region can not, but it is worth something for pasturage purposes; and the plains below can not all be irrigated. The nonirrigable portion, which is several times larger than the area which can be irrigated, has value for pasturage purposes. But this pasturage can be and is being rapidly destroyed by being overfed. It can not be fenced and used as pasturage grounds as in the eastern or humid lands, because the pasturage is scant and a large tract is needed to support a small herd—so large that fencing in small tracts is impossible. In the main the stock raised on this pasturage must be fed during the winter; the cattle, horses, and sheep, therefore, that feed on the summer pasturage of the district must winter on the farms of the district that are cultivated by irrigation, and the people who can utilize these lands best, who live in the district and engage in agriculture, should by some means have control of the pasturage. They must have control of the forest areas, because their agriculture depends upon them, and the non-forest areas can better be controlled by them than by anybody else.

Here the people are to be scattered from Canyon City to the Kansas line in communities dependent upon irrigation. About them on every hand on the plains will be pasturage lands over which their cattle may roam, and far above on the river will be the forest lands which constitute the catchment basin for their agriculture. All of this land must by some means or other be placed under the control of these farmers, for its management is vital to their industries because of the water, timber, and pasturage which it affords. There must necessarily be small bodies of land actually cultivated and large bodies of land will forever remain uncultivated, and the management of the uncultivated lands is vital to success on the cultivated lands. If the water, the timber, and the grass are to be utilized and protected from destruction—and all of the values inhering in them are liable to destruction to a greater or less extent by mismanagement—then these people who are interested therein should have control and management of the unoccupied lands as a body politic, and should be allowed to make their own rules and regulations for its protection and use.

There is another great fact to be brought out in the consideration of the upper Arkansas district. I spoke of Canyon City as being in the neighborhood of a critical point on the river. Above in the mountain region the rivers, all the streams, are clear water, and they run usually in deep, narrow canyons; but there are mountain valleys along water courses, in some places especially, where the waters are to be stored. But on leaving the mountains below Canyon City the waters speedily become turbid, as they are loaded with mud. The streams are no longer deep, swift, and clear, but they become broad, shallow, and muddy. Now the best place to take out these waters for irrigation is here near Canyon City, before they become loaded with mud. Experience shows that this mud is of no value to agriculture, but that it clogs and chokes the canals and water-ways, so that it is difficult to maintain irrigation works, and the sandy water injures the soil. The waters are taken out below after they have become more or less muddy, but always to a disadvantage. But, still more, the waters are now taken out from point to point along the valley from Canyon City nearly down to the Kansas line in a most wasteful and expensive manner. One or two high-line ditches on either side, with laterals running toward the river, should be constructed so as to control all the waters of the Arkansas, and this must ultimately be done for economy's sake. This economy appears in two ways: First, the works necessary to be made can be made much more cheaply by that plan; second, the waste of water is much less. But in order to carry out the water in this manner the rights already acquired by the water companies to carry water below for shorter distances and near to the river must be extinguished. The existing rights, therefore, are obstructive rights; they constitute an obstruction to the development of the entire region, and they constitute an obstruction to the cheapest method of supplying the country with water.

It is thus that obstructive rights are established—rights inhering in water companies as distinct from the rights of the farmers cultivating the soil. If a river is taken out at numerous points along its course to irrigate a section of country close to the river, lands that lie in the flood-plane, the lands themselves can never be properly drained and only the poorest agriculture can be carried on. But if the waters are taken high up on lands that have natural drainage or that can be drained at little expense, the agriculture will be very greatly improved. Then a multiplicity of small dams along a stream involves the construction of many lines of canal, which are in the aggregate expensive, and water lost by them through evaporation and seepage is very great; and so all the water is not used. To take the water of the Arkansas out by great canals, as I have indicated, would be to double or treble the area irrigated, and the lands cultivated would be better acre for acre, and the cost of irrigating the entire tract by the high-line canals would be no greater than, and perhaps not so great as, to irrigate the small tracts. But there is another condition of great importance in this connection. On the broad valley where these mountain streams enter the valleys and plains below and spread out over the sands, the waters permeate these sands for wide distances on either side and are by them re-evaporated to the heavens; so that a great flood of water may come from the mountains and pour onto the plains, but it will not be carried far down toward the Kansas line, for it steadily diminishes, being lost in the sands, which send it back to the air. The nearer the water can be taken out to the critical point which I have indicated the greater the amount of water which can be saved. So that there are four reasons why the water should be taken out at this critical point, each one substantial and important in itself and each one sufficient to control the matter, while altogether they are so important that they can not be neglected. These four reasons are: First, high-line canals are least expensive; second, they save water which would be lost by absorption and evaporation in the numerous low-line canals; third, they carry the water to better lands; fourth, they save the water from being evaporated in the sands of the lower basin.

We next come to a consideration of the Fountain district. Coming down from around Pike's Peak we have a beautiful stream of water, all of which can be used in its valley below before reaching the Arkansas itself, as indicated by the lines which I have drawn on the map. Now the people who live on these irrigable lands below are dependent npon the catchment areas above, and are interested in the preservation of the forests, alike for agricultural purposes and that they may use the timber; they are the only people directly and economically interested in them; and they are all interested in common in the same things—the water, the timber, and the pastnrage. They also must construct storage reservoirs above them and must run canals on lands which they do not own. From the Fountain eastward to the Kansas line and from the divide between the Platte and the Arkansas on the north down to the boundary of the great Upper Arkansas basin which I have described, you see there is a great district on the plains. The streams in that district head in the highlands at the north. They are Chico Creek, Horse Creek, Rush Creek, and Big Sandy River, with some minor streams. These streams, not heading in the mountains, are not perennial; they are only wet-weather streams. Often fine streams are running about their sources when no water is found in their lower courses nearer the Arkansas, the waters sinking away and being lost in the sands, where they are evaporated. I have thrown all of these into one great district. About the headwaters of the streams there are piñons and cedars, but very little forest growth valuable for commercial purposes. The region is ultimately to be one chiefly devoted to pasturage purposes. Still, much land may be cultivated by the storage of the storm-waters.

South of the Arkansas we have, first, the St. Charles River, not a very large stream, but its waters can all be stored and all used within its own valley before reaching the Arkansas, in the district which I have outlined as you see on the map. Passing eastward, we come to the Huerfano River, a fine mountain stream heading in high mountains and having abundant basins for the storage of its waters. Here as on the St. Charles and on the Upper Arkansas basin and elsewhere, the people are interested in the preservation of the forests, in order that their sources of water supply may be protected; and they are also interested in the preservation of the grasses. They have three great values, which they must protect, in water, timber, and grass, and they should be allowed to protect them for themselves, for they are the only people who have a direct interest in them. Then come the Apishapa River and the Animas River, each constituting an independent district. In the Apishapa all the people are interested in the three great problems. The same is true with the people of the Las Animas Valley. You will see that I have cut off a district along the lower part of the Arkansas, a district which is in part in Colorado and should extend two or three degrees into Kansas. This district has its own drainage area, and will largely be dependent upon the storage of storm-waters; but the waters which escape into the sand basin of the river itself can be utilized and be brought up to the surface by pumps or by gravity; that is, the upper portions of the sand basin may be drained onto the lower portions, and much irrigation may be developed thereby. There will often escape from the other districts more or less water, especially at flood times and seasons of great rain, all of which will flow down into this lower district, and can there be caught and used in irrigation. In the western half of the United States the total rainfall, if evenly distributed throughout the country, would be pretty great.

Mr. PICKLER. In the western half?

Director POWELL. Yes, in the western half. In this region of country I am speaking of there is considerable rainfall, but it is not evenly distributed from region to region. It varies from 3 inches to 60 or 70 inches annually.

The CHAIRMAN. The mean annual rainfall?

Director POWELL. Yes, the mean annual rainfall. This is dependent upon complex conditions. Generally the rainfall increases from north to south, due to the configuration of the coast and the trend of the great oceanic currents. The rainfall increases from the lowlands to the highlands also, so that taking it altogether the chief precipitation of rain is on the mountains. When the clouds gather about the mountains, drifting here and there, there are great storms, while the valleys below are quite clear; and this goes on month after month and year after year. So the waters are concentrated, in the main, in the mountains. In the mountains there may be 25, 40, or 60 inches of rain, while in the valleys below there may be only 3, 6, 10, or 15 inches, as the case may be.

Mr. HANSBROUGH. What is the average in the western region? I suppose that could not be ascertained accurately.

Maj. POWELL. No, sir; but I should say about 20 inches.

Mr. HANSBROUGH. That is sufficient for ordinary agriculture.

Maj. POWELL. Yes, if it is distributed through the year well.

The CHAIRMAN. A statement is made that in Portland it is about 20 inches, and at San Francisco it is about 25 inches, and when you get as far south as San Diego it is less than 10 inches; so there is a gradual diminution. I think the amount of rainfall required for the production of crops, for an ordinary production, would be about from 20 to 25 inches.

Maj. POWELL. It depends upon when it falls; 9 inches of rain falling during the season of growing crops would be sufficient for the growing crops if it would come just at the right time, but that is not to be expected. There are some portions of Dakota where the greater part of the rainfall comes during the season of growing crops, and there are other regions of the country, say in Texas, where the maximum rainfall is in the winter time.

Thus, the waters fall on the mountains and roll down in rivers to the sea. About one-half the streams of the arid region have no outlet to the sea. They sink in the interior, in salt lakes, and in the sand. Only about one-half of the streams of the arid region are ultimately discharged into the sea. In these regions, where the rainfall is not more than 10 or 12 inches, very little of the water gets to the sea; it is absorbed by the sand and discharged into salt lakes. On another map, which I once had before you, the region where the waters do not flow to the sea was delineated. All of this region along the plains in western Kansas and eastern Colorado is one without perennial streams, except as they come through from the mountains beyond. The people of this region would therefore have to depend largely upon the storage of storm-waters. But, on the other hand, the rainfall gradually increases as we go eastward, so that there are many seasons when irrigation is not necessary; and in those years when it is necessary a smaller supply of water need be furnished artificially.

The hour of 12 having arrived, the question was discussed by the committee whether Major Powell should be further heard at this meeting.

Mr. HERBERT. I move that the meeting adjourn until Saturday, and it be understood that Major Powell commences talking at half past 10 o'clock, whether there is anybody to talk to except the chairman or not.

Thereupon the committee adjourned until half past 10 o'clock Saturday morning, March 1.

COMMITTEE ON IRRIGATION,
Saturday, March 1, 1890.

The committee met pursuant to adjournment, Mr. Vandever in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. J. W. POWELL, Director of the Geological Survey, addressed the committee as follows:

Mr. Chairman and gentlemen of the committee, I place before you to-day a map of the Rio Grande, including all the area drained by that stream north of the Texas line. There are some important facts relating to the utilization of the arid lands which can be well elucidated by considering that region of country, and I present the map again for that region. In talking to you at the last meeting about the irrigation problems presented in the valley of the Arkansas I called your attention to the fact that that valley could be divided into districts, each one an independent unit. The whole arid region may be divided in like manner into natural districts or drainage basins, each one of which has its problems so interwoven that the entire district must be considered in planning its system of irrigation works, but which is practically independent of all other districts. These hydrographic basins, as I call them, are of three classes, viz, headwater districts, river-trunk districts, and lost stream districts.

The headwater districts commence in the mountains and extend down the streams far enough to include catchment areas and farming areas. They are found not only on the main streams, but on all perennial laterals or tributaries. Usually each lateral or tributary forms a natural district by itself. But the great rivers flow on across the plains and down the great valleys, and their trunks must be divided into districts, each one of which presents an independent system of works. These I call river-trunk districts. Then in the arid lands there are many streams which do not flow into great rivers and ultimately to the sea, their waters being lost in the sands or emptying into salt lakes. These I call lost stream districts. All three classes of districts are illustrated in the Arkansas basin, as I presented the subject to you at the last meeting, and all of these classes are represented in the Rio Grande region, the map of which is before you.

In considering this subject and planning the work of the irrigation survey it has been found that a natural district or hydrographic basin must be considered as a unit in which all the problems are interrelated. In order to report upon a district and recommend a plan of works we must know for such district how much water will be supplied for irrigation, where the diverting-dam sites, reservoir sites, and canal sites are situated, and where the lands to be irrigated lie. And it has been found, after a careful examination and from the best data we have on hand, that there will be about one hundred and fifty such districts in the arid region, and that if the survey is carried out it will need a separate report on each.

I have therefore found it necessary, for the administration of the Survey, to consider these hydrographic basins, and have been studying them for some time, in fact for years before the survey was organized, for I early recognized that ultimately these natural features would present conditions which would control the engineering problems of irrigation and which would ultimately control the institutional or legal problems. The study which I have made in this direction can not of course be considered final. An actual survey on the ground is necessary to define the limits of each basin, and a very careful survey is especially necessary to define the limits of the trunk districts. The headwater districts, or those of the first class, and the lost stream districts, or those of the third class, are quite easily discovered; but the districts of the second class require very careful study for their determination. The meaning of this will more fully appear from the illustrations which I am able to present to you to-day in considering the Rio Grande Valley.

First, we have the Saguache River, a river with tributaries—a number of beautiful creeks. The river flows into a sink, and the drainage is lost in the sands. Now, the utilization of that water affects that valley only. It is independent of all the other regions of the country.

The CHAIRMAN. Do you not think there is a possibility of its finding an outlet into the channel of the Rio Grande below at some distant point?

Maj. POWELL. Not to any amount. The region of country at the sink is one of sand and the water sinks in these sands and is evaporated. It is only on very rare occasions—many years apart—that there will be a great flood which will cause it to overflow and open a channel to the Rio Grande. In ordinary years all the water which is used must be in the valley here [indicating], hence it is an independent basin. This is what I call a district of the third class—a lost river district. It will be noticed that in this district the people who engage in agriculture here can not possibly have any conflict about water rights with the people of any other district. They may use all of this element which they can catch and spread it upon their lands, and nothing will be cut off from any other district; nor can they obtain water from any other district to put upon their lands. And they are interested not only in the water, they are interested in the forests about the fountains whence their waters come, and they are the people who should be interested in the grasses which grow in the valleys and on the hills and mountain slopes.

The Saguache district, therefore, is clearly defined in nature. Its boundary is marked everywhere by the parting of the waters.

Passing over to the Rio Grande proper we have the San Luis district, which is also a headwater district. The San Luis Park is a beautiful tract of land, and high mountains stand around it and gather great quantities of water. This is a region lately redeemed for agriculture, but already all the flow of critical years with extreme dry seasons is used in agriculture, and the companies that are specially interested in these water rights are preparing to store and use all its waters which flow throughout the season. It may be possible that they can use all, and that the area of good land to be cultivated will be sufficient. We do not yet know the amount of water that flows in the streams, nor do we know the amount of good available land. Be this as it may, we are able to state that this great district is a unit, and that it must be considered as such in planning the proper system of irrigation works, and that its people as a body will be interested in the management of its waters, its forests, and its pastures. And they are the only people to be interested, except to this extent, that if the waters are not used here they will flow into trunk districts below to be used there. If the people of the districts below, in New Mexico, could lay an embargo upon irrigation in the San Luis Valley, larger areas in New Mexico could be cultivated, but the loss of water on the way would be such that they would not equal in area ot lands that could be irrigated in Colorado. It is therefore manifestly to the advantage of the agricultural interests of the country that the people of Colorado who live in the San Luis Valley should be permitted to develop their agriculture to the utmost and use all the waters that they can put upon good agricultural lands.

The Rio Grande, in crossing the line between Colorado and New Mexico, enters a canyon and flows for about 50 miles through the gorge, and its waters can not be taken out along this stretch. This canyon ends where Taos River, coming from the east, joins the Rio Grande. The Taos is a beautiful stream, and all of its waters can be used in its own valley—all that run during the season of irrigation, and all that can be stored, so that the waters of the Taos may ultimately be cut off from the Rio Grande.

The region of country on either side of the canyon of which I have made mention—Embudo Canyon—has lava fields and is not agricultural; but some fair timber grows there and much water comes down into the canyon, so that when the river emerges into the valley at the foot of Embudo Canyon it is a fine stream, and must always be so whatever water is taken out in Colorado above. Some 40 or 50 miles below the river enters another canyon. Between these two canyons lies the valley of San Ildefonso, into which come some small creeks from the east, and the water of the Rio Grande can be taken out at the foot of Embudo Canyon and spread over the San Ildefonso Valley and make here a river-trunk district of the second class. This is a district also well defined in nature. Its catchment area is lava fields above and mountains on every hand, and its irrigable or farming area is the low valley stretching back from the Rio Grande on either side.

Near the foot of San Ildefonso the Chama enters from the west. The Chama is a large river for that country, and its tributaries drain great mountains, and there are many beautiful valleys scattered about through the region. The lower portion of the Chama runs through a sand plain, and these sands are volcanic ashes which drift and blow into the river and fill it with sediment. The Rio Grande above the mouth of the Chama is a clear, beautiful river, but at the mouth of the Chama it is transformed by the mud of the Chama itself. It then becomes a river of mud and continues such to the Gulf, as it takes up sands along its way. The Chama basin is another natural basin, having timber lands, pasturage lands, and agricultural lands.

At the foot of San Ildefonso Valley the Rio Grande enters White Rock Canyon and continues its course through a deep gorge for 40 or 50 miles. Along this course its waters can not be used for irrigation. The canyon walls are hundreds of feet, and in some places more than a thousand feet, above the waters. But the high volcanic plateau on the east furnishes a notable amount of water to this stream, and on the west there is a group of great volcanoes from which many beautiful streams flow, so that if all the water should be cut off at the head of White Rock Canyon there would still come into the Rio Grande, through the course of this gorge, a large body of water to be used below—water which can not be used elsewhere, as none of the streams above on either side of the canyon have agricultural lands along their courses. But they have great forests. Here some of the finest forests of New Mexico are found. This is the great catchment area for the valley below White Rock Canyon.

Some flood waters will always come down the Rio Grande from San Ildefonso Valley, however thoroughly the country may be utilized, and additional water will be caught in the canyon itself, and so the valley below will have a good supply. White Rock Canyon empties below into a valley which I shall call the Albuquerquè Valley. In it lies Bernalillo, Albuquerque, Los Lunas, Socorro, and other towns. Now, all the water that comes out of White Rock Canyon can be used in the Albuquerque Valley, as it may be diverted below the White Rock Canyon and carried out and stored on the flanks of the valley. There is now much agriculture in this valley, and some of it is very ancient. Including the catchment area about White Rock Canyon and the hills and mountains on either side, and the valley where agriculture can be carried on, we have another natural district or hydrographic basin—a district of the second class, or stream-trunk district. Now, it will be seen that all the water to be used in this great valley comes from the mouth of White Rock Canyon. Whoever has control of that point—owns that dam site and has the right to take the water out of its natural channel and carry it into canals—has command of all the agriculture of that great district.

I wish to explain further that the people who have settled here have taken out the waters of the Rio Grande and utilized them during the season of irrigation, but they have not yet resorted to storage, and the waters which they use are used to very poor advantage. The flood plain, or strip of country next to the river, which is sometimes overflowed, is broad and sandy; the river itself is shallow and is a river of mud, and it is very wide, so it flows into these sands and is evaporated to a very large extent and thus lost to agriculture. Then the people have constructed low-line ditches near to the Rio Grande, and take out the water by a system which is exceedingly wasteful and which is destroyed more or less with every flood. Ultimately they will find it to their advantage to take the water higher up, near the mouth of White Rock Canyon, and carry it out by high-line canals, and store the surplus in the lateral valleys. By this means the area of agriculture in the valley can be increased five or ten fold.

Mr. LANHAM. Suppose this dam is constructed that you speak of here——

Director POWELL. At the mouth of White Rock Canyon?

Mr. LANHAM. Yes, sir. What effect would that have upon the supply of water below that point of the stream?

Director POWELL. They could take out all the water for canals below by constructing a dam at White Rock Canyon. It is possible to take all the water of the Rio Grande there during the season of irrigation. It is also possible to take out all the water there during the non-irrigating season. If the water for the non-irrigating season is to be stored, you are compelled to take it out there. You can not take it out by the present ditches, for they do not lie on high enough ground; but if a canal is constructed from the mouth of White Rock Canyon, and a diverting dam built there, and lakes made—there are good places—all the water can be used in the valley. So, not only is it necessary to take the water out at that one point and utilize the entire flow during the season of irrigation, but it is also necessary to take it out at that point in order to store the water which now runs to waste. So that if the water is taken out at this one point, all together, the area of irrigation will be multiplied ten times. But that can not be done without considering the rights of the people who now use some of the water by improvident and obstructive dams.

Mr. LANHAM. If you store the water above here by means of this dam you speak of, what is going to be the effect upon the flow of the stream say 100 or 150 miles below?

Director POWELL. I suppose that if the water was wholly taken out here at this point, the water which could be utilized at El Paso would be very small, provided no water is stored and only the water running during the irrigating season is used. If all the water should be taken out here and stored, it would cut off more than two-thirds of the flow at El Paso; but in doing that you would irrigate a million or two acres of land above here, and if you allowed it to flow down there it would irrigate 40,000 or 60,000 acres of land only, as it is wasted on the way down by evaporation in the sands.

Mr. HERBERT. If all the water was stored at that point you have indicated above here, and if utilized, would it be sufficient to irrigate all the lands that could be rendered arable along the Albuquerque Valley?

Director POWELL. No, sir.

Mr. HERBERT. Then there is no water supply here that can be used to irrigate the whole valley?

Director POWELL. No, sir; there is not enough water here, and I doubt if half the land can be irrigated.

Mr. HERBERT. This is a valley extending from Bernalillo down to or below Socorro?

Director POWELL. From White Rock Canyon past Albuquerque.

Mr. HERBERT. Then it would take all the water that would otherwise have been stored by this dam at El Paso?

Director POWELL. Not all the water, because there are some feeders down below.

Mr. HERBERT. If the water along all these feeders of the Rio Grande was used as soon as it could be utilized to advantage at points, it would really dry up the Rio Grande down to El Paso?

Director POWELL. For all practical purposes for irrigation. It is possible to cut off all of the water of the Rio Grande above El Paso which can be utilized for irrigation. It is possible to cut it all off at one place or another.

Mr. HERBERT. And use all to advantage above?

Director POWELL. And use all to advantage above.

The CHAIRMAN. Storm water and all?

Director POWELL. No, sir; only the stream flow of the Rio Grande.

Mr. LANHAM. What do you say about the torrential flow there?

Director POWELL. Let me explain that. Irrigation has a peculiar limit that must be always understood. The amount of water falling in the valley of the Rio Grande annually from year to year varies. One year it will be from 8 to 10 inches, taking the whole country, mountains and all. Another year in the valley of the Rio Grande it may amount to 20 inches. Years of smallest rainfall limit the amount of agriculture, unless the water be stored from one year to another, for if you develop irrigation beyond the minimum year and do not store for the critical year, you will have some years when the agriculture will be disastrous, while other years it will be successful. When the disaster comes it is absolute; the fields dry up. When the disasters are absolute, or when the people can not irrigate their lands for one or two entire seasons, that agricultural community is destroyed. They not only lose all of the crops of that year, but they lose all of their vines and all of their fruit trees. One or two dry seasons coming together in this manner are so disastrous that the people can not live on their lands; they are compelled to go away. Hence the irrigation is limited by the dry seasons. If, then, all the water is used in one region above to its utmost capacity of the dry season, that destroys the region below, for in the dry season there is no storm water below.

Off to the east, here as you see on the map, is the Santa Fé Creek, on which the city of Santa Fé is situated. It also constitutes a distinct basin with irrigable lands, timber lands, and pasturage lands, and all its waters can be caught and used in the Santa Fé Valley, so that no considerable amount will ultimately flow from the Santa Fé Creek into the Rio Grande.

On the west we have the Jemez River, where another natural district of the first class is found. The Jemez River drains the Tewan Mountains and plateau. The catchment area is well wooded. Fine forests are found and great mountain meadows are seen, but the land above is cold and is not valuable for agriculture, except for pasturage, and perhaps a little hay may be cut with advantage. The many streams which head in the Tewan Mountains and plateau find their way into deep canyons. On leaving the mountains, near Jemez Pueblo, the whole body of the stream can be taken out and put on the mesa above Albuquerque or west of Albuquerque and Bernalillo. It is another natural hydrographic basin of the first class.

Below Albuquerque we have the Rio Puerco. All of its waters can be used in the upper portion of its valley, and there is much more land than the water will serve.

Very little water ever runs into the Rio Grande from the Puerco, and that comes only at flood time. It is a hydrographic district of the third class, with irrigable, timber, and pasturage lands and with many fine sites for reservoirs.

Where the Albuquerque district should end and the next district, embracing the Mesilla Valley and the El Paso Valley, should begin, I am not able to state, but from such information as I have been able to collect I believe that below Socorro a new natural division can be made.

Mr. HERBERT. Could I interrupt you to ask how much of that territory is private property—say from the source of the Rio Grande to its mouth?

Director POWELL. It is impossible for me to give an answer.

Mr. HERBERT. Well, above El Paso?

Director POWELL. The circumstances are peculiar in New Mexico. There are old Spanish claims of millions of acres. The claims that have been actually confirmed are few in number. The unconfirmed claims are very great in the aggregate. The amount which has been taken up by homestead and preemption act and other laws for disposing of the public domain is not very great.

Mr. HERBERT. Are there any railroad grants crossing the Rio Grande?

Director POWELL. There are grants along the Atlantic and Pacific, but I believe they have not been confirmed.

Mr. HERBERT. Has the Texas Pacific any grants crossing there?

Mr. LANHAM. That is lower down.

Mr. HERBERT. Has the Denver and Rio Grande any?

Director POWELL. I believe not. In the main the most of the land grants in all the southern half of the United States include but small amounts of irrigable land. The conditions for running the best railroad lines controlled them, and they kept out of regions of country which are more broken and furnish water in abundance. That is true of the Texas and Pacific or Southern Pacific and the Atlantic and Pacific and of the Union Pacific and Central Pacific. They had little idea at the time that these irrigable lands would be valuable, and they left them to one side; but they embrace irrigable lands sometimes. I have the grants platted on a map at my office, and could bring the map to the committee if so desired.

Mr. HERBERT. We would be glad to have you append it to your testimony.

Director POWELL. Very well.

Let us go on to consider the region of the Rio Grande below, from Socorro to a point on the river 30 or 40 miles below El Paso. Here there are two valleys, Mesilla Valley above El Paso and the valley below, a part of which is in the Republic of Mexico and a part in Texas. Now, it is possible to cut off from these two valleys all of the waters which flow during the season of irrigation in critical years and destroy all the agriculture therein unless the waters of the nonirrigation seasons are stored. During the nonirrigating season large bodies of water come into the Rio Grande from the mountains on either side. There are high mountains to the west and high mountains to the east, but there are few perennial streams and they are only small creeks. The principal body of the water comes in as storm water. But the area is pretty large and its waters can be stored immediately above El Paso and at the head and along the flanks of the Mesilla Valley. At the Point of Rocks, at the head of Mesilla Valley, all of the waters of the Rio Grande can be captured again and be taken out into the Mesilla Valley and used once more. The waters of the nonirrigating season can be stored on the flanks of the valley, and there is more land than all the waters will serve. Still there is a mountain catchment area on either side of the Mesilla Valley the waters of which will flow through the valley at El Paso at flood times, and these waters can be stored to be used in the valley below in Texas and Old Mexico. But I do not think there is enough of these waters to support all the agriculture now developed if the waters of the Rio Grande are all taken out at the Point of Rocks.

To maintain the irrigation now developed in the El Paso and Mesilla Valleys some division of the waters must be here made. The catch from Socorro down, coming from the mountains on either side, and the surplus which may come down in great floods from the Rio Grande above, must be divided between the Mesilla Valley and the El Paso Valley to maintain the agriculture already established and to give some development to the same. Just how this can be done to advantage is not known; the topographic survey has not proceeded far enough. We know where the waters can be stored for the El Paso Valley, and I have already explained that to the committee some days ago. We can create a great reservoir with reasonable economy immediately above El Paso; we can also create a reservoir or series of reservoirs in the Mesilla Valley; but how much water can be caught and held in these reservoirs we do not know, and can not know until the topographic survey is completed, for on that we depend to determine the water supply. It is safe to say, however, that the reservoir at El Paso may be constructed, and I incline to think that the rights to the present irrigation in the Mesilla Valley may be maintained, and the rights in the El Paso Valley maintained, and that irrigation in both districts may be increased, but to what extent and to what size these reservoirs should be constructed is yet unknown. It will require another year's survey to determine these facts. This, however, is certain, that there can be no development of irrigation in these valleys through the use of the waters of the irrigating season only; in fact the present agriculture can not be maintained unless the waters are stored.

The irrigation already developed in Colorado and the upper valleys of New Mexico is destroying the agriculture here. Two more years of development will cut it all off when dry seasons come. The only hope for these valleys is through storage, and how the entire problem is to be solved by storage is not yet known. Nor can it be done without some interference on the part of the United States. If the General Government does not step in and by definite legislation assign specific waters to El Paso and the Mesilla, the El Paso Valley will surely be destroyed, and the Mesilla Valley can be almost ruined by the people of the Albuquerque Valley. What is needed is the construction of storage reservoirs and their protection by the assignment of specific catchment areas to those reservoirs. The Government must say that a certain catchment area can be used for the Mesilla Valley and that the remaining catchment area must be used for the Albuquerque Valley. A State, a Territory, and a foreign country are involved, and they can not settle the problem for themselves. There is only one way to protect this ancient irrigation in the El Paso and Mesilla Valleys and their right to use the water of the irrigating season and to proceed as they have heretofore done without storage, and that is to destroy all irrigation in Colorado and all of the lately developed irrigation in the valley of the Rio Grande in New Mexico above, and to prohibit forever the use of the waters there; and this would mean that to maintain 75,000 to 100,000 acres of agriculture several million acres of development must be stopped. Of course, this can not be done; they must resort to storage, and somehow storage rights must be fixed and maintained.

Mr. LANHAM. What is your solution of the question? It seems to me a man who lives at the source of a river may be in good condition, although a comparatively new country, and the man who lives below him, although his ancestors may have lived there for a hundred years, is deprived of irrigation. What is the solution of that question?

Maj. POWELL. Senator Reagan has introduced a bill which I think, is a solution of it.

Mr. LANHAM. Will you allow me to draw your attention for a moment to the lower Rio Grande? Here in the El Paso Valley are Mexicans and Americans. We have Mexican citizens on the American side of the river also. These people have been practicing agriculture for about two centuries.

Maj. POWELL. Yes, sir.

Mr. LANHAM. These communities above are comparatively recent. Now, what is your idea, to allow the communities above to cut off and destroy all the supply of water to the exclusion of the people below?

Maj. POWELL. I think their rights must be maintained. There are two considerations of primary importance in the matter. The first is to protect the rights of the people who have the vested rights; second, to prevent new vested rights from becoming practically an impediment in the development of the country.

The CHAIRMAN. Let me suggest here that your system of damming and retaining waters at different points on these streams is not unlike the system adopted to improve navigation on the principle of slack-water navigation. It economizes water where it can be easily utilized.

Maj. POWELL. There is this difference in it, which is a radical difference. When water is taken out for the purpose of slack-water navigation or for powers, the water is returned to the channel, but in the case of irrigation it is largely used.

The CHAIRMAN. That is the same rule in regard to irrigation. They take it out and devote it to irrigation purposes and return it, so it is left in the channel.

Maj. POWELL. But the greater part is never returned.

The CHAIRMAN. It is evaporated.

Maj. POWELL. It is evaporated to the heavens. It would be manifestly bad policy if by some process, in order to protect 50,000 acres at Albuquerque, we had to stop the irrigation of several million acres of land above.

Mr. LANHAM. What right has anybody to take the entire water of a river and divert it from the people below? Suppose I live 10 miles above my neighbor on a river, would it be right to take the whole body of that stream from my neighbor?

Maj. POWELL. No, I think not. I think if rights have been established in that valley they must be maintained.

Mr. LANHAM. Is it not a fact that the rights of the people in the Rio Grande Valley, from Santa Fé down to the mouth of it, are older than any rights above?

Maj. POWELL. Altogether. But the new rights are in other States, and they have no remedy at present. If the people below are to be destroyed they ought to be bought out. But provision can be made for those below to secure the surplus of water which is not used now during the season of irrigation. It would be possible to secure the rights to 50,000 acres in El Paso Valley and destroy 4,000,000 acres above. All that can be avoided by the use of the water stored, the surplus of the storm waters.

The CHAIRMAN. Your idea is, then, that the Government of the United States can fairly and legally provide for catching the water from the water-sheds and making use of it—putting it in a way in which it can be economically used?

Maj. POWELL. I would like to go over the Rio Grande, because I believe I could make it clearer than to go all over the United States. I suppose I had better go over that after it is written out by the stenographer.

Mr. LANHAM. I wish you would go over, in your revision, this problem in reference to the people of the Rio Grande. I feel a very deep and profound interest in it. That valley would all be ruined under the conditions you name.

Maj. POWELL. Suppose, Mr. Chairman, not to weary you with an extended talk, that I be allowed to insert eight or ten pages about the water of the Rio Grande and how it can be used and all rights protected.

The CHAIRMAN. I wish you would do that.

Maj. POWELL. I can do that without an interminable talk to you, gentlemen. I am afraid that I have wearied you already.

Mr. HERBERT. You are not wearying me, for I feel a very great interest in it.

The MEMBERS OF THE COMMITTEE. And we are deeply interested in it.

Maj. POWELL. The area drained by the Rio Grande above El Paso is a little more than 23,500,000 acres, or about 37,000 square miles. But much of the region is mountainous. Even if there was water enough it would not be possible to irrigate one-half of the land. Of the arable lands only a portion is irrigable, from the fact that there is not water to supply them all. It may be that when all the waters of the Rio Grande are used in Colorado and New Mexico, and in the valley of El Paso, in Texas and the Republic of Mexico, from three to four million acres can be cultivated; but this can be done only by using all of the waters and storing all those that now run to waste. And then the irrigable lands must be properly selected, so that the waters can be used to the best advantage. That none may be wasted they must be stored where there is the least evaporation, and the lands must be selected near where they are stored, and the waters must not be permitted to run through sand valleys, where they are evaporated. They must be taken out from the streams and stored to the best advantage and used without waste. Then it may be possible to irrigate from three to four million acres. Of course the estimate is rough, because the surveys have not been perfected, and it may be too great; I do not think it is too small. Now, the problem which you ask me to solve is this: How can these waters be used to the best advantage? How can they be divided among the best lands, and how can the rights of the present irrigators be maintained? I shall try to answer these questions and certain collateral problems that are involved, and to do so shall go over the ground again district by district.

Commencing, then, at the head of the Rio Grande Valley, we first meet with the Saguache. This river sinks in the sands; except in very great floods it discharges no water into the Rio Grande. Its valley, therefore, is an independent district; one of the third class. All that can be done in the Saguache district is to select the best irrigable lands and provide that the waters shall not be used where they will be largely wasted.

Then we have a district drained by the headwaters of the Rio Grande—a district of the first class. All or nearly all of its waters can be used within the district on good lands, but the lands must be selected or the waters will be wasted. The district lies wholly within the State of Colorado.

The next district below on the river is the San Ildefonso. This is a trunk district, and thus belongs to the second class. For 60 miles down below the Colorado line the river can not be taken out, as it runs in a canyon. The lands on either side are of little value and should be used only for pasturage and forest purposes. This upper portion of the San Ildefonso Valley is naturally the catchment area for the waters to be used in the valley below the mouth of Embudo Canyon. There are some creeks that come into this valley from the mountains on the east. This district, therefore, has a great catchment area which will supply a large quantity of water which should be dedicated to the use of the farmers of the valley below. But they should understand that they can not maintain rights to use water coming from the San Luis district; that they should develop their agriculture wholly from the supply of their own catchment area. The best lands lie on either side of the river in the valley below Embudo Canyon and along sections of the eastern tributaries. These lands should be selected in sufficient amount to use all the waters of the district, and all other lands should be deprived of the right to use water for irrigation; then there could be no controversy about water rights in the district. Settlers could not go upon the nonirrigable lands and illegally take the water, farming could be developed in the valley to the greatest extent and on the best lands, and the farmers would be secure from depredations by other farmers going above them and "pirating" the water, to use a term common in the western country.

Midway in this district and at the head of the irrigable lands the Taos joins the Rio Grande. It is a fine stream, and its drainage basin constitutes a district of the first class. All the waters of the Taos can be used in its own valley, and it should be established that the people of that district have a right to use all of those waters, and that the people in the San Ildefonso Valley below can never maintain the right to have those waters flow down to their valley; that the Taos Valley is not a part of the catchment area of the San Ildefonso Valley.

In the lower part of the San Ildefonso Valley the Chama joins the Rio Grande. The basin drained by this river constitutes a district of the first class. All its waters can be used at home, and it should be established that the people have the right to use them there, and that no right can be maintained to the use of its waters outside the district.

At the foot of the San Ildefonso Valley the Rio Grande again traverses a deep canyon for a distance of 50 miles. Along this course it receives many important tributaries that drain high mountains, and on these irrigation can not be practiced to any advantage. It is a pasturage and timber region, and is a catchment area for a district below. The canyon is known as White Rock Canyon. At its mouth the waters can be taken out again and spread over a large valley. In this valley there are already a number of considerable towns. Albuquerque is the principal city, and we will call it the Albuquerque Valley, and the district including the valley and the catchment area above, the Albuquerque district. It is of course a trunk district, and hence belongs to the second class. Now, it should be established that the people of the Albuquerque district can not maintain rights to use water not caught within their district; that all of the volume of the Rio Grande in the San Ildefonso above belongs to the people of that valley; that the only waters which the Albuquerque farmers can use and permanently maintain rights to are those falling from the heavens over their district.

The irrigable lands of the Albuquerque district are in excess of the water supply. The nearer to the mouth of the White Rock Canyon they can be used, the greater is the area that can be irrigated. Perhaps this district should terminate at Socorro. Perhaps it should go down to San Marcial. A careful topographic and hydrographic survey is necessary to determine this boundary. The district would at any rate be more than 150 miles in length, and it is a long sand basin. If the irrigable land should be selected in the southern end of the district much of the water would be lost on its way; if selected in the northern end of the district this water could be saved. The Rio Grande will irrigate two acres in the northern end of the valley for every acre that can be irrigated in the southern end of the valley. But there are lands already irrigated in the southern end of the valley, and their rights should be maintained—at least, until they are justly extinguished. Doubtless this will ultimately be done. It is of prime importance that no more rights be established in the southern region of the district.

To the east of the White Rock Canyon lies Santa Fé Creek. It is a beautiful stream of water, and the region which it drains forms a district of the first class. Here the city of Santa Fé is situate, and the waters of the great creek are all used in irrigation during the summer months. An attempt has been made to store water, but it has proved a failure. The site of the reservoir was among hills that had been denuded of their forests and grasses, and the reservoir was destroyed by the enormous and rapid accumulation of débris. Other and better reservoir sites can be found where the forests are not yet destroyed. The farmers of the district should have control of these forests, or they can not greatly increase the area of irrigation in the district. The lands to be irrigated lie on a plateau in the neighborhood of the city, and are already of great value. The principal catchment area is in high mountains where there are extensive forest lands, and where there should be pasturage lands, but these are largely destroyed by overfeeding. The pasturage and timber lands greatly need protection in the interests of agriculture below.

Just above Bernalillo the Jemez joins the Rio Grande, and here we have another district of the first class. The Jemez now discharges a part of its waters into the sand, for there is a long stretch of dunes extending from Zia down to the Rio

Grande. Still, the river has a volume sufficient to carry part of its waters over these sands and discharge them into the Rio Grande. The catchment area is the Tewan Mountains and the Tewan Plateau, a lofty region covered with beautiful forests and rich grass lands yet uninjured by fire or overfeeding. The mountain meadows are abundant and beautiful, and the forests are among the best in New Mexico. The lands to be cultivated by this river lie on the mesa west of Bernalillo and Albuquerque. The waters can be stored in the mountain meadows and elsewhere very cheaply, but it will be expensive to take the water across the sand dunes onto the irrigable lands of the mesa. The mesa itself and the catchment area both should constitute one district. The waters of the mountains should be attached to the lands of the mesa, and the right to use the waters should permanently inhere there. The settlers in the valley of the Rio Grande should not be able to acquire rights to the waters, for in so doing they would be chiefly wasted. The catchment area is a volcanic district, and volcanic cinders and ashes abound; and these conditions make it necessary to carefully protect the lands, otherwise they will silt the streams and fill the reserviors. The forest area is, therefore, chiefly valuable as a catchment area, and should never be denuded of its trees.

The next stream is the Puerco, which comes in below from the west. It heads in the Nacimiento Mountains, the western slope of the Tewan group. Along this range of mountains there are several beautiful streams that flow into a distant valley into the dry channel of the Puerco, for it here flows through sands, and passes only in extreme floods into the Rio Grande. Practically, it is a district of the third class. Its waters have been used in irrigation in the settlements near the mountains, which are to some extent well situated for such purposes. But farming is chiefly carried on in the valley of the Puerco, and in that region can not be permanently maintained to advantage. The rights to irrigate so far from the mountains must be permanently extinguished if the Puerco is to be used to the best advantage. The catchment area is the slope of a great mountain range covered with fine forests, and there are many good reservoir sites. The pasturage is also extensive, but the pasturage and the forests must be protected to save the agriculture. The irrigable lands of the Puerco should be carefully selected, and no other lands should be cultivated. The reservoirs must be selected in the valleys and on the slopes of the mountains, where they will not be subject to destruction by silting if the forests and grasses are not carefully preserved.

From Socorro southward to El Paso is a distance of about 200 miles by the river. There is already irrigation in the Mesilla Valley above El Paso, and there is also much farming below El Paso in Texas and the Republic of Mexico. Through much of the way from Socorro to the head of the Mesilla Valley the river canyons again, and there is a natural catchment area for the country below. This upper region should be declared the catchment area for the Mesilla Valley. At the mouth of this canyon there is a place called Point of Rocks, near Fort Selden. Now, it is possible to take out all the waters of the Rio Grande derived from the catchment area just described at this point, and there is land enough in the Mesilla Valley to use it. But this would cut off all the water from the El Paso Valley below. There is a short pass or gorge just above El Paso through which the Rio Grande runs. This divides El Paso Valley from Mesilla Valley. To maintain the rights of present irrigators in Mesilla Valley and El Paso Valley alike, it becomes neceasary to unite these two valleys into one district and to divide the waters between them. There is water enough coming from the catchment area below Socorro to maintain all the agriculture yet developed and to increase it somewhat—how much we do not know, as the survey is unfinished. Nor do we know how to divide the waters. The El Paso Valley is partly in Texas and partly in the Republic of Mexico. The Mesilla Valley is in New Mexico. It is thus that the waters of the Rio Grande in this district must be divided between three peoples, and unless some authority steps in and makes this division the irrigators of the Mesilla Valley can take all the waters from Texas and old Mexico and destroy all the farming below. The survey has developed the fact that we can store water with reasonable economy and in sufficient amount immediately above El Paso, at the gorge of which I have spoken, to supply the wants of all the farming in the valley below in both countries, and from the same reservoir an additional area can be served, but there is no wisdom in constructing this reservoir unless steps are taken to provide a catchment area for it and to protect that catchment area from spoliation.

It is thus that the El Paso problem can not be solved by the construction of a dam at El Paso and the establishment of a reservoir to hold water for the valley below. A catchment area must also be provided, and in providing this the rights in the Mesilla Valley must be maintained. It is true that if the dam is constructed at El Paso now, flood waters in sufficient quantities will come down to serve present wants, but these flood waters can be caught above, and ultimately will be, and it will be wise to pay heed to the ultimate conditions. How many years ere this will be I do not know; it will depend upon the rate of development, an uncertain factor. But schemes have been projected and begun in the Rio Grande Valley within the last eighteen months to take one-half of the ultimate supply of water. Most of these schemes have been projected without any proper consideration of the conditions to be met in order to utilize the greatest amount of land. If they are completed and rights finally established on the ground selected, then one-half of the value of the Rio Grande Valley is forever destroyed. The rights and interests thus established will be so wasteful of water that the Rio Grande will sustain only one-half of its possible population. This statement is very conservative. It may be and it is even probable that the water will be able to do only one-third of its duty. And the Rio Grande is a fair illustration of the facts and conditions pertaining to every great river in the arid lands.

This, then, is needed in the Rio Grande Valley, that its agriculture may develop normally and that all rights established may be maintained: First, it should be divided into irrigation districts, as I have described. In each district the catchment area and the irrigable lands should be determined and defined. To define the irrigable lands, it is necessary to measure the waters, in order to discover how much land can be used. Then the irrigable lands should be declared such, and the law should prevent any other lands being irrigated. Then the catchment areas should be defined, and settlement on the catchment areas for agricultural purposes should be prohibited, and the people farming on the irrigable lands should have a right to control the catchment areas and to protect and use the forests and grasses. Then, in each district the storage basins should be segregated and reserved from sale and occupation, so that they may not fall into the hands of speculators whose rights would have to be purchased before the waters were stored; but the people who live in the district as a body politic and corporate should have a right to control these storage basins for the common use. The dam sites and the canal sites ought in like manner to be designated and preserved from sale to individuals and held for the common use of the people. By this plan the irrigable lands would be held to severalty by the people; the sites for reservoirs, canals, and dams, and the catchment areas would be held in common in each district. But in the El Paso district, in which the catchment area is in New Mexico, and a part of the irrigable lands in the Mesilla Valley of New Mexico and a part in the El Paso Valley of Texas and old Mexico, some means must be provided to divide the waters. It is an interstate and an international problem; but the rights of all the people now cultivating the soil should be maintained.

To define the districts a topographic survey is necessary; to define catchment areas, and irrigable areas, and to select the reservoir sites, canal sites and dam sites, a topographic survey is necessary; to divide the waters, a hydrographic survey is necessary, and a hydrographic survey is based upon and can be most economically made through the agency of a topographic survey. In selecting the lands in headwater districts, they should be taken in regions low enough to have a good agricultural climate. In the trunk districts the lands should be as near to the points where the waters are taken from the rivers by diverting dams as possible, that these lines may be the shortest and that the least water may be wasted. The reservoir sites, other things being equal, should be selected on the highest lands, where the evaporation is least. As far as possible, reservoirs should be selected away from the channels of the principal streams, where they can be maintained at the least cost and where the danger of destruction is least. The principal lines of canal should all be designated in advance, in order that impedimentary and obstructive rights may not be established. These obstructive rights are of two classes: First, where a lateral stream joins a main stream, the waters of the lateral should be taken to lands sufficiently high up its course to be out of the way of the development of irrigation on the principal stream. The principal stream usually has a lower gradient, and its waters can not be taken to very high lands; and if the waters of the lateral stream occupy the low lands, the waters of the principal stream can not be used. This condition of affairs has arisen in many cases already in the development of irrigation in the West. The obstructions of the second class relate to low-line canals taken out along the course of a stream which runs in a sand plain. If the canals are taken out here, the whole length of line is extravagantly great, and the loss of water is correspondingly great. All canal lines should be made as high as possible.

Such are the most important conditicns which relate to the utilization of water for irrigation and to the development of agriculture in arid lands. They are all of great importance; no one can be neglected without doing serious injury to agricultural industries. If these things were done in advance of more dense settlement, and then the people permitted to control their affairs in their own way—divide the waters among themselves in each district as they please, protect and utilize the forests in obedience to their own judgment corrected by experience as time goes on, use the pasturage for their flocks and herds and protect it from destruction that they may thus use it—the arid lands would furnish homes to prosperous, peaceful, and happy people.

At another time I shall have something to say about water rights.

Let us now pass westward, across the great Rocky Mountain divide, and we come to the Gila River, which flows westward into the Colorado. I place before you a map of the Gila River and its tributaries, together with a portion of the Colorado River and this small river known as Bill Williams' Fork, which is a tributary to the Colorado. You will see that the Gila River heads in the Mogollon Range and the San Franciscan Mountains, and runs westward to the Colorado. Then it has a tributary on the north known as Salt River, and an important tributary of the Salt River is the Verde.

The Gila, above the mouth of the Salt, constitutes a great hydrographic basin, with timber lands, pasturage lands, and irrigable lands, extending southward toward the Southern Pacific Railroad in this region [indicating on map], southward and westward from Florence. There are good sites for storage reservoirs in the upper regions of the Gila and elsewhere throughout the catchment area. And upon this catchment area above, and the reservoirs which must be constructed there, and the canals which must head above and connect the river and the reservoirs with the irrigable lands, the farmers of the agricultural region must depend. They are also interested in the protection of the forests and their utilization, and have a common interest in the grass lands of the region drained by the Gila.

The Salt River and the Verde head in a great line of cliffs which extend across Arizona from the Colorado River to the San Francisco Mountains. The line of cliffs cut off the lowlands on the south and west from a great table-land or plateau above, known as the Mogollon Mesa, or the Great Colorado plateau. On this plateau many high mountains or extinct volcanoes are found, and many small streams come down here to feed the Salt River and the Verde, and the two streams together constitute a great hydrographic basin, with timber lands, pasturage lands, and irrigable lands. The town of Phœnix is situated in the center of the irrigable district. The Upper Gila and the Salt River districts are of the first class, as they are head-water districts.

Below the junction of the two streams the Gila River gives rise to a trunk district. What water it has we do not yet know. A sufficient examination of the country has not yet been made to warrant predictions as to the possible extent of agriculture therein. On the north there are two streams which belong to the third class: The Agua Fria heads near Prescott and sinks before it reaches the Gila; but at flood tide a little water runs over. Then to the west we have the Hassayampa Creek, which also has a dry channel most of the year along its lower course. We have, for the present, thrown these streams into the Lower Gila, or trunk district, until we know more of their possibilities for agriculture.

North of this trunk district we have Bill Williams' Fork and its tributaries. Little is yet known about the quantity of water which it will supply for irrigation. It is partly a mountainous region and partly a district of lowlands, and there are pasturage lands and timber lands.

The CHAIRMAN. You know the Indians, the Pimas and Maricopas, on their reservation to the south, and that they have a large area thoroughly ditched by their own labor?

Maj. POWELL. Yes; there is another irrigation district, and opportunities to store water. Southern Arizona does not appear on this map. We do not know how to divide it into districts, nor do we know how its waters are to be utilized. The streams are few and small. Artesian wells can be obtained in some places, but no great amount of agriculture can be developed thereby. The sand basins, from which waters must be pumped, are more extensive. In the main the people will have to depend upon the storage of storm waters.

Mr. LANHAM. I would like to hear you for a few moments on that proposition. I saw recently an account of a great destruction of life somewhere in Arizona.

Maj. POWELL. The construction of dams for all purposes, for power and for irrigation, is a very ancient art. If you go to the Book of Chronicles, you will find that they diverted rivers onto the lands. Dam construction is very old. In the provinces of India dams have been constructed by thousands and hundreds of thousands for irrigation purposes. Some have been destroyed and brought disaster, as at Johnstown in Pennsylvania last summer and at Hassayampa in Arizona a few days ago. In both these cases a glance at the map will show why these dams were destroyed. In the case of the Hassayampa dam it was the simplest thing imaginable. Now let me make that clear. The Hassayampa dam was planned for a dry wash. It was for the storage of storm waters. The area drained was 320,000 square miles. The Hassayampa is surrounded by three great mountains, rising a little more than 7,000 feet above the level of the sea. On one side is Mount Tritle, rising 7,500 feet. The mountains are not clad with forests. A few scattered trees grow, but in the main the mountains are naked, solid rock. Now, it is possible that one storm in these mountains may bring a fall of rain to the amount of 2 inches, or even more. If that stream receives 2 inches of rainfall, after a rain that has previously soaked the ground, almost the whole amount will be delivered into the wash below. I computed the matter a day or two ago, and I found that to protect that dam it was necessary to have a waste-weir which would discharge 6 acre-feet of water every second.

The CHAIRMAN. Equal to how many inches?

Maj. POWELL. I could not tell that without making a computation; but a great many inches. Now, a glance at the map reveals that condition. In constructing a dam for the storage of flood waters and storm waters, one of the fundamental propositions is that the degree of declivity must be known. That is to say, the dam must be related to the catchment area, and means must be provided by which all the water in the greatest possible storm can be controlled. Otherwise, when a great storm occurs, the works are liable to destruction. In the Hassayampa no provision was made for one of these great storms, and when it came it broke all before it.

Mr. HERBERT. But if it is stored——

Maj. POWELL. Now here is this dry wash, and an ignorant engineer believes the dam is safe from all the water that comes from a storm, for he has never seen it at flood-time. It may be that once in ten or twenty years there comes a storm which becomes a vast flood, and then the dam goes. Of course, in planning these reservoirs we must provide for all conditions. It is idle to say that we can not plan against them; we have simply to collect the facts and provide against all contingencies. In looking over India, where this matter of dam construction has been going on for a long time, I find there are dams which have been used for more than a thousand years. There are some that have been breached and abandoned.

In planning reservoirs and all hydraulic works for irrigation, a hydrographic survey is necessary. It is a primary condition that we learn how much water is to be controlled at any and all times. A hydrographic survey is based on a topographic survey, by which the catchment area is measured and the declivities determined. Then, the rainfall being known, in a general way—that is, the mean annual rainfall, the maximum annual rainfall, and the maximum stormfall—we are able to determine how much water is to be controlled. In getting at this we also have to gauge the typical streams. But I propose to explain this matter more fully to the committee when I lay before it the operations of the survey for the past year. Of course, works can be constructed after *guessing* at the amount of water to be controlled; but this is dangerous to life and property. If the estimates of water are too great, works are made too expensive; if they are too small, the works will be destroyed. Sound work can not be done without a hydrographic survey, and this must be based on a topographic survey.

SELECT COMMITTEE ON IRRIGATION,
March 13, 1890.

The committee met pursuant to adjournment, Mr. Vandever in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. POWELL said:

Mr. Chairman and gentlemen of the committee: I place before you this morning a map of the Colorado River and its tributaries, together with the entire area drained thereby. The river heads in the Wind River Mountains of Wyoming, and is there known as Green River. The Grand heads in the Middle Park of Colorado, and the name Colorado is attached to the river from the junction of the Grand and Green to the Gulf of California. A portion of Wyoming, a portion of Colorado, a portion of New Mexico, a portion of Utah, a portion of Nevada, a portion of California, and a portion of Arizona are all drained into the Colorado, and its waters are thus to be divided between seven States and Territories. The great valley of the Colorado is naturally divided into two very distinct parts. The lower and much the smaller part lies but little above the level of the sea, except that here and there volcanic mountains are found. The upper and larger part is an elevated region of plateaus and mountains. The step from the lower to the higher region is very abrupt, and is marked by a great line of cliffs which face the south.

The upper basin, which is divided by deep gorges or canyons into plateaus, lies from 5,000 to 7,000 feet above the level of the sea. About the rim of the basin there are high mountains, the Wasatch and the Uintas on the west, the Wind River Mountains on the north, and the great Rocky Mountains on the east. To a large extent the rivers run through deep canyons and can not be taken out on the lands. For this reason the irrigable lands are greatly limited. The Colorado itself cut through the lower portion of the plateau region in a deep canyon from 5,000 to 6,000 feet below the general surface of the country. The Green and Grand are also in canyons for much of their courses, and all of the upper streams cañon more or less. In the main the irrigable lands lie at the foot of the mountains, and the entire country can be carved into irrigation districts very conveniently, but unfortunately some of these districts must be in two or more States. As the boundary line of States are not natural lines, Wyoming and Utah are involved in some of the districts, Wyoming, Utah, and Colorado, in one natural district, Colorado, New Mexico, and Utah in another, Colorado and Utah in a number of trunk districts, and Arizona and Utah in several head-water districts of lateral streams. In every district important forest and pasturage interests are involved; in fact, the whole of this upper region of the Colorado is largely pastoral. The mountains are lofty, and great elevated plateaus exist, and the forests are abundant. In general there is more water than there is land, and only a few places will it be necessary to store the waste in this upper region.

The Colorado heads in the north and runs to the south, and it is about 2,000 miles in length. The northern region is elevated, the southern depressed, coming down practically to the level of the sea. It is a great river. These changes of altitude and latitude involve great changes of climate, and permit of a great variety of agricultural productions. The valleys in Wyoming are very beautiful, but they are very high and subject to deep snows with late and early frosts, and only a small variety of crops can be raised. Great meadows may be cultivated, and potatoes, rye, barley, and oats to some extent may be raised. Perhaps in the very lowest valleys of Wyoming a little wheat may be grown. I will call this upper region the potato region. Down the river farther, in southern Wyoming, Utah, and Colorado wheat can be raised to advantage. These I call the wheat lands; and there are some very beautiful valleys to be irrigated by the Yampa, the White, the Grand, the Green, and the Uintah Rivers. Here there will ultimately be some of the finest agricultural districts of the West, for the waters are abundant, coming from great mountain ranges, and the forests of the catchment areas are of the first order. Still farther down the Colorado there are a few canyon valleys where some agriculture may be carried on; but in the main southern Utah, southwestern Colorado, and northern Arizona, will be a catchment area for the great valley of the Colorado below. However thoroughly the upper valleys may be developed, the Colorado will discharge from the mouth of the Grand Canyon into the valley below an enormous stream of water, sufficient to irrigate several million acres of land. There are some beautiful valleys just above the cliffs, far back from the river, where corn can be raised to good advantage and where vines and fruit trees flourish. These are the corn lands. In the great valley below, vines, cotton, sugar-cane, oranges, lemons, date-palms, and all the products of subtropical climates can be raised to advantage. There is a great supply of water, and a great body of land; but we do not yet know how these waters can be taken out onto the land. Ultimately they are to be divided between California and Nevada on the one side and Arizona on the other. The mouth of the river is in the territory of the Republic of Mexico, and in that lower region there are extensive tracts of available land. The utilization of the Colorado, therefore, involves an international problem, and interstate problems also must be solved.

I shall not take up this vast region district by district, as time would fail me to enter into the subject to so great an extent; but I will dwell a few moments to point out the conditions which exist in two natural districts, which will be sufficient to illustrate the subject. I should be pleased to dwell on this part of the subject, for the great valley of the Colorado is one with which I am most familiar, having explored, traversed, and surveyed much of it myself. I will call your attention first to the Kanab district, which is really a district of the third class, as the Kanab sinks in the sands, though it reappears many miles below, where it enters a deep canyon and obtains a new supply of water. The Kanab heads in Utah, in high plateaus, where there are great forests. Near its source there is a beautiful little valley, valuable for pasturage, and which can be cultivated to raise hay and potatoes, but it is too cold for general agriculture, and the waters of the Kanab should not be used thereon. Twenty-five or thirty miles farther down, the Kanab emerges from a deep canyon into a valley plain. Here all of its waters can be used in agriculture, and they are now used there so far as they can be without storage. But the irrigable lands lie along the Territorial line, a small part being in Utah. a greater part in Arizona. It is thus that the lands that depend upon the same reservoirs and upon the same canals must be divided between the two Territories. The principal farming lands should be in Arizona, the reservoirs must all be in Utah. The Kanab is only a small stream, and not a very large area can be cultivated; but the district is large and valuable for pasturage purposes. Unfortunately it is rapidly being destroyed. The forests of the catchment area are also disappearing, as they are being devastated by fire.

To the west lie the Rio Virgen and its tributaries. Here is another natural district; part of its catchment area is in Utah and a part in Nevada. The irrigable lands are also partly in Utah and partly in Nevada, and the pasturage lands are in like manner divided. The Rio Virgen is already supplied with several flourishing settlements; but the forests and grasses are disappearing. It is possible to cut off nearly all the water from Nevada and use it in Utah, and this is being done, and through this agency most of the settlements in Nevada have failed. At one time there were several flourishing towns and agricultural districts on the Virgen, in the latter State, but development of agriculture above has laid them waste. The position of the State line here is peculiarly unfortunate, as it divides the district in a very bad way, as you see. But, more than that, here is a large area of Arizona, lying on the north side of the Grand Canyon, which can be crossed only at one point for 500 miles. This gorge, separating the northern portion of Arizona from the main body of the Territory, and impassable except at one point, is from 2,000 to 6,000 feet in depth. The citizens of Arizona who live on the north side can not go to their capital or communicate with the people of the other side without going out of the Territory and traveling hundreds of miles. All that district should be attached to Utah.

Mr. HERBERT. The river forms the line between Arizona and California, I believe.

Maj. POWELL. Yes, sir; the river forms the line.

Mr. HATCH. Is that blue line the river? I can not see distinctly from here.

Maj. POWELL. Yes, sir; it is the Colorado River. The immediate valley of the Colorado, in its lower course, is not very wide; still, it is probable that considerable areas can be irrigated on both sides of the river. Perhaps this can be done to good advantage by pumping. It may be that it will not pay to control so great a river to irrigate the bottom lands. The settlers are already using pumps very successfully. Just to the west, here in southern California, there is a vast area of good land. How the waters are to be got there we yet do not know. There are also good lands in Mexico—this region, as you see [indicating]. Here, farther in the interior of California, is a great sink, which is a continuation of the basin of the Gulf of California, and the region lies below the level of the sea.

Mr. HERBERT. Is that fertile land?

Maj. POWELL. It would be fertile if covered with water; but it can not be irrigated or cultivated from the fact that it can not be drained. If the land were irrigated it would soon be destroyed by alkaline salts; and as it is below the level of the sea, there is no possibility of drainage. The impossibility of drainage is a considerable difficulty.

I will next take up the map of Utah. As there is a great deal of country to go over I will select only salient points as we go along, lest I weary you.

The region represented on the map before you will illustrate some rather important facts in connection with the control of the waters for irrigation. The Sevier River heads just opposite the Kanab. It flows northward until it leaves the mountains, and runs out to the sand plain or desert on the west and enters the Sevier Lake, a salt lake, a sink. There is a development of agriculture originally along the plain of the lower river. It has been developed here to the extent of utilizing all the waters of the irrigating season, but no waters have been stored. Some of the country is being rapidly settled on the headwaters up in the mountains. The waters from the land originally irrigated are being taken away, so that some of the farmers are compelled to abandon part of the land which before was irrigated in this region of country. The places for storing are in these upper regions. The waters of the Sevier ought to be used in the two sections of the lower valley, where wheat and corn can be raised and a great variety of other crops: but in order to do it the waters must be stored in the mountain regions above, where the storage basins are. This upper region is well forested and contains a great body of pasturage land. The land below, where agriculture is to be practiced, is almost—not entirely, but almost—destitute of grass, but very valuable for agriculture, as it is a warm climate. If the region here is to be irrigated to the entire capacity of the Sevier River, then the water must be stored in the upper regions, and the people who irrigate these valleys must have control, by some process or other, of the waters of the upper region.

It is the same problem as is exhibited elsewhere; the people are interested in the protection of the forests about the sources of their water, and in the protection of the grasses, so as to feed their cattle in the summer. This is the story over and over again wherever we may go, a peculiar fact being that in general the agriculture is dependent upon the land not owned by the agriculturists, or not occupied directly by the agriculturists—that is, the waters come from another region. The canals have to be constructed over other lands, the storage basins are not lands that are occupied for agriculture, and the catchment areas are in other districts, where they must be protected from destruction by waste of the forests, etc., so that wherever agriculture is to be developed by the utilization of the streams of the country, the people themselves, the agriculturists, have an interest in some other country. That is the most important fact about the whole system of irrigation everywhere.

There are some other interesting problems on the Sevier, but I will pass on to Salt Lake Valley. The Salt Lake Valley is one where some evils growing out of improvident projection of canals and improvident utilization of waters are very clearly illustrated. The Jordan heads in the Wasatch Mountains and in the Uintah Mountains beyond. There are a number of small streams here [indicating on map]. These streams run into Utah Lake. The river is known as the Jordan from the point where it leaves Utah Lake to the point where it enters Salt Lake.

Mr. HERBERT. Is Utah Lake salt?

Maj. POWELL. It is not salt; it is fresh water. Salt Lake is salt. There is irrigation all along these streams, on the Provo, the Spanish Fork, and so on. A fine area around Utah Lake is already irrigated by streams which run from the mountains. A great many creeks run down from the Wasatch Mountains into Jordan River that are used for irrigation. On entering the country the people settled low down comparatively in the valley of the Jordan and took the water from these streams that run down into the Jordan and brought it on the plains or lowlands near the Jordan River. Then ultimately they wanted to use the Jordan itself. Utah Lake is itself a great storage reservoir, and it is utilized to some extent for that purpose now, and only a small expenditure is needed to make it a storage reservoir of vast resources; but the people there can not utilize it because they have entangled themselves with prior rights. They have taken out the waters of these streams onto the only land that can be reached by the Jordan, instead of taking them higher up in the lateral valleys. Now, in order to utilize the whole Jordan they must move this agriculture by the banks of the Jordan away to districts up the tributary streams. We are coming to that condition everywhere in the West. The tendency is first to utilize small streams on the lands that should be reserved for the large streams. Then when the large stream is to be used it can not be, because of vested rights. They are adjusting these matters by Church authority in Utah, but we can not elsewhere in the country manage it that way.

Now, another problem is illustrated clearly in Utah. Utah Lake is a natural reservior, and it would take only a small dam and the opening of canals to irrigate all this valley of the Jordan. But the people who settled on these plains settled along the margin of the lake; established their homes near the lake. If the water which goes into Utah Lake is to be stored and all of it saved by constructing a dam—which can be done very cheaply at the outlet of the lake—and make a reservoir for all the waters of the year, then all this agriculture has to be bought out, because the lands will be flooded. They have already irrigated from one to two hundred thousand acres of land by raising a dam two or three feet high at this point, but they did it without first consulting the people above. As soon as they stopped the waters here and dammed them upon the land, there resulted a contest between two counties, Salt Lake County and Utah County, and it was settled locally by Church arbitrators. One county paid one-third of the expense, the other paid one-third, and the Church paid one-third, so that the matter was settled. But a large area below, on the Jordan, could be irrigated if all these rights along the margin of the river were bought out.

Mr. HANSBROUGH. Is that area settled upon now?

Maj. POWELL. Yes, sir.

Mr. HANSBROUGH. That can be irrigated?

Maj. POWELL. Yes, sir; that area.

Mr. HANSBROUGH. This is wild land?

Maj. POWELL. Yes, sir; and that wild land can not be settled now, because it is blocked by the settlement above; and that is the condition we are coming to again and again all over the arid lands, blocking the utilization of the waters by establishing impedimentary rights elsewhere. If the canals projected and begun during the past years, since the passage of the act creating an Irrigation Survey, are actually constructed, and the various plans before Congress for granting rights of way are actually granted, and if the various plans for granting rights of way by States and Territories are actually given, and the canals constructed there which are now projected—if all the schemes on hand to-day and developed in the last eighteen months are carried out, it will be impossible to utilize all the waters of the country without buying out vested rights to the amount of several hundred million dollars. The process now is to block development in the manner in which I have spoken. That arises from the fact that the first irrigation goes into a country regardless of the future development of the country, and selects first the smaller streams that can be taken out the cheapest, and takes the water on the lowest land, when the water ought to be taken out near the source.

Mr. PICKLER. How do you account for the multiplicity of schemes in the last eighteen months?

Maj. POWELL. It is because of the large increment of value given to land by reason of irrigation. It is so enormous that there is no difficulty in obtaining hundreds of millions of dollars for the land's redemption Hardly a week passes that some foreign or American investment company does not write to me asking for information Capital is offering everywhere. You must appreciate what it means to take desert land that has little or no value and make it worth anywhere from $30 to $200 an acre, and after these lands have been increased thus in value, to obtain permanent right to water and make a permanent investment The opportunities for investment and for making grand fortunes are so great that money pours into the country for the purpose

Mr. HERBERT. You have estimated that it will take several hundred million dollars to buy out the rights that will be vested if existing plans are carried out What is your estimate of the amount that would be required to buy out vested rights in order to carry out the provisions of the bill which is before us, the general bill?

Maj POWELL. I think that less than one-fifth. That bill does not propose that the Government shall do it, but provides for condemnation of rights and that the people shall do it themselves I think while I am on this point it is best to go to another in regard to these impedimentary or obstructive rights which are growing up in the country I can illustrate it on the map here Going back here to Phoenix At first the irrigators take out a stream in a cheap way They plant a sand dam or a brush dam or a bowlder dam, just enough to check the flow of water a little, so as to turn a part of the water into a canal They run low-line canals over the land and irrigate a strip of lowland which at times of very high water will be overflowed by the river Two or three miles below they take out another such canal, and still below another Thus, along the course of a stream they will take out twenty or fifty little canals following the stream. Now, in order that the water shall flow into these canals it is necessary that a much larger volume than the canals themselves will carry shall go past them If the two, three, ten, or twenty canals were consolidated and a point selected upon the stream where the river closes in and has a rocky bottom, and a great dam were constructed and one great canal used to irrigate the country that can be supplied, two, four, or ten times the amount of land could be irrigated and the one great canal would cost less than the many canals originally established But the canals originally established will not permit a high-line canal to be taken out, because those persons not only want the water which flows in their canals to go down, but they must have a sufficient volume of water to pass their canal mouths so that their canals may catch some. The dams are not sufficient to catch the whole body of the water, and only a little can be turned off by these canals, so they must have a great body of water flowing down the river in order to get a small body out in the canal This is quite an important consideration

Mr HATCH It results in a great waste of water.

Maj. POWELL The result of which is a great waste of water It is illustrated here in this region of country They want to irrigate a large tract of land. A company is organized to do it That company buys up all the land and takes out the water above In order to buy these earlier men out they not only have to purchase the lands but they must also purchase the water rights.

It will thus be seen that there are two classes of impedimentary rights which are being established in the country The first arises through the utilization of small streams on lands which should be reserved for the service of the large streams, and by this means rights and interests are established which prevent the proper utilization of the large streams The second class relates to the construction of wasteful low-line canals that prevent the construction of high-line canals where the waters could be used much more economically in the aggregate, and where none would be wasted Some of these rights are already established, and provision must be made by some authority for their gradual extinguishment, but the matter of most importance is to prevent their establishment in the future. The evil is already seen, and it should not be permitted to grow.

The CHAIRMAN. Is not the southern part of California under irrigation more than the north?

Maj. POWELL. There is much irrigation development there. A survey ought to be made there. When the committee reaches the place to question me in reference to the surveys I want to bring the matter out, Mr. Chairman, if you please.

The State of Nevada has but little water. The mountains of Nevada are low in the main, and the waters mostly fall on the mountains. The principal bodies of water which fall in the mountains of Nevada are not used in that State. They must be used in another State. On the other hand, the principal streams which are to be used in Nevada head in another State. The State lines chance to run in that manner. Before you is a map of a portion of Nevada which illustrates it. Here is Truckee River. We have made a survey of the Truckee River, so I am able to give definite facts about it. It is part of last year's work. The waters of the Truckee River may be stored in part in Nevada, but in chief part in California. The upper waters of the Truckee River can be stored in five or six lakes and in some mountain valleys with great economy, but the lands to be irrigated thereby lie in the State of Nevada. The State of Nevada made an appropriation which proposed to give the income derived from the lands which are granted by the United States and some other sources to the development of irrigation. They passed an appropriation last year, if I remember rightly, of $150,000 to be used in creating storage reservoirs.

Mr. HERBERT. In Colorado?

Maj. POWELL. No, sir; in the State of Nevada; and when we came to examine the condition of affairs, the physical condition, it was found that the work had to be done in California; so it was blocked. The timber above the water sources there must be preserved to protect these water rights. All this great farming district, and it is a rich farming district, requires for its protection authority to manage the forest above the reservoirs. The same statement applies to the Carson River and the Walker River. These three rivers, surveys of which have been made, can have all their waste waters stored in the State of California and in their own State, but in order to do it there must be some right in the farmers below to control the land above, and when storage basins are thus constructed, there must be established some way in which they can protect them.

I think I will not go on to explain the reservoir systems in this region. There are many other small streams throughout Nevada which can be utilized, but the chief reservoirs are on these three streams which I have mentioned. The chief source of irrigation in Nevada is the storage of the storm-waters, so that the great development of irrigation in that State depends upon conditions very much like those pertaining to the region along the one hundredth meridian, which I will afterwards explain. I am going over the ground very rapidly, not to weary you; if I have not explained this matter fully enough I shall be pleased to answer any questions.

This is a map of Southern California and of a portion of Nevada. I have divided this into irrigation districts, as ultimately it must be done. Somehow or other, by some authority or other, the people who live in these districts must as a body politic control all the waters, all the timber, and all the pasturage within each. How it is to be accomplished I do not know, but it is a necessity for the country. I wish to call attention to the Kern River, which is now used largely for irrigation. On its headwaters there are some fine basins which can be used for storage of water. It is a very highly developed agricultural district, and it has been developed by a company obtaining land along the lower part of the river; this region of country here [illustrating on map]. Had that river chanced to be taken out from 50 to 75 miles farther up than where it was taken out, the ultimate area irrigated would have been more than twice the amount.

Mr. HERBERT. What river is that?

Maj. POWELL. The Kern.

The CHAIRMAN. I would call your attention to one fact about the irrigation of the Kern. That has been done mostly by Haggin and Carr. They control—I got this from themselves—about 400,000 acres of land. They have got water enough to irrigate 2,000,000 acres of land. I have a report from the registrar of the land office at Los Angeles, which states that in that district there are 13,000,000 acres of land in the Mohave and Colorado Desert subject to entry under the desert land act. Here is one company who control the water that will irrigate 2,000,000 acres of land, and they now control about 350,000 to 400,000 acres.

Mr. HERBERT. Is that company incorporated under the laws of California? Have they a charter to take out that water?

The CHAIRMAN. It is a partnership.

Mr. HERBERT. Have they any charter granted by the State of California?

The CHAIRMAN. Only under the old law of prior appropriation.

Mr. HERBERT. That is a law of the State.

The CHAIRMAN. Yes, sir.

Mr. PICKLER. That is the law of all these States, the law of prior appropriation.

Maj. POWELL. It is the law of all of them.

The CHAIRMAN. They have got one canal 3, 4, or 5 miles, 120 feet surface width, 80 feet in the bottom, and it is 6 feet deep, and that is made as a feeder to small canals.

Mr. HERBERT. What I was trying to ascertain was whether there were any statutes in the State of California upon this question of irrigation.

The CHAIRMAN. We have a good law now under which we are organizing irrigation districts; that is known as the Wright bill, and under that law they are authorized to issue bonds, and they are being issued, and are being taken with great rapidity, perhaps two millions of money having been invested in these irrigation bonds in California, and before it gets through it will run up to fifty millions.

Mr. HERBERT. What is the nature of that law; is it a general law by which any parties complying with certain conditions can incorporate themselves and acquire rights?

Maj. POWELL. The Wright bill of California will rapidly develop the irrigation of the country. The Wright bill of California will affect the establishment of conflicting rights in a very bad way, and it will ultimately result, as far as it is carried into effect (and it will be carried into effect very rapidly)—it will ultimately result in all the irrigation of that land falling into the hands of companies, and either the farming will be done by wholesale, or the farming will get into the hands of individuals and the companies own the waters. It has very good features. The difficulty with the Wright bill is this, that it does not provide for the organization of irrigation districts as natural hydrographic basins. Any tract of land or region of country may be organized into an irrigation district, and the people may issue bonds to raise the money for the construction of irrigation works. But these districts will soon be in conflict with one another, as there are no means yet provided for the division of the waters among them. If the law had provided for irrigation districts such as I have described to you, it would be a long step in the right direction. As it is, it will ultimately lead to the multiplication of controversies, and put neighborhood at war with neighborhood. In most of the States—if I remember rightly in all the other States which have been organized—the State constitutions declare that the waters are the property of the people, but at the same time rights are granted to companies and individuals to control the water as distinct from the land, so that the tendency, except in southern California, and also in Utah, is to put the lands and the waters in the hands of capitalists or corporations; and that is going on at a very rapid rate. In southern California, at Greeley and other places in Colorado, in the Mexican settlements, and in Utah, the tendency is to put the control in the hands of small owners. Outside of these, all the lands and all the waters are coming under the control of companies at a rapid rate, at the rate of millions of dollars annually.

The CHAIRMAN. As a general thing the water is rented out to the consumer.

Maj. POWELL. In that country?

The CHAIRMAN. Except Haggin and Carr, where they own practically the great bulk of land.

Maj. POWELL. This matter on the Kern River illustrates what is going on everywhere except in the particular regions I have mentioned.

The CHAIRMAN. This firm is now endeavoring to sell the land at reasonable rates —the land with the water attached, both go together.

Mr. HERBERT. You spoke of Utah and some other regions in which the tendency is for small owners to get control. Will you explain in your testimony and append, if you please, to your answers the local laws and regulations under which this is accomplished?

Maj. POWELL. Yes, sir. The settlements in southern California have been made by men who appreciate this question. The streams are not large. Irrigation depends on springs, small sources, and to some extent on artesian wells, and the use of the water on these streams in some cases has been in litigation. Now gradually the communities are buying up the rights. At Riverside they had a long litigation and resorted at one time to shotgun protection against the water company. But finally they compromised the matter and bought the companies out as a community; and in the main, communities are getting control of the water in southern California.

In all Spanish communities the world over, not only Mexico and California, but in Spain, the common law provides for that; the old law that has come down through centuries keeps the control of the water in municipalities. They seem to think they are doing the same in Colorado and in some of the States and Territories by providing in their constitutions that the water belongs to the people, but when they charter a company or an individual and give to him the right to take out the water, they convey that which should belong to the people, just as much as if a man should seize and possess without a charter—the effect is just the same. So while they think they accomplish this matter they have not done it, because in connection with the reservation which generally declares that the waters belong to the people, they further provide in the statutes that grants may be made to individuals and corporations to take out the water instead of leaving it in the hands of municipalities or bodies of people at large. You see how that defeats the general purpose of the statutes.

Mr. HERBERT. One difficulty, I understand, in the way is, in this country they are much more strict in upholding vested rights than they are in countries governed by the civil law. The Dartmouth College case has gone a long way in the settlement of this question. The holding in that case affected the question very seriously.

Maj. POWELL. There are two methods of controlling irrigation and dealing with these questions. Throughout all lands, where agriculture depends upon irrigation anywhere, there are two diverse systems of administration. The Spanish and Italian people provide one system of administration; the French and English provide another. This, I think, is worthy of explanation. It will be understood, first, that agriculture where irrigation is practiced is practically under conditions with which we are unfamiliar in this country. We come from a humid land, where a man may make a farm for himself, because the clouds supply sufficient rain; but wherever agriculture is dependent upon irrigation the agriculturist is dependent upon the river and catchment area away from his land. The second fact is, that if the land is to be irrigated, irrigation works are to be constructed, perhaps costing $100,000, $500,000, $5,000,000, or $10,000,000 before anybody can cultivate anything. We find one of these two systems ultimately prevail; either the people are put in possession of the rights by municipalities and work out their own systems of administration for themselves, as in the Spanish colonies and in Spain itself; or the British system prevails, where the Government owns the works, and takes possession of the waters and supplies the water to the farmers and charges them for it. This is the British system in India. The chief revenue which the British Government derives from India is the tolls on its irrigating canals. Now, before you there are two bills, one looking in one direction, the other exactly in the opposite direction, in reference to this matter; one putting the control in municipalities, the other putting it in the National Government; and the issue has got to be met, because the people are commencing the work of irrigation. They have already irrigated seven or eight million acres of land in the country. They are flowing into the country in large numbers, and capital is ready to be invested, and the country will be irrigated because of the enormous increment in value to the property which arises from irrigation; and some system has to be adopted to regulate it.

The CHAIRMAN. The Constitution confers upon Congress the right to regulate commerce between the States, but it does not go far enough to reach this question of irrigation.

Mr. HERBERT. One method of getting the control of this matter into the hands of municipalities would be to turn over the lands to the several States and Territories and let them control it. Of course that would not answer for all these cases of which the Major is speaking, but it is a question whether that would not be after all the best we could do.

Mr. PICKLER. To turn the lands over?

Mr. HERBERT. Yes, sir; to the States and Territories.

The CHAIRMAN. That would be a good suggestion. The same difficulty would exist which still exists of conflicts between adjoining States and Territories unless you would enlarge the definition of commerce.

Mr. HERBERT. The Constitution is pretty elastic under the construction of some people. Commerce does not include simply that which flows upon the water and is transferred from one locality to another. It includes also what is produced in the ground.

Maj. POWELL. There is before you, Mr. Chairman and gentlemen of the committee, a map of the Bear River. It heads in Wyoming chiefly, up here in the mountains; then runs into Utah, passes into Idaho, and returns into Utah. The catchment area is in part in Utah and in part in Wyoming. It will be remembered, when we see a great area of country like that, that the catchment area is a mountain area, that there the water is concentrated and there the great volume of water falls, and that very little falls in the valley below.

Mr. HERBERT. It is a great water-shed.

Maj. POWELL. It is a great water-shed. The catchment area is chiefly in Utah, and the irrigation—not the whole of it, but a little of it—is in Idaho. Its reservoirs will be partly in Utah, partly in Idaho, and partly in Wyoming. A little agriculture can be practiced along here in Idaho, but the principal part of it commences near the line between Idaho and Utah and extends down the valley to Salt Lake. The greater part of the waters are to be utilized there. But in order to utilize these waters fully, somehow or other the right to control the irrigation works in Idaho and Wyoming also must be obtained. This is one of the most complex problems which we have. There is a very beautiful body of land along the Bear River, and irrigation has already been practiced, and the people are in conflict. The governor of Idaho and the people of Idaho have petitioned the Secretary of the Interior to stop the development of the irrigation work by the people of Utah. The matter is in controversy, and the controversy is very bitter between the two Territories.

The CHAIRMAN. Can you determine the volume of water flowing in those streams?

Maj. POWELL. We are measuring it.

The CHAIRMAN. You know that is an important element in the problem.

Maj. POWELL. When I come to explain what the survey is doing I will show you in regard to that.

Mr. Chairman, I now place before you a map of the great Snake River Valley. The river heads in Wyoming, and making a great bend southward passes through Idaho Territory, then turning northward it becomes the boundary line between Idaho and Oregon; then it forms a portion of the boundary line between Idaho and Washington, where it empties into the Columbia. It is thus that Wyoming? Idaho, Oregon, and Washington are interested in the waters of this great river and its tributaries. At the headwaters of the stream, in Wyoming, we have a great catchment area where deep snows and heavy rains fall. In the storage of the waters of this stream the mountain reservoirs must be chiefly in Wyoming, but the waters from these reservoirs must be used in Idaho. We have in the survey already discovered sites for reservoirs sufficient to irrigate more than 3,000,000 acres of land, and the water coming from the Wyoming mountains is sufficient to fill them. One of the great reservoir sites is in part in Wyoming and in part in Idaho. The survey of this region has just begun, but we already know where to take out the waters from these reservoirs and put them on Idaho lands to the north of the river. These lands lie comparatively low, are warm, the climate is salubrious, and ultimately there must be a great body of agriculture developed; but it is manifest from what I show you that some means must be provided by which the people of Idaho who engage in agriculture on these lands can protect their sources of water supply in Wyoming and have control of the irrigation works which they must construct there.

Passing down the river you see a number of streams which head in Nevada on mountains. These streams flow northward into the Snake or Shoshone River. The catchment areas are in part in the mountains of Nevada and in part in the mountains of Idaho, and the storage must be there and irrigating works must be constructed there, but the lands to be irrigated lie down the streams farther, in the Territory of Idaho. Idaho therefore depends upon Wyoming for the headwaters of the Snake, and on Nevada for the headwaters of these tributaries. The Owyhee River, that heads in Nevada, runs across the corner of Idaho into Oregon. The catchment area and storage basins are in Nevada and Idaho, but the irrigable lands are chiefly in Oregon; the people of Oregon, therefore, must by some means have control of the sources of their water supply in Nevada and Idaho.

All of these rights in Idaho involve the irrigation of from 6,000,000 to 8,000,000 or perhaps 10,000,000 acres of land. The principal agricultural values of the State are therefore involved in interstate contests and interstate rights. If these rights are not settled a vast and beautiful agricultural region in Idaho will remain undeveloped and agriculture will be driven into the mountains of Wyoming. If the water of the Snake is to be taken out in Idaho, the lands to which it is to be taken should be immediately designated, and the places on the river where the waters are to be diverted should also be fixed, for if rights to improvident works are acquired the development of agriculture to the extent of cultivating 1,000,000 or 2,000,000 acres will completely prevent the development of 7,000,000 or 8,000,000 acres, and perhaps more, by methods which I have already explained.

Mr. HATCH. That blue line represents the Snake River?

Maj. POWELL. Yes, sir.

Mr. HATCH. Is the upper part of that map north?

Maj. POWELL. Yes, sir.

The CHAIRMAN. It is a tributary of the Columbia?

Maj. POWELL. Yes, sir; the portion which is above that line is turned westward and runs into the Columbia, becoming the boundary line between Oregon and Washington.

Mr. HATCH. What is that small river up there?

Maj. POWELL. That is the Salmon River.

Mr. Chairman, the general facts which I have been presenting in relation to the utilization of the stream waters of the arid lands can be illustrated in the same manner from a consideration of the rivers of the North, and I have prepared these maps which you see for that purpose. I could go on with a description of the Columbia and its tributaries and bring out essentially the same class of facts which I have elucidated in my statement up to the present time. The utilization of the Missouri River and its great tributaries for irrigation, if properly considered, would reveal just such facts as I have been presenting. It would show that there are many international, interstate, and intercommunity problems which must sooner or later be solved. In all of these streams it can be shown that if the entire service of the water is to be secured the lands must be properly selected, and that for this purpose the high mountain regions should be excluded, that is, irrigable lands should not be selected therein, but that everywhere lands should be selected as near to the mountains as possible, in order that the full value of the waters may be obtained. Everywhere it could be shown that the irrigable lands are dependent upon catchment areas where forests and grasses are abundant. Everywhere it could be shown that the great body of the water must be stored in the mountains on the catchment areas, and not in the midst of the irrigable lands. In like manner, it can be shown that all of the irrigating works must be constructed on these catchment areas, outside of the lands irrigated. It is thus that the farmers or the irrigable lands, when such lands are properly selected, are primarily and radically interested in the management of the catchment areas. Already the time is exhausted, and I can not take up these additional illustrations.

I have attempted to divide all of the arid lands dependent upon stream waters into irrigation districts, and these provisional districts I have shown you on the maps which I have presented. There are about 140 of these districts as they are now planned, and each district is about as large as two ordinary counties; but they do not in any way conform to county lines, county lines being artificial, as are the State lines, while the irrigation-district lines which I have traced are natural. These irrigation districts as I have plotted them are only provisional; a final survey is necessary to determine them with accuracy. There are a number of trunk districts as I have laid them out which will ultimately be divided, but our knowledge at the present time is not sufficient to enable us to divide them wisely. It is probable that about 150 districts will be needed, and possibly more, so that each district shall be composed of its irrigable lands and catchment area. But I beg to say, in conclusion, that the division into natural irrigation districts is simple and can be readily accomplished by a reasonably careful survey of the ground; and let me say that if that were done each district would have its catchment areas with timber lands and pasturage lands and sites for irrigation works, and in the midst of each district, or low down it, the irrigable lands would be found in a somewhat compact body.

Mr. HANSBROUGH. I would suggest, Mr. Chairman, that it is only 2 or 3 minutes to 12 o'clock.

Thereupon the committee adjourned to meet on Saturday, March 15, at half past 10 a. m.

As requested by the committee, the following extracts from constitutions and statutes of States in the arid region are appended by Maj. Powell:

EXTRACTS FROM THE CONSTITUTIONS OF STATES RELATING TO IRRIGATION.

[From the constitution of Colorado.]

SEC. 5. The water of every natural stream not heretofore appropriated within the State of Colorado is hereby declared to be the property of the public, and is dedicated to the use of the people of the State, subject to appropriation as hereinafter provided:

SEC. 6. The right to divert unappropriated waters of every natural stream for beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using water for domestic purposes shall have preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have the preference over those using the same for manufacturing purposes.

[From the proposed constitution of Wyoming.]

ARTICLE No. VIII.

IRRIGATION AND WATER RIGHTS.

SECTION 1. The water of all natural streams, springs, lakes, or other collections of still water, within the boundaries of the State, are hereby declared to be the property of the State.

SEC. 2. There shall be constituted a board of control, to be composed of the State engineer and superintendents of the water divisions, which shall, under such regulations as may be prescribed by law, have the supervision of the waters of the State and of their appropriation, distribution, and diversion, and of the various officers connected therewith; its decisions to be subject to review by the courts of the State.

SEC. 3. Priority of appropriation for beneficial uses shall give the better right. No appropriation shall be denied except when such denial is demanded by the public interests.

SEC. 4. The legislature shall, by law, divide the State into four water divisions, and provide for the appointment of superintendents thereof.

SEC. 5. There shall be a State engineer, who shall be appointed by the governor of the State and confirmed by the senate; he shall hold his office for the term of six years, or until his successor shall have been appointed and shall have qualified. He shall be president of the board of control, and shall have general supervision of the waters of the State and of the officers connected with its distribution. No person shall be appointed to this position who has not such theoretical knowledge and such practical experience and skill as shall fit him for the position.

[From the constitution of Montana.]

ARTICLE III.

SEC. 15. The use of all water now appropriated, or that may hereafter be appropriated, for sale, rental, distribution, or other beneficial use, and the right of way over the lands of others for all ditches, drains, flumes, canals, and aqueducts necessarily used in connection therewith, as well as the sites for reservoirs necessary for collecting and storing the same, shall be held to be a public use.

[From the constitution of Washington.]

ARTICLE XXI.

SECTION 1. The use of the waters of this State for irrigation, mining, and manufacturing purposes shall be deemed a public use.

[From the proposed constitution of Idaho.]

ARTICLE XV.

WATER RIGHTS.

SECTION 1. The use of all waters now appropriated, or that may hereafter be appropriated, for sale, rental, or distribution; also of all water originally appropriated for private use, but which after such appropriations has heretofore been, or may hereafter be, sold, rented, or distributed, is hereby declared to be a public use, and subject to the regulation and control of the State in the manner prescribed by law.

SEC. 2. The right to collect rates or compensation for the use of water supplied to any county, city, or town, or water district, or the inhabitants thereof, is a franchise, and can not be exercised except by authority of and in the manner prescribed by law.

SEC. 3. The right to divert and appropriate the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall (subject to such limitations as may be prescribed by law) have the preference over those claiming for any other purpose; and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes. And in any organized mining district those using the water for mining purposes or milling purposes connected with mining shall have preference over those using the same for manufacturing or agricultural purposes. But the usage by such subsequent appropriators shall be subject to such provisions of law regulating the taking of private property for public and private use as referred to in section fourteen of Article I of this constitution.

SEC. 4. Whenever any waters have been, or shall be, appropriated or used for agricultural purposes, under a sale, rental, or distribution thereof, such sale, rental, or distribution shall be deemed an exclusive dedication to such use; and whenever such waters so dedicated shall have once been sold, rented, or distributed to any person who has settled upon or improved land for agricultural purposes with the view of receiving the benefit of such water under such dedication, such person, his heirs, executors, administrators, successors, or assigns, shall not thereafter, without his consent, be deprived of the annual use of the same when needed for domestic purposes, or to irrigate the land so settled upon or improved, upon payment therefor, and compliance with such equitable terms and conditions as to the quantity used and times of use as may be prescribed by law.

SEC. 5. Whenever more than one person has settled upon or improved land with the view of receiving water for agricultural purposes under a sale, rental, or distribution thereof, as in the last preceding section of this article provided, as among such persons priority in time shall give superiority of right to the use of such water in the numerical order of such settlements or improvements; but whenever the supply of such water shall not be sufficient to meet the demands of all those desiring to use the same, such priority of right shall be subject to such reasonable limitations as to the quantity of water used and times of use as the legislature, having due regard both to such priority of right and the necessities of those subsequent in time of settlement or improvement, may by law prescribe.

SEC. 6. The legislature shall provide by law the manner in which reasonable maximum rates may be established to be charged for the use of water sold, rented, or distributed for any useful or beneficial purpose..

CHAPTER XXXIV.

An act to provide for the organization and government of irrigation districts, and to provide for the acquisition of water and other property, and for the distribution of water thereby for irrigation purposes. [Approved March 7, 1887.]

The people of the State of California, represented in senate and assembly, do enact as follows:

SECTION 1. Whenever fifty or a majority of freeholders owning lands susceptible of one mode of irrigation from a common source, and by the same system of works, desire to provide for the irrigation of the same, they may propose the organization of an irrigation district under the provisions of this act, and when so organized such district shall have the powers conferred or that may hereafter be conferred by law upon such irrigation districts.

SEC. 2. A petition shall first be presented to the board of supervisors of the county in which the lands or the greatest portion thereof is situated, signed by the required number of freeholders of such proposed district, which petition shall set forth and particularly describe the proposed boundaries of such district, and shall pray that the same may be organized under the provisions of this act. The petitioners must accompany the petition with a good and sufficient bond, to be approved by the said board of supervisors, in double the amount of the probable cost of organizing such district, conditioned that the bondsmen will pay all said cost in case said organization shall not be effected. Such petition shall be presented at a regular meeting of the said board, and shall be published for at least two weeks before the time at which the same is to be presented, in some newspaper printed and published in the county where said petition is presented, together with a notice stating the time of the meeting at which the same will be presented. When such petition is presented, the said board of supervisors shall hear the same, and may adjourn such hearing from time to time, not exceeding four weeks in all; and on the final hearing may make such changes in the proposed boundaries as they may find to be proper, and shall establish and define such boundaries: *Provided*, That said board shall not modify said boundaries so as to except from the operations of this act any territory within the boundaries of the district proposed by said petitioners, which is susceptible of irrigation by the same system of works applicable to the other lands in such proposed district, nor shall any lands which will not, in the judgment of the said board, be benefited by irrigation by said system be included within such district: *Provided*, That any person whose lands are susceptible of irrigation from the same source shall, upon application of the owner to said board, be entitled to have such lands included in said district. Said board shall also make an order dividing said district into five divisions, as nearly equal in size as may be practicable, which shall be numbered first, second, third, fourth, and fifth, and one director shall be elected from each district. Said board of supervisors shall then give notice of an election to be held in such proposed district, for the purpose of determining whether or not the same shall be organized under the provisions of this act. Such notice shall describe boundaries so established, and shall designate a name for such proposed district, and said notice shall be published for at least three weeks prior to such election in a newspaper published within said county; and if any portion of such proposed district lie within another county or counties, then said notice shall be published in a newspaper published within each of said counties. Such notice shall require the electors to cast ballots which shall contain the words, "Irrigation district—yes," or "Irrigation district—no," or words equivalent thereto, and also the names of persons to be voted for to fill the various elective offices hereinafter prescribed. No person shall be entitled to vote at any election held under the provisions of this act unless he shall possess all the qualifications required of electors under the general election laws of this State.

SEC. 3. Such election shall be conducted in accordance with the general election laws of the State: *Provided*, That no particular form of ballot shall be required. The said board of supervisors shall meet on the second Monday next succeeding such election, and proceed to canvass the votes cast thereat; and if upon such canvass it appear that at least two-thirds of all the votes cast are "Irrigation district—yes," the said board shall, by an order entered on their minutes, declare such territory duly organized as an irrigation district, under the name and style theretofore designated, and shall declare the persons receiving, respectively, the highest number of votes for such several offices to be duly elected to such offices. Said board shall cause a copy of such order, duly certified, to be immediately filed for record in the office of the county recorder of each county in which any portion of such lands are situated, and must also immediately forward a copy thereof to the clerk of the board of supervisors of each of the counties in which any portion of the district may lie; and no board of supervisors of any county including any portion of such district shall, after the date of the organization of such district, allow another district to be formed including any of the lands in such district without the consent of the board of directors thereof; and from and after the date of such filing the organization of such district shall be complete, and the officers thereof shall be entitled to enter immediately upon the duties of their respective offices upon qualifying in accordance with law, and shall hold such offices, respectively, until their successors are elected and qualified. For the purposes of the election above provided for, the said board of supervisors must establish a convenient number of election precincts in said proposed district, and define the boundaries thereof, which said precincts may thereafter be changed by the board of directors of such district.

SEC. 4. An election shall be held in such district on the first Wednesday in April, eighteen hundred and eighty-eight, and on the first Wednesday in April in each second year thereafter, at which an assessor, a collector, and a treasurer and a board of five directors for the district shall be elected. The person receiving the highest number of votes for any office to be filled at such election is elected thereto. Within ten days after receiving their certificates of election, hereinafter provided for, said officers shall take and subscribe the official oath and file the same in the office of the board of directors. The assessor shall execute an official bond in the sum of ten thousand dollars, and the collector an official bond in the sum of twenty thousand dollars, and the district treasurer an official bond in the sum of fifty thousand dollars, each of said bonds to be approved by the board of directors; and each member of said board of directors shall execute an official bond in the sum of twenty-five thousand dollars, which said bonds shall be approved by the judge of the superior court of said county where such organization was effected, and shall be recorded in the office of the county recorder thereof and filed with the secretary of said board. All official bonds herein provided for shall be in the form prescribed by law for the official bonds of county officers.

SEC. 5. Fifteen days before any election held under this act, subsequent to the organization of any district, the secretary of the board of directors shall cause notices to be posted in three public places in each election precinct, of the time and place of holding the election, and shall also post a general notice of the same in the office of said board, which shall be established and kept at some fixed place to be determined by said board, specifying the polling places of each precinct. Prior to the time for posting the notices the board must appoint for each precinct, from the electors thereof, one inspector and two judges, who shall constitute a board of election for such precinct. If the board fail to appoint a board of election, or the members appointed do not attend at the opening of the polls on the morning of election, the electors of the precinct present at that hour may appoint the board or supply the place of an absent member thereof. The board of directors must, in its order appointing the board of election, designate the house or place within the precinct where the election must be held.

SEC. 6. The inspector is chairman of the election board, and may—

First. Administer all oaths required in the progress of an election.

Second. Appoint judges and clerks if, during the progress of the election, any judge or clerk cease to act. Any member of the board of election, or any clerk thereof, may administer and certify oaths required to be administered during the progress of an election. The board of election for each precinct must, before opening the polls, appoint two persons to act as clerks of the election. Before opening the polls, each member of the board and each clerk must take and subscribe an oath to faithfully perform the duties imposed upon them by law. Any elector of the precinct may administer and certify such oath. The polls must be opened one hour after sunrise on the morning of the election, and be kept open until sunset, when the same must be closed. The provisions of the political code concerning the form of ballots to be used shall not apply to elections held under this act.

SEC. 7. Voting may commence as soon as the polls are opened, and may be continued during all the time the polls remain opened, and shall be conducted as nearly as practicable in accordance with the provisions of chapter nine of title two of part three of the political code of this State. As soon as the polls are closed the judges shall open the ballot-box and commence counting the votes; and in no case shall the ballot-box be removed from the room in which the election is held until all the ballots have been counted. The counting of ballots shall in all cases be public. The ballots shall be taken out, one by one, by the inspector or one of the judges, who shall open them and read aloud the names of each person contained therein, and the office for which every such person is voted for. Each clerk shall write down each office to be filled, and the name of each person voted for for such office, and shall keep the number of votes by tallies as they are read aloud by the inspector or judge. The counting of votes shall be continued without adjournment until all have been counted.

SEC. 8. As soon as all the votes are read off and counted, a certificate shall be drawn up on each of the papers containing the poll list and tallies, or attached thereto, stating the number of votes each one voted for has received, and designating the office to fill which he was voted for, which number shall be written in figures and in words at full length. Each certificate shall be signed by the clerk, judge, and the inspector. One of said certificates, with the poll list and the tally paper to which it is attached, shall be retained by the inspector and preserved by him at least six months. The ballots shall be strung upon a cord or thread by the inspector, during the counting thereof, in the order in which they are entered upon the tally list by the clerks; and said ballots, together with the other of said certificates, with the poll list and tally paper to which it is attached, shall be sealed by the inspector in the presence of the judges and clerks, and indorsed "Election returns of (naming the precinct) Precinct," and be directed to the secretary of the board of directors, and shall be immediately delivered by the inspector, or by some other safe and responsible carrier designated by said inspector, to said secretary, and the ballots shall be kept unopened for at least six months, and if any person be of the opinion that the vote of any precinct has not been correctly counted, he may appear on the day appointed for the board of directors to open and canvass the returns, and demand a recount of the vote of the precinct that is so claimed to have been incorrectly counted.

SEC. 9. No list, tally paper, or certificate returned from any election shall be set aside or rejected for want of form, if it can be satisfactorily understood. The board of directors must meet at its usual place of meeting on the first Monday after each election to canvass the returns. If, at the time of meeting, the returns from each precinct in the district in which the polls were open have been received, the board of directors must then and there proceed to canvass the returns, but if all the returns have not been received the canvass must be postponed from day to day until all the returns have been received or until six postponements have been had. The canvass must be made in public and by opening the returns and estimating the vote of the district, for each person voted for, and declaring the result thereof.

SEC. 10. The secretary of the board of directors must, as soon as the result is declared, enter in the records of such board a statement of such result, which statement must show—

First—The whole number of votes cast in the district.

Second—The names of the persons voted for.

Third—The office to fill which each person was voted for.

Fourth—The number of votes given in each precinct to each of such persons.

Fifth—The number of votes given in the district to each of such persons.

The board of directors must declare elected the person having the highest number of votes given for each office to be filled by the voters of the district. The secretary must immediately make out and deliver to such person a certificate of election signed by him and authenticated with the seal of the board. In case of a vacancy in the office of assessor, tax collector, or treasurer, the vacancy shall be filled by appointment by the board of directors. In case of a vacancy in the office of member of the board of directors, the vacancy shall be filled by appointment by the board of supervisors of the county where the office of such board is situated. An officer appointed as above provided shall hold his office until the next regular election of said district, and until his successor is elected and qualified.

SEC. 11. On the first Wednesday in May next following their election the board of directors shall meet and organize as a board, elect a president from their number, and appoint a secretary. The board shall have the power, and it shall be their duty, to manage and conduct the business and affairs of the district, make and execute all necessary contracts, employ and appoint such agents, officers, and employés as may be required, and prescribe their duties, establish equitable by-laws, rules, and regulations for the distribution and use of water among the owners of said lands, and generally to perform all such acts as shall be necessary to fully carry out the purposes of this act. The said by-laws, rules, and regulations must be printed in convenient form for distribution in the district. And it is hereby expressly provided that all waters distributed for irrigation purposes shall be apportioned ratably to each landowner upon the basis of the ratio which the last assessment of such owner for district purposes within said district bears to the whole sum assessed upon the district: *Provided,* That any landowner may assign the right to the whole or any portion of the waters so apportioned to him.

SEC. 12. The board of directors shall hold a regular monthly meeting, in their office, on the first Tuesday in every month, and such special meetings as may be required for the proper transaction of business: *Provided,* That all special meetings must be ordered by a majority of the board; the order must be entered of record, and five days' notice thereof must, by the secretary, be given to each member not joining in the order. The order must specify the business to be transacted, and none other than that specified must be transacted at such special meeting. All meetings of the board must be public, and three members shall constitute a quorum for the transaction of business, but on all questions requiring a vote there shall be a concurrence of at least three members of said board.

All records of the board shall be open to the inspection of any elector during business hours. The board, and its agents and employés, shall have the right to enter upon any land in the district to make surveys, and may locate the line for any canal or canals, and the necessary branches for the same, on any of said lands which may be deemed best for such location. Said board shall also have the right to acquire, either by purchase or condemnation, all lands and waters and other property necessary for the construction, use, supply, maintenance, repair, and improvement of said canal or canals and works, including canals and works constructed and being constructed by private owners, lands for reservoirs, for the storage of needful waters, and all necessary appurtenances. In case of purchase, the bonds of the district, hereinafter provided for, may be used at their par value in payment; and in case of condemnation the board shall proceed, in the name of the district, under the provisions of title seven of part three of the code of civil procedure. Said board may also construct the necessary dams, reservoirs, and works for the collection of water for said district, and do any and every lawful act necessary to be done, that sufficient water may be furnished to each landowner in said district for irrigation purposes. The use of all water required for the irrigation of the lands of any district formed under the provisions of this act, together with the rights of way for canals and ditches, sites for reservoirs, and all other property required in fully carrying out the provisions of this act, is hereby declared to be a public use, subject to the regulation and control of the State, in the manner prescribed by law.

SEC. 13. The legal title to all property acquired under the provisions of this act shall immediately and by operation of law vest in such irrigation district, and shall be held by such district in trust for and is hereby dedicated and set apart to the uses and purposes set forth in this act. And said board is hereby authorized and empowered to hold, use, acquire, manage, occupy, and possess said property as herein provided.

SEC. 14. The said board is hereby authorized and empowered to take conveyances or other assurances for all property acquired by it under the provisions of this act, in the name of such irrigation district, to and for the uses and purposes herein expressed, and to institute and maintain any and all actions and proceedings, suits at law or in equity, necessary or proper in order to fully carry out the provisions of this act, or to enforce, maintain, protect, or preserve any and all rights, privileges, and immunities created by this act or acquired in pursuance thereof. And in all courts, actions, suits, or proceedings, the said board may sue, appear, and defend, in person or by attorneys, and in the name of such irrigation district.

SEC. 15. For the purpose of constructing necessary irrigating canals and works and acquiring the necessary property and rights therefor, and otherwise carrying out the provisions of this act, the board of directors of any such district must, as soon after such district has been organized as may be practicable, estimate and determine the amount of money necessary to be raised, and shall immediately thereupon call a special election, at which shall be submitted to the electors of such district possessing the qualifications prescribed by this act, the question whether or not the bonds of said district shall be issued in the amount so determined. Notice of such election must be given by posting notices in three public places in each election precinct in said district for at least twenty days, and also by publication of such notice in some newspaper published in the county, where the office of the board of directors of such district is required to be kept, once a week for at least three successive weeks. Such notices must specify the time of holding the election, the amount of bonds proposed to be issued, and said election must be held and the result thereof determined and declared, in all respects as nearly as practicable, in conformity with the provisions of this act governing the election of officers: *Provided*, That no informalities in conducting such an election shall invalidate the same, if the election shall have been otherwise fairly conducted. At such election the ballots shall contain the words, "Bonds—Yes," or "Bonds—No," or words equivalent thereto. If a majority of the votes cast are "Bonds—Yes," the board of directors shall immediately cause bonds in said amount to be issued; said bonds shall be payable in gold coin of the United States, in installments as follows, to wit: At the expiration of eleven years not less than five per cent. of said bonds; at the expiration of twelve years not less than six per cent.; at the expiration of thirteen years not less than seven per cent.; at the expiration of fourteen years not less than eight per cent.; at the expiration of fifteen years not less than nine per cent.; at the expiration of sixteen years not less than ten per cent.; at the expiration of seventeen years not less than eleven per cent.; at the expiration of eighteen years not less than thirteen per cent.; at the expiration of nineteen years not less than fifteen per cent.; and for the twentieth year a percentage sufficient to pay off said bonds; and shall bear interest at the rate of six per cent. per annum, payable semiannually on the first day of January and July of each year. The principal and interest shall be payable at the office of the treasurer of the district. Said bonds shall be each of the denomination of not less than one hundred dollars, nor more than five hundred dollars, shall be negotiable in form, signed by the president and secretary, and the seal of the board of directors shall be affixed thereto. They shall be numbered consecutively as issued, and bear date at the time of their issue. Coupons for the interest shall be attached to each bond signed by the secretary. Said bonds shall express on their face that they were issued by authority of this act, stating its title and date of approval. The secretary shall keep a record of the bonds sold, their number, the date of sale, the price received, and the name of the purchaser.

SEC. 16. The board may sell said bonds from time to time in such quantities as may be necessary and most advantageous, to raise money for the construction of said canals and works, the acquisition of said property and rights, and otherwise to fully carry out the objects and purposes of this act. Before making any sale the board shall, at a meeting, by resolution, declare its intention to sell a specified amount of the bonds, and the day and hour and place of such sale, and shall cause such resolution to be entered in the minutes, and notice of the sale to be given, by publication thereof at least twenty days, in a daily newspaper published in each of the cities of San Francisco, Sacramento, and Los Angeles, and in any other newspaper, at their discretion. The notice shall state that sealed proposals will be received by the board, at their office, for the purchase of the bonds, till the day and hour named in the resolution. At the time appointed the board shall open the proposals, and award the purchase of the bonds to the highest responsible bidder, and may reject all bids, but said board shall in no event sell any of the said bonds for less than ninety per cent of the face value thereof.

Sec. 17. Said bonds, and the interest thereon, shall be paid by revenue derived from an annual assessment upon the real property of the district, and all the real property in the district shall be and remain liable to be assessed for such payments as hereinafter provided.

Sec. 18. The assessor must, between the first Monday in March and the first Monday in June, in each year, assess all real property in the district, to the persons who own, claim, have the possession or control thereof, at its full cash value. He must prepare an assessment book, with appropriate headings, in which must be listed all such property within the district, in which must be specified, in separate columns, under the appropriate head—

First—The name of the person to whom the property is assessed. If the name is not known to the assessor, the property shall be assessed to "Unknown owners."

Second—Land by township, range, section, or fractional section, and, when such land is not a congressional division or subdivision, by metes and bounds, or other description sufficient to identify it, giving an estimate of the number of acres, locality, and the improvements thereon.

Third—City and town lots, naming the city or town, and the number and block according to the system of numbering in such city or town, and the improvements thereon.

Fourth—The cash value of real estate, other than city or town lots.

Fifth—The cash value of improvements on such real estate.

Sixth—The cash value of city and town lots.

Seventh—The cash value of improvements on city and town lots.

Eighth—The cash value of improvements on real estate assessed to persons other than the owners of the real estate.

Ninth—The total value of all property assessed.

Tenth—The total value of all property after equalization by the board of directors.

Eleventh—Such other things as the board of directors may require.

Sec. 19. The board of directors must allow the assessor as many deputies, to be appointed by him, as will, in the judgment of the board, enable him to complete the assessment within the time herein prescribed. The board must fix the compensation of such deputies, which shall be paid out of the treasury of the district. The compensation must not exceed five dollars per day for each deputy, for the time actually engaged, nor must any allowance be made but for work done between the first Monday in March and the first Monday in August in each year.

Sec. 20. On or before the first Monday in August in each year the assessor must complete his assessment book, and deliver it to the secretary of the board, who must immediately give notice thereof, and of the time the board of directors, acting as a board of equalization, will meet to equalize assessments, by publication in a newspaper published in each of the counties comprising the district. The time fixed for the meeting shall not be less than twenty nor more than thirty days from the first publication of the notice, and in the meantime the assessment book must remain in the office of the secretary for the inspection of all persons interested.

Sec. 21. Upon the day specified in the notice required by the preceding section for the meeting, the board of directors, which is hereby constituted a board of equalization for that purpose, shall meet and continue in session from day to day, as long as may be necessary, not to exceed ten days, exclusive of Sundays, to hear and determine such objections to the valuation and assessment as may come before them; and the board may change the valuation as may be just. The secretary of the board shall be present during its sessions, and note all changes made in the valuation of property, and in the names of the persons whose property is assessed, and within ten days after the close of the session he shall have the total values, as finally equalized by the board, extended into columns and added.

Sec. 22. The board of directors shall then levy an assessment sufficient to raise the annual interest on the outstanding bonds, and, at the expiration of ten years after the issuing of bonds by the board, must increase said assessment, for the ensuing ten years, in the following percentage of the principal of the whole amount of bonds then outstanding, to wit: For the eleventh year, five per cent, for the twelfth year, six per cent, for the thirteenth year seven per cent, for the fourteenth year, eight per cent, for the fifteenth year, nine per cent, for the sixteenth year, ten per cent, for the seventeenth year, eleven per cent, for the eighteenth year, thirteen per cent, for the nineteenth year, fifteen per cent, and for the twentieth year, a percentage sufficient to pay off said bonds. The secretary of the board must compute and enter in a separate column of the assessment book the respective sums in dollars and cents to be paid as an assessment on the property therein enumerated. When collected the assessment shall be paid into the district treasury, and shall constitute a special fund, to be called the "Bond Fund of (naming the district) Irrigation District."

SEC. 23. The assessment upon real property is a lien against the property assessed, from and after the first Monday in March for any year; and such lien is not removed until the assessments are paid or the property sold for the payment thereof.

SEC. 24. On or before the first day of November, the secretary must deliver the assessment book to the collector of the district, who shall, within twenty days, publish a notice in a newspaper published in each of the counties comprising the district, if there be lands situated in more than one county in such district, that said assessments are due and payable and will become delinquent at six o'clock p. m. on the last Monday of December next thereafter; and that unless paid prior thereto, five per cent. will be added to the amount thereof, and also the time and place at which payment of assessments may be made. The notice shall also specify a time and place within each election precinct of the district, when and where the collector will attend to receive payment of assessments, and shall be published for fifteen days, and a printed copy of said notice shall be posted for the same time in some public place in each precinct. The collector must attend at the time and place specified in the notice, to receive assessments, which must be paid in gold and silver coin; he must mark the date of payment of any assesssment in the assessment book opposite the name of the person paying, and give a receipt to such person, specifying the amount of the assessment and the amount paid, with a description of the property assessed. On the thirty-first day of December of each year, all unpaid assessments are delinquent, and thereafter the collector must collect thereon, for the use of the district, an addition of five per cent.

SEC. 25. On or before the first day of February, the collector must publish the delinquent list, which must contain the names of the persons and a description of the property delinquent, and the amount of the assessments and costs due opposite each name and description. He must append to and publish with the delinquent list a notice, that unless the assessments delinquent, together with costs and percentage, are paid, the real property upon which such assessments are a lien will be sold at public auction. The publication must be made once a week for three successive weeks, in a newspaper published in each of the counties comprised in the district. The publication must designate the time and place of sale. The time of sale must not be less than twenty-one nor more than twenty-eight days from the first publication, and the place must be at some point designated by the collector.

SEC. 26. The collector must collect, in addition to the assessments due on the delinquent list and five per cent. added, fifty cents on each lot, piece, or tract of land separately assessed, one half of which must go to the district and the other to the collector for preparing the list. On the day fixed for the sale, or some subsequent day to which he may have postponed it, of which he must give notice, the collector, between the hours of ten o'clock a. m. and three o'clock p. m., must commence the sale of the property advertised, commencing at the head of the list and continuing alphabetically, or in the numerical order of the lots or blocks, until completed. He may postpone the day of commencing the sales, or the sale, from day to day, but the sale must be completed within three weeks from the day first fixed.

SEC. 27. The owner or person in possession of any real estate offered for sale for assessments due thereon may designate in writing to the collector, prior to the sale, what portion of the property he wishes sold, if less than the whole; but if the owner or possessor does not, then the collector may designate it, and the person who will take the least quantity of the land, or in case an undivided interest is assessed, then the smallest portion of the interest, and pay the assessments and costs due, including two dollars to the collector for the duplicate certificate of sale, is the purchaser. If the purchaser does not pay the assessments and costs before ten o'clock a. m. the following day, the property, on next sale day, before the regular sale, must be resold for the assessments and costs. After receiving the amount of assessments and costs, the collector must make out in duplicate a certificate, dated on the day of sale, stating (when known) the name of the person assessed, a description of the land sold, the amount paid therefor, that it was sold for assessments, giving the amount and the year of the assessment, and specifying the time when the purchaser will be entitled to a deed. The certificate must be signed by the collector, and one copy delivered to the purchaser, and the other filed in the office of the county recorder of the county in which the land sold is situated.

SEC. 28. The collector, before delivering any certificate, must in a book enter a description of the land sold, corresponding with the description in the certificate, the date of the sale, purchasers' names, and the amount paid, regularly number the description on the margin of the book and put a corresponding number on each certificate. Such book must be open to public inspection, without fee, during office hours, when not in actual use. On filing the certificate with such county recorder the lien of the assessments vests in the purchaser, and is only divested by the payment to him, or to the collector for his use, of the purchase money and two per cent. per month from the day of sale until redemption.

SEC. 29. A redemption of the property sold may be made by the owner, or any party in interest, within twelve months from the date of purchase. Redemption must be made in gold or silver coin, as provided for the collection of State and county taxes, and when made to the collector he must credit the amount paid to the person named in the certificate, and pay it, on demand, to the person or his assignees. In each report the collector makes to the board of directors, he must name the person entitled to redemption money, and the amount due to each. On receiving the certificate of sale the county recorder must file it and make an entry in a book similar to that required of the collector. On the presentation of the receipt of the person named in the certificate, or of the collector, for his use, of the total amount of the redemption money, the recorder must mark the word "Redeemed," the date, and by whom redeemed, on the certificate and on the margin of the book where the entry of the certificate is made. If the property is not redeemed within twelve months from the sale, the collector, or his successor in office, must make to the purchaser, or his assignee, a deed of the property, reciting in the deed substantially the matters contained in the certificate, and that no person redeemed the property during the time allowed by law for its redemption. The collector shall receive from the purchaser, for the use of the district, two dollars for making such deed.

SEC. 30. The matter recited in the certificate of sale must be recited in the deed, and such deed duly acknowledged or proved is prima facie evidence that—

First. The property was assessed as required by law.

Second. The property was equalized as required by law.

Third. That the assessment were levied in accordance with law.

Fourth. The assessments were not paid.

Fifth. At a proper time and place the property was sold as prescribed by law, and by the proper officer.

Sixth. The property was not redeemed.

Seventh. The person who executed the deed was the proper officer.

Such deed, duly acknowledged or proved, is (except as against actual fraud) conclusive evidence of the regularity of all the proceedings from the assessment by the assessor, inclusive, up to the execution of the deed. The deed conveys to the grantee the absolute title to the lands described therein free of all incumbrance, except when the land is owned by the United States or this State, in which case it is prima facie evidence of the right of possession.

SEC. 31. The assessment book or delinquent list, or a copy thereof, certified by the collector, showing unpaid assessments against any person or property, is prima facie evidence of the assessment, the property assessed, the delinquency, the amount of assessments due and unpaid, and that all the forms of the law in relation to the assessment and levy of such assessments have been complied with.

SEC. 32. When land is sold for assessments correctly imposed, as the property of a particular person, no misnomer of the owner or supposed owner, or other mistake relating to the ownership thereof, affects the sale or renders it void or voidable.

SEC. 33. On the first Monday in each month the collector must settle with the secretary of the board for all moneys collected for assessments, and pay the same over to the treasurer; and within six days thereafter he must deliver to and file in the office of the secretary a statement under oath, showing:

First. An account of all his transactions and receipts since his last settlement.

Second. That all money collected by him as collector has been paid.

The collector shall also file in the office of the secretary on said first Monday in each month the receipt of the treasurer for the money so paid.

SEC. 34. Upon the presentation of the coupons due to the treasurer, he shall pay the same from said bond fund. Whenever, after ten years from the issuance of said bonds, said fund shall amount to the sum of ten thousand dollars, the board of directors may direct the treasurer to pay such an amount of said bonds not due as the moneys in said fund will redeem, at the lowest value at which they may be offered for liquidation, after advertising for at least four weeks in some daily newspaper in each of the cities hereinbefore named, and in any other newspaper which said board may deem advisable, for sealed proposals for the redemption of said bonds. Said proposals shall be opened by the board in open meeting, at a time to be named in the notice, and the lowest bid for said bonds must be accepted: *Provided,* That no bond shall be redeemed at a rate above par. In case the bids are equal, the lowest numbered bond shall have the preference. In case none of the holders of said bonds shall desire to have the same redeemed, as herein provided for, said money shall be invested by the treasurer, under the direction of the board, in United States gold-bearing bonds, or the bonds of the State, which shall be kept in said "bond fund," and may be used to redeem said district bonds whenever the holders thereof may desire.

SEC. 35. After adopting a plan of said canal or canals, storage reservoirs, and works, the board of directors shall give notice, by publication thereof not less than twenty days in one newspaper published in each of the counties composing the district, provided a newspaper is published therein, and in such other newspapers as they may deem advisable, calling for bids for the construction of said work, or of any portion thereof; if less than the whole work is advertised, then the portion so advertised must be particularly described in such notice; said notice shall set forth that plans and specifications can be seen at the office of the board, and that the board will receive sealed proposals therefor, and that the contract will be let to the lowest responsible bidder, stating the time and place for opening said proposals, which at the time and place appointed shall be opened in public, and as soon as convenient thereafter the board shall let said work, either in portions or as a whole, to the lowest responsible bidder, or they may reject any or all bids and readvertise for proposals, or may proceed to construct the work under their own superintendence with the labor of the residents of the district. Contracts for the purchase of material shall be awarded to the lowest responsible bidder. Any person or persons to whom a contract may be awarded shall enter into a bond, with good and sufficient sureties, to be approved by the board, payable to said district for its use, for double the amount of the contract price, conditioned for the faithful performance of said contract. The work shall be done under the direction and to the satisfaction of the engineer, and be approved by the board.

SEC. 36. No claim shall be paid by the treasurer until allowed by the board, and only upon a warrant signed by the president, and countersigned by the secretary; *provided*, that the board may draw from time to time from the construction fund and deposit in the county treasury of the county where the office of the board is situated, any sum in excess of the sum of twenty-five thousand dollars. The county treasurer of said county is hereby authorized and required to receive and receipt for the same, and place the same to the credit of said district, and he shall be responsible upon his official bond for the safe-keeping and disbursement of the same, as in this act provided. He shall pay out the same, or any portion thereof, to the treasurer of the district only, and only upon the order of the board, signed by the president and attested by the secretary. The said county treasurer shall report in writing, on the second Monday in each month, the amount of money in the county treasury, the amount of receipts for the month preceding, and the amount or amounts paid out; said report shall be verified and filed with the secretary of the board. The district treasurer shall also report to the board, in writing, on the first Monday in each month, the amount of money in the district treasury, the amount of receipts for the month preceding, and the amount and items of expenditures, and said report shall be verified and filed with the secretary of the board.

SEC. 37. The cost and expense of purchasing and acquiring property and constructing the works and improvements herein provided for shall be wholly paid out of the construction fund. For the purpose of defraying the expenses of the organization of the district, and of the care, operation, management, repair, and improvement of such portions of said canal and works as are completed and in use, including salaries of officers and employés, the board may either fix rates of tolls and charges, and collect the same from all persons using said canal for irrigation and other purposes, or they may provide for the payment of said expenditures by a levy of assessments therefor, or by both said tolls and assessments; if by the latter method such levy shall be made on the completion and equalization of the assessment roll, and the board shall have the same powers and functions for the purposes of said levy as are now possessed by boards of supervisors in this State. The procedure for the collection of assessments by such levy shall in all respects conform to the provisions of this act relating to the payment of principal and interest of bonds herein provided for.

SEC. 38. The board of directors shall have power to construct the said works across any stream of water, watercourse, street, avenue, highway, railway, canal, ditch, or flume which the route of said canal or canals may intersect or cross, in such manner as to afford security for life and property; but said board shall restore the same, when so crossed or intersected, to its former state as near as may be, or in a sufficient manner not to have impaired unnecessarily its usefulness; and every company whose railroad shall be intersected or crossed by said works, shall unite with said board in forming said intersections and crossing, and grant the privileges aforesaid; and if such railroad company and said board, or the owners and controllers of the said property, thing, or franchise so to be crossed, can not agree upon the amount to be paid therefor, or the points or the manner of said crossings or intersections, the same shall be ascertained and determined in all respects as is herein provided in respect to the taking of land. The right of way is hereby given, dedicated, and set apart, to locate, construct, and maintain said works over and through any of the lands which are now, or may be, the property of this State; and also there is given, dedicated, and set apart, for the uses and purposes aforesaid all waters and water rights belonging to this State within the district.

SEC. 39. The board of directors shall each receive four dollars per day, and mileage at the rate of twenty cents per mile, in attending meetings, and actual and necessary expenses paid while engaged in official business under the order of the board. The board shall fix the compensation to be paid to the other officers named in the act, to be paid out of the treasury of the district: *Provided*, That said board shall, upon the petition of at least fifty, or a majority of the freeholders within such district therefor, submit to the electors at any general election a schedule of salaries and fees to be paid hereunder. Such petition must be presented to the board twenty days prior to a general election, and the result of such election shall be determined and declared in all respects as other elections are determined and declared under this act.

SEC. 40. No director or any other officer named in this act shall in any manner be interested, directly or indirectly, in any contract awarded or to be awarded by the board, or in the profits to be derived therefrom; and for any violation of this provision, such officer shall be deemed guilty of a misdemeanor, and such conviction shall work a forfeiture of his office, and he shall be punished by a fine not exceeding five hundred dollars, or by imprisonment in the county jail not exceeding six months, or by both such fine and imprisonment.

SEC. 41. The board of directors may, at any time, when in their judgment it may be advisable, call a special election, and submit to the qualified electors of the district the question, whether or not a special assessment shall be levied for the purpose of raising money to be applied to any of the purposes provided in this act. Such election must be called upon the notice prescribed, and the same shall be held and the result thereof determined and declared in all respects in conformity with the provisions of section fifteen of this act. The notice must specify the amount of money proposed to be raised, and the purpose for which it is intended to be used. At such elections the ballot shall contain the words, "Assessment—yes," or "Assessment—no." If two-thirds or more of the votes cast are "Assessment—yes," the board shall, at the time of the annual levy hereunder, levy an assessment sufficient to raise the amount voted. The rate of assessment shall be ascertained by deducting fifteen per cent. for anticipated delinquencies from the aggregate assessed value of the property in the district, as it appears on the assessment roll for the current year, and then dividing the sum voted by the remainder of such aggregate assessed value. The assessments so levied shall be computed and entered on the assessment roll by the secretary of the board, and collected at the same time and in the same manner as other assessments provided for herein; and when collected shall be paid into the district treasury for the purposes specified in the notice of such special election.

SEC. 42. The board of directors, or other officers of the district, shall have no power to incur any debt or liability whatever, either by issuing bonds or otherwise, in excess of the express provisions of this act, and any debt or liability incurred, in excess of such express provisions, shall be and remain absolutely void.

SEC. 43. In case the volume of water in any stream or river shall not be sufficient to supply the continual wants of the entire country through which it passes, and susceptible of irrigation therefrom, then it shall be the duty of the water commissioners, constituted as hereinafter provided, to apportion, in a just and equitable proportion, a certain amount of said water upon certain or alternate weekly days to different localities, as they may, in their judgment, think best for the interest of all parties concerned, and with due regard to the legal and equitable rights of all. Said water commissioners shall consist of the chairman of the board of directors of each of the districts affected.

SEC. 44. It shall be the duty of the board of directors to keep the water flowing through the ditches under their control to the fullest capacity of such ditches in times of high water.

SEC. 45. Navigation shall never in any wise be impaired by the operation of this act, nor shall any vested interest in or to any mining water rights or ditches, or in or to any water or water rights, or reservoirs or dams, now used by the owners or possessors thereof, in connection with any mining industry, or by persons purchasing or renting the use thereof, or in or to any other property now used directly or indirectly in carrying on or promoting the mining industry, ever be affected by or taken under its provisions, save and except that rights of way may be acquired over the same.

SEC. 46. None of the provisions of this act shall be construed as repealing or in any wise modifying the provisions of any other act relating to the subject of irrigation or water commissioners. Nothing herein contained shall be deemed to authorize any person or persons to divert the waters of any river, creek, stream, canal, or ditch, from its channel, to the detriment of any person or persons having any interest in such river, creek, stream, canal, or ditch, or the waters therein, unless previous compensation be ascertained and paid therefor, under the laws of this State authorizing the taking of private property for public uses.

SEC. 47. This act shall take effect immediately.

SELECT COMMITTEE ON IRRIGATION,
Saturday, March 15, 1890.

The committee met pursuant to adjournment, Mr. Vandever in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. POWELL said:

Mr. Chairman and gentlemen of the committee, in presenting this subject to you heretofore I have tried to illustrate the facts to you by means of concrete instances, taking up one valley after another and indicating the more important problems which arose in those valleys. I had prepared a large number of maps in order to present the subject over the entire arid region, but the time taken up on one or two of these valleys has been so great that I fear I shall weary you with too long an account, and I have thought best, if the members of the committee agree to it, not to take up any more of these special basins, but to give a general outline of the subject, bringing together the problems which relate to the arid lands and to the use of the waters, so as to occupy very much less time than I have been doing heretofore.

If this is satisfactory, Mr. Chairman, I will proceed. I have also brought with me a number of diagrams relating to the artesian wells of the arid region, but perhaps it would be well to sum up first what I was going to say in relation to the districts. It will be remembered that when I presented the map I stated that the extent of the arid region irrigated is practically about 1,340,000 square miles. In addition to that there are about 250,000 square miles of sub-humid region where irrigation is being practiced to a small extent, and where crops can be raised some years without irrigation and other years can not be, so that the problem involves an area of more than one and a half million square miles. Within that region there are 8,000,000 acres of land which have already been irrigated, and as shown by the map, it is distributed throughout the States and Territories of the region, so that already there is a basis of experience in farming by means of irrigation sufficient to warrant the statements which have been made as to the necessity of irrigation and the value of the lands when irrigated, and this experience has also developed to a large extent the problems which arise under this new industry.

It will be understood, I think, from the concrete instances which I have presented, that not all of that land can be irrigated. It would be a large estimate to say that one-tenth of it can be irrigated by perennial streams. When all the waters are used—every spring, brook, creek, and river; when all the storm waters are used; when all the waters which now run to waste during the season of non-irrigation are stored, and when there is a complete and full development of that country, it will still be a large estimate to say that 10 per cent of it can be irrigated. The amount of water falling is exceedingly variable, from 2 to 3 inches in some regions of the country, and from 16 to 18 inches in other regions of country. On non-irrigable lands in the mountains the rainfall rises to 60 and 70 inches, but on the lands to be irrigated there is nowhere within this region 20 inches of rainfall, and the average will be less than 10 inches of rainfall on such lands.

Mr. PICKLER. What amount of rainfall is necessary to raise wheat, supposing it falls at the right time?

Maj. POWELL. Eight inches, if it falls at the right time, but if it is distributed throughout the year, more than that is required. It being understood, then, that when all the waters are used only a portion of the lands can be served, it comes to be an important problem to know what lands shall be served. Now, all things considered, this is the greatest problem that the subject presents. It is possible to select the lands in such a manner that the good lands can be served, or in such a manner that poor lands can be served. It is possible to select the lands in such a manner that ultimately less than one-tenth of the country can be irrigated—I mean less than one-tenth of the million and a half square miles of land.

If the lands are selected improperly at points far away from the catchment areas, then the amount of lands to be irrigated is diminished thereby. If the lands to be irrigated on the Rio Grande were selected low down on the Rio Grande, instead of distributed along its course in each catchment area, and the whole body was selected in New Mexico, it would not be possible to irrigate one-twentieth of the land that could be irrigated if the lands were selected by catchment basins and the water relegated to the lands close to where the waters are caught. I think that the illustrations which I have presented to you fully bring out this fact. For example, suppose it should be declared by some authority that the waters of the Rio Grande should be used to serve the lands in the Mesilla Valley and Bernalillo Valley, as I have pointed them out on the map before you, and that in order to irrigate these lands other lands should not be irrigated. Then certainly the amount which could be irrigated by all the waters of the Rio Grande would not be more than one-twelfth of what could be irrigated should the region of country be divided into catchment areas, and the people in each catchment area be allowed to irrigate the land immediately connected with that catchment area. If I do not make myself clear, I beg of you to interrogate me in the matter.

The lands to be irrigated are of themselves, without water, practically valueless. The lands which can be irrigated to the best advantage in any region of country are practically valueless for pasturage purposes, and they never bear timber. It is an important fact in connection with this that the irrigable lands are neither pasturage lands nor timber lands. They lie lower in the valleys, where the rainfall is less, and the pasturage on the lowlands is so exceedingly scant that they are comparatively valueless for pasturage purposes. The better pasturage lands lie higher, and all the timber lands are higher, and in general the timber lands are not valuable for agriculture by irrigation.

The increase of these otherwise valueless lands by putting water upon them is very great. I think it may be stated without bordering on exaggeration that in general an acre of land with the water right attached thereto, when once irrigated, is given an increase in value from comparatively nothing, or one or two dollars an acre, to from $30 to $200 per acre. I know of no irrigated lands that sell for less than that, and I know of many that sell for much more; and I think it is quite within the limits of a reasonable statement to say that the irrigable lands vary from $30 to $200 per acre, with the water rights attached thereto. It will thus be seen that the increment of value given to lands by reason of their being irrigated is sufficient to pay the cost of constructing the irrigation works many times over. So there is no need of any Government aid in the construction of irrigation works. The increase given to the lands themselves will always warrant the expenses necessary to construct the irrigation works. There is no difficulty, therefore, to obtain capital to irrigate the lands. Capital is offered in vast quantities for this work. The real difficulty lies in the fact that at present there is no security to the small farmer and no security to the investor.

Let me explain that a little further. The land itself is valueless without the water. If a company owns that water, unless protected by local, national, or State law in some manner the farmer becomes the servant of the company. This has already led to a great deal of litigation and conflict in the country in the adjusting of rights between the farmer and the corporations furnishing the water, and it has led to the destruction in many places of the corporate properties, and in others to their impairment. On the other hand it has made some companies rich because the process of litigation has sometimes worked one way and sometimes the other.

The general subject which I am just now mentioning is not a national subject, but rather one belonging to the State, and in general the States and Territories are taking up the question of water rights and solving them, some in one way and some in another; but in the main they are solving them in the direction which will give the management of the water to corporate companies and the management of the land to farmers. Another line of development is to give the water and the land to companies, and many of these companies are formed. The process by which this is done is threefold. Only one needs to be mentioned now. The company wishing to enter into an enterprise of irrigation will go among the farmers and get options on their lands, or induce people to settle in the country with the understanding that they will buy them out, or will go among the farmers and make contracts with them to furnish water perpetually at such and such a rate, and the increase of value which it will give to the land induces the farmer to make contracts of this character. Whenever it is possible, the company usually prefers to buy the land. The vast increase of value given to the land enables it to get a profit.

The main difficulty which arises in the question is that there is at present no system whatever, local, State, or national, by which all the waters can be relegated to specific lands. There is a general theory of law which is sustained in the courts, and in some States and Territories by statutes, which provides for priority of right. But it does not affect questions of water right between different districts and between different States. Let us see. Here is a river which can irrigate a few hundred thousand acres of land. The land below where that river runs is rich and can be irrigated to good advantage, and canals are constructed for the purpose. In the *immediate neighborhood, within, say, a county, a number of claims are established* to the use of the water locally, then this use can be regulated under the law of priority. Now, suppose a man goes up that stream 50 or 200 miles on a creek or some smaller river and takes a portion of the water which runs into the great stream, he does not take it in such a way that the man far below, living in another county or State, can identify the water which he uses as the particular water taken out by that man from a spring, or brook, or creek, or river far up; and the courts have generally claimed that a man must identify his water if he wants to enjoin the use of the river far above; that he must identify the water which he would have used below. This has led almost everywhere throughout the country to conditions which have protected irrigation schemes high up. The effect is to gradually drive the settlement up stream. They are moving higher up the streams. In doing this they move into regions of country where only hay and potatoes can be cultivated. In quite a number of regions, as in Utah and in some places in New Mexico and Idaho, they are beginning to make settlements where they have snow six months in the year. People know that above they can not have their water rights cut off. They go up where the water falls, and the process is driving the agriculture of the country into the mountains.

Without the intervention of the Government, a condition of affairs is growing up through which there will ultimately be presented enormous claims. If in the State of Kansas the people are sold land under the desert-land act at so much per acre and required to irrigate the land before they can obtain possession, and if after the land is irrigated all the water is taken from them, they seem to think that they have a right to come back to the Government to protect them in the use of the land, saying that they have bought it from the Government under a virtual contract that if they would irrigate it they would have water rights, and that they did irrigate with this understanding, and then the water was cut off above. Either the Government must prevent this or the rights of the people will be destroyed; and if the people above are allowed to go ahead and irrigate and redeem their lands, then the question arises, How shall the rights be settled between the two communities? They are in different States or different Territories, as the case may be, and shall the Government allow two communities to be established on the basis of agriculture, depending on the use of one body of water, one in opposition to the other, with a knowledge that in time one or the other of these communities will be destroyed?

You have had before you for consideration, gentlemen. cases of this kind, and it must be manifest that one or the other of the communities must be destroyed; the Government has given these lands at so much per acre under the condition that they shall be irrigated. The outcome of it will be that from each community thus cut off, an appeal will be made to Congress for aid. They will say that for ten or twenty years, as the case may be, you sold land to people above and told them to irrigate it, and they irrigated it, and now the waters are taken away from us and we want compensation. It will be in this manner that a vast system of claims upon the Government will be established. How they will be settled by Congress, I do not know.

I spoke a moment ago about capital offering and people being desirous to engage in irrigation, so that the country is being developed very rapidly and will be much more rapidly in the future. Under the present conditions the great fortunes that are made by irrigation are made, in the main, by middlemen, by promoters, who get capital from the East and get options in the West, and construct works and organize construction companies and operating companies and companies for supplying water to the farmers; and in that manner, in the main, the vast increment of value which arises from irrigation is going into the hands of irrigation promoters, those who organize the companies, and the farmers and investors are left to contend for their rights and soon must be ruined. I especially dwell upon the fact—for it is one of the most serious—that every river of magnitude throughout the arid region runs through two or more States. The Rio Grande and the Colorado and the Columbia present international problems. On the north there are half a dozen smaller streams that lie between British America and our own territory. Omitting the international problems and passing them by, every State and every Territory is complicated with some other State or Territory. The State and Territorial lines chance to have been drawn across areas everywhere in such a manner, on every river of magnitude, that there is scarcely a creek of any magnitude or any smaller river in all that country which does not involve interests of two or more counties or two or more States.

The present State lines and present county lines were not laid out with the end in view of securing a homogeneous body of people, a people having one common interest in one county or one State government. If this country had been divided into counties and States by river basins, that difficulty would have been avoided. If it had happened that States had been divided by river districts, all these problems could have been solved by the States themselves; but as the facts actually exist the problems can not be solved by State governments, and they are of the most serious character and involve interests of enormous magnitude. It is well known to you, gentlemen, how a fishing ground on a little bit of territory between two States comes to be a matter of bitter contest between the States; but what will it be between States when a vast system of agriculture is in controversy between them?

This is no ideal difficulty. It has arisen between Colorado and Nebraska. Governors have threatened violence, and it has created a great deal of contention. The subject has been introduced into Congress and an investigation ordered. Questions between Colorado and Kansas have in like manner arisen in Congress. Shall the agriculture of Kansas be destroyed in favor of Colorado? or shall the agriculture of Colorado be destroyed in favor of Kansas? are questions already before the Congress of the United States. The same question arises between Texas and New Mexico. Soon it will arise between Colorado and New Mexico. There is a bitter contest at present in the Department of the Interior between Idaho and Utah. Conventions have been held; governors have petitioned the Secretary of the Interior in reference to a division of the water of Bear River.

Now they are beginning to develop agriculture in the States farther north, and the same question will arise between the Dakotas and Montana, and between Montana, Oregon, and Washington, and between Oregon and Nevada, and between California and Nevada. I have shown you that very often the bodies of irrigable lands are so situated that the waters caught in one State have to be used in another. Six million acres of land in Idaho will depend wholly upon waters caught in Wyoming. Three-fourths of the agriculture of Nevada depends upon water caught in California. So that the interstate problems are enormous, so enormous that I almost hesitate to state what I believe to be their magnitude. I think that there is not less than $500,000,000 involved. But one case that I have given you shows that over 5,000,000 acres of land in Idaho depends upon waters to be caught and stored in Wyoming Territory. This is simply one illustration; and suppose in that case they are worth only $30 per acre. That means lands to the amount of $150,000,000 just between two States.

Now, gentlemen, I have presented these facts to you, and I do not know whether it is modest for me to suggest a solution of the problems; but if you will hear me on the subject I would like to speak a few minutes upon what I think is the solution.

Mr. HATCH. For one, I would be very glad to hear it. That is what we are here for.

Maj. POWELL. It takes me out of my proper function as an executive officer of the Government, to suggest legislative measures, but I think there are three methods by which it can be solved, two of which I deem impracticable under our form of government; the other, I think, is wholly practicable under our form of government.

The General Government may take control of these waters and construct the irrigating works and be well remunerated thereby by charging the people for the water, and have control of the whole thing, nationalizing the agricultural institutions of the arid country. Or the General Government may declare, in accordance with the theory of one of the bills before you, that, while it will not construct the works, it will authorize the people to construct the works by granting charters for the same. If this form should be taken and rights be given to irrigate without a proper inspection or be given at random, it will ultimately result in piling up against the Government the most enormous claims. I think the statements I have made heretofore are sufficiently explicit to show why this would be, without arguing the point further. It may institute a commission, as constituted in this bill, with an organization to make surveys, to examine the streams and the lands, etc., and authorize that commission to charter private bodies or corporations or individuals to do this work. That is the theory of this bill before you. That would need a great central commission and local State commissions and a vast body of marshals, United States courts, etc. By that scheme it is proposed that corporations shall control the water and farmers control the lands, and that farmers shall be supplied with water by the corporations, and shall not have control of the water themselves. That is like saying that the Government of the United States shall assume the control and supply of waters for all the cities and towns of the United States under one vast system through commissioners, who grant charters to individuals to supply this town or that town with water, or this city or that city, as the case may be, and that all the water supplied to the cities and towns in the United States should be supplied under charters granted by a United States commission.

That is the theory of one of the bills before you, that the United States commission shall, through the aid of a body of executive officers and a body of engineers and a body of surveyors, determine what ought to be done in granting charters, so that charters shall not interfere with charters, and right not interfere with right, and grant charters to water companies to supply farmers. Either of these methods of nationalizing the affair I deprecate, without stopping to state my reasons.

On the other hand, a study of the problem for 20 years has led me to the conclusion that it is possible to solve it in a manner in harmony with the institutions of this country. I think it is possible to divide all the arid region where irrigation is dependent on living streams into natural districts. I am not speaking of irrigation by the storage of storm waters, artesian waters, etc. I am speaking of irrigation from sources where these great water rights are involved—that it is possible to divide into two or three hundred districts the whole of that vast empire, so that all the water, all the land, all the timber, and all the pasturage will be divided among these districts in such a manner that the people of one district will have control of the group of common values in these districts, and do as they please with them. My theory is to organize in the United States another unit of government for specific purposes, for agriculture by irrigation, for the protection of the forests which are being destroyed by fire, and for the utilization of the pasturage which can only be utilized in large bodies; that is, to create a great body of commonwealths. In the main these commonwealths would be like county communities in the States. In many cases the districts would compose portions of two States. If it were possible to solve it so that every district would be within one State, and let the whole thing be turned over to the States, it would be to the best advantage, but to turn over the subject to the States under the facts which actually exist is to turn over to the States an endless conflict. Let the General Government designate the boundaries of these districts and let the Government make the surveys and say that the waters of each stream shall be used on specified lands.

Mr. HATCH. If it will not interrupt you right there, I understand you to say you would refer to the Federal Government the jurisdiction over the waters and over the timber and over the pasturage?

Major POWELL. No, sir; I should turn all over to the people by districts and by States. I would have the Government declare the boundary of an irrigation district for this purpose, and then say to the people of these districts, Control these interests for yourselves. Let Congress do something more; let it say within each district, *There* is a body of land which is irrigable, and you can use all the water in that district on that body of land and nowhere else. Then say to the people You can settle that district which is declared irrigable; you can settle that by homesteads, and that pasturage and that timber we turn over to you on this condition, that the States will agree that the people who live in any district which is to be divided by a State line may themselves organize their own government and use the water belonging to them as a district. Declare further that this law is inoperative until the States agree to it. Leave it to the States to agree to it, and if they are willing that a part of their people shall organize with a part of the people of another State for the purpose of forming an irrigation district, but for no other purpose—if they allow the people to make their own laws and govern themselves in the distribution of that water, then the Government will turn over to the people of such district the use of the timber and the use of the pasturage.

The people living in a district are the only people interested in its pasturage and forests, as I have shown to the committee. Say to the States, If you will allow the people, wherever these interstate districts are found, to organize solely for the purpose of controlling the water, we will turn over all to them. We will not give the lands, but the General Government will declare that the pasturage lands and the timber lands are held by the General Government as the custodian of the people, and they are allowed the benefit and use of the timber and pasturage thereof, but that no individual shall get control of either the timber or pasturage lands.

Mr. PICKLER. Then the people in the irrigable parts of that district would practically own the pasturage land and timber?

Major POWELL. No, sir; they would own no land, but would practically own the pasturage and timber; the title must remain in the General Government.

Mr. PICKLER. That is, that these people would have the use of it?

Major POWELL. Precisely. Let them make their own laws to govern the use of that timber in their own way and govern the pasturage in their own way. If they want that timber destroyed, if they want to sell it, if they want to destroy it and wipe out irrigation, they are responsible for it, and let them do as they please. Say to them, You can not sell this land, you need this wood, and you need this timber for your farms, and if you protect it from fires and cut it in such a manner that it will not injure your rivers and sources of supply for irrigation, you may have the timber. The pasturage is a matter of some importance, but far less than the timber.

I believe, Mr. Chairman, that the simplest possible solution to this problem is as follows:

Let the General Government organize the arid region, including all of the lands to be irrigated by perennial streams, into irrigation districts by hydrographic basins in such a manner that each district shall embrace all of the irrigable lands of a catchment basin and all of a catchment basin belonging to those lands, and determine the amount of water which each catchment area will afford, and then select sufficient irrigable lands for that water to serve, and declare that the waters of the catchment area belong to the designated lands and to no other, and prohibit the irrigation of any other lands. In order to maintain existing rights, declare all lands irrigated at the present time to be irrigable lands. This will divide the water among the lands and prevent conflict, and rights will not grow up where they can not be maintained. Then let the people of each such irrigation district organize as a body and control the waters on the declared irrigable lands in any manner which they may devise. Then declare that the pasturage and timber lands be permanently reserved for the purposes for which they are adapted, and give to the people the right to protect and use the forests and the grasses. Let the Government retain the ownership of reservoir sites, canal sites, and head-work sites; but allow the people of each district to use them, as a body, so as to prevent speculation in such sites, which would ultimately be a tax on agriculture.

Some of these districts would lie in two States. To this arrangement the consent of the States should be obtained, and all the districts should be organized under State laws. The Government should not grant these privileges to the districts until the States themselves ratify the agreement and provide statutes for the organization of the districts and for the regulation of water rights, the protection and use of forests, and the protection and use of pasturage. This is the general plan which I present. There are minor questions to be considered, but the fundamental principles of the system are simple, as I have stated them.

Mr. HATCH. Take the arid region. That is subject to reclamation by irrigation, as you have described it. What are the general products which have been produced? What are the crops?

Maj. POWELL. In my testimony there is a good deal on that subject.

Mr. HATCH. I will not trouble you, then, to repeat it. I just wanted to know if it had already been stated.

Maj. POWELL. I can do it in one sentence: Everything that can be cultivated between the climate of Norway and the climate of Egypt. They are already cultivating date palms in one portion of the country, oranges, lemons, and all the products of Egypt. One of the great products of California is the Egyptian corn.

The hour of 12 o'clock having arrived, the committee thereupon adjourned to meet on Thursday next.

SELECT COMMITTEE ON IRRIGATION,
Thursday, March 27, 1890.

The committee met pursuant to adjournment, Mr. Hansbrough in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. POWELL said:

Mr. Chairman and gentlemen of the committee, at the last meeting the chairman requested me to speak at this meeting about the artesian waters of the arid region and about the prospects of irrigating the Great Plains; and I have brought with me this morning maps and diagrams for that purpose. Here is before you a map of the arid region like one which I presented before, except that it is colored to show the distribution of the artesian waters so far as known. Of course they are only known to a limited degree. The artesian districts are colored in blue, as you see. To the east of the arid region, on the Red River in Dakota, we have an artesian basin which is known as Lake Agassiz, the basin being an extinct lake. The geology of that basin has been known for some time, as the Red River country was examined by members of the Geological Survey some years ago. Mr. Chamberlin, now president of the Wisconsin University, had charge of the work.

Here in the James Valley of the Dakotas we have other artesian wells, which I will dwell upon somewhat later in my remarks and present a map of the two Dakotas giving them more in detail. On this map not all the individual wells are marked—that is to say, they are marked by groups, not by individual wells; so there are more of the wells than the dots indicate. Sometimes the colored spots represent two, three, or more, as the case may be. There are also wells in Texas. In Arizona we have a few artesian wells which are known; in Utah we have a few artesian wells, and in southern California we have some. There are a few at the north, as you see, in Washington and Oregon. This gives at a glance and in a simple way what is known as to the distribution of the artesian waters up to the present time.

It can not be doubted, however, that there are many more basins, as the country has not been examined very fully (only casually in fact) for artesian waters, and many more artesian basins may be expected. I present this to show the distribution of the artesian wells as known.

I will now take North and South Dakota more in detail. This [indicating] is the same general line, separating the subhumid from the arid region, as shown on other maps which I have placed before you. This is a map of the two Dakotas. You will notice that the spots here are classified; that some of them are in solid color, and others are arranged with bars. The different characters of dots represent different artesian basins. A large part of the artesian water of the Dakotas where irrigation is necessary will be seen as coming from a geologic formation different from that of the wells farther east. To explain this subject I have a general diagram. It is a geological section of the two Dakotas, extending from the Rocky Mountains on the west to the eastern border of the State. The green represents rocks of the Cretaceous age. The formation you see below dotted in black represents the base of Cretaceous rocks, the Dakota sandstone. This sandstone is pervious to water. It is composed of sands and gravels, and contains a greater part of the water represented by the artesian wells that are marked with rings and two cross bars. On top of this Cretaceous formation we have glacial formations, which are not represented in the diagram. They lie on top, and these artesian wells come from rocks below. Some wells are in the outlying strips of Tertiary rocks, but the great supply which has been found in the two Dakotas comes from this Dakota sandstone. Here is Huron, here the White River, here Highmore, here Miller, and here the Missouri River.

Now the geological conditions under which artesian waters are found are very well known. The subject has been studied throughout the world. Most of the artesian waters of the world have been studied to such an extent that we know their geological conditions. It is known, in the first place, that in metamorphic rocks no water has been found. So in making an examination of a country we can exclude large areas, the geology of which is such that we know artesian waters can not be found therein. Artesian waters are found only in sedimentary rocks that are pervious to water—through which water can creep.

You will see that the diagram extends from the Rocky Mountains on the west to the eastern border of the Dakotas, and that this Dakota sandstone, in which the best artesian wells are found, underlies the country throughout the entire distance. But on the west, along the foothills of the mountains, this sandstone comes to the surface, as represented in the diagram. In all the region from the northern boundary far to the south, the edge of the sandstone outcrops in this manner, and over this outcrop is found the catchment area for the waters which percolate down through the sandstone eastward, under the central part of North and South Dakota. All the water found in the artesian district, in the belt along the one hundredth meridian, comes from this distant outcrop. It is not possible to get from the artesian wells of the plains, that are derived from this sandstone, any more water than gets into this upturned edge. All that is evaporated at the surface is lost, and all that runs away in streams is lost. Only that which is caught and percolates down through the sandstone comes into central Dakota. We know, too, that there can not be a free flow from this upturned edge through the hundreds of miles of sandstone to the James River Valley. If there were a perfectly free flow of water in the James River Valley, it ought to have a sufficient pressure to throw it as high, or nearly as high, as the outcropping rocks of the catchment district, but the pressure is far less. This is testimony to the condition of flow through the Dakota sandstone; the flow is not free but is obstructed on the way. The sandstone is not sufficiently porous to permit the catchment area at this great altitude to have its full effect in pressure on the wells of the James River Valley. The actual pressure found on the artesian wells of the eastern region is but a small fraction of what it would be if the hydrostatic pressure were equal to the difference of altitude between the wells and the catchment surfaces.

Now I want to consider what are the sources of water for irrigation on the Great Plains and to give a little idea of the need for water, and the conditions under which it can be used. The region of country along the Great Plains lying near to the one hundredth meridian has considerable rainfall. I should say from 15 to 22 inches of rain is found on an average. Some years it will be more and some years less. Under these conditions the rainfall is sufficient for agriculture some years, and in other years it is insufficient, and it has happened in the last twenty odd years coming under my observation that the dry years fall in groups of one, two, or three, as the case may be. When one dry year only occurs, and is followed by wet years, the disaster to agriculture is not so great, but when two or three dry years come in succession the agriculture is cut off for a long time, and then the disaster is very great indeed. It has happened in the last twenty years that the district of country which I have pointed out, and which I have heretofore called the subhumid region, has been settled here, there, and elsewhere, not bodily throughout the whole country, but in small districts. The people come in during wet seasons and commence agricultural operations, and in dry seasons abandon their homes. There are portions of Kansas that have been abandoned in this manner three times. The disaster occuring there has of course been very great. A part of Dakota has been settled, and they have had two or three dry seasons, and the people are suffering very greatly by reason of the failure of their crops, and it is manifest that for prosperity the people must provide against these disasters that come in dry years. That these dry years will come from time to time is certain. That there is any material change in the climate of the country, due to its settlement or other causes, does not appear from the records. It is denied by the experience of mankind everywhere that climatic changes come from trivial causes, or causes which are under control of man. We know they come from secular causes through long periods of time.

Mr. HATCH. That is, they think history will repeat itself in a term of years.

Maj. POWELL. In a term of years; yes, sir. Investigations have been made by numbers of scientific men who have discussed the problem; the subject has been studied for a long time, and a vast amount of data has been accumulated; and all show local and temporary oscillations, but no permanent change.

Here, then, is a district of country of 300,000 or 400,000 square miles, extending from the northern border to the southern border, where, during more than half the years of any lengthy period, we may expect agricultural operations to be prosperous by reason of sufficient rain, more prosperous than anywhere else in the humid regions of the United States. Whenever, in any district of country, there is just sufficient rainfall and no more, that is the best condition for that agriculture which is dependent upon rainfall. Any increase above that is injurious. For a portion of the time, say two-thirds to the east of the line, one-half along the line, and one-third west of the line, there is rainfall enough. What then becomes necessary is to supply additional water in seasons of drought, so there may not be a time when disaster comes to the farmer. To furnish the water necessary for these disastrous years, we have to furnish a smaller amount than in other regions of country.

Now, what waters can be found for this purpose? I will speak first of artesian wells. Something can be obtained from artesian wells, but not a very great amount. The experience from artesian wells fully warrants what I am stating now. They have been bored at different places in the world and used for irrigation wherever they could be used, and it bears out the statement I make that the supply from artesian sources is always limited, is always very small, and that no great area can be irrigated thereby. If all the artesian wells in the world which are used for irrigation were assembled in one county of Dakota they would not irrigate that county.

The CHAIRMAN. That is a strong statement, and I am afraid it will not be borne out by the facts.

Mr. PICKLER. There are many fine wells that I know of myself.

Maj. POWELL. Let me go into this somewhat in detail, so that you may see that I am not considering the matter carelessly. An artesian well which will give a cubic foot of water per second is a well far better than the average; that is, a well which will give 7 to 8 gallons per second. There are wells that will give more and there are wells that will give less than 1 cubic foot per second. A cubic foot of water per second in Dakota in the eastern portion of the subhumid region will irrigate about 200 acres and in the western portion about 125.

The CHAIRMAN. You say the wells marked by solid red would irrigate 200 acres and those in the western portion marked with bars would irrigate about 125.

Maj. POWELL. I am not speaking of any specific well; I am speaking of a hypothetical well which will turn out a cubic foot of water per second. We measure flowing waters in cubic feet per second. There are wells in that region which will turn out several cubic feet each, but many which turn out less.

Mr. PICKLER. How many gallons will that make a minute?

Maj. POWELL. About 450 gallons per minute. That is to say, the experience of mankind shows that it takes a certain amount of water to irrigate an acre. That amount of water per acre is on an average throughout the United States an acre-foot of water for an acre of land, but in the region of which I am speaking now they do not need that much water, and would need, say, 6 inches of water for an acre of land. To get 6 inches of water over each acre of land, say 1,000 or 10,000, takes a pretty big supply. We see an artesian well in the arid country with a bore of about 4 to 6 inches, as the case may be, pouring out a fine stream of water, and it looks a large stream and strikes the eye with a good deal of force, but when you actually compute the amount of water which it supplies, you find that amount is small. Now, there is something more to be said in that direction. The number of artesian wells in every district that has been experimented with is always limited, and to make this plain I have prepared a written statement which I will incorporate in my remarks unless you desire me to read it.

ARTESIAN IRRIGATION ON THE GREAT PLAINS.

Artesian reservoirs can never be an important source of water for irrigation. The supply of water thus naturally stored is small. The share of it which agriculture can economically obtain through wells is still smaller. Though irrigation has aided agriculture from the earliest times and though artesian wells have long been understood, the world has succeeded in using artesian water for agriculture in but a few exceptional spots. The Great Plains may become one of these exceptional localities, but the conditions do not warrant great expectations.

In order to make these propositions clear, it is necessary to give consideration to some of the general facts and principles affecting artesian water supply, to the economic conditions limiting the utilization of artesian water for irrigation, and to the special conditions existing on the Great Plains. A brief account will also be given of such irrigation as is based on artesian water supply in various countries of the world.

GENERAL CONSIDERATIONS AFFECTING ARTESIAN WATER SUPPLY.

An artesian reservoir is usually a bed of sand or sandstone or other porous rock, included between strata of clay or shale or other fine-grained rock through which water can not freely flow. It is necessary that the porous stratum come to the surface at some point so as to receive a supply of water from rain. If all the points at which it comes to the surface or communicates freely with the surface lie higher than the point at which water is to be drawn through wells, the reservoir is of a type which may be denominated as perfect; but if the stratum communicates with the surface also at points which lie lower than the point from which boring is made, the reservoir is imperfect. In the case of an imperfect reservoir the possibility of an artesian flow depends upon the resistance opposed by the porous bed to the free flow of water.

Permanent flow.—The quantity of water which can be annually and in perpetuity drawn from an artesian reservoir manifestly can not exceed the quantity annually supplied to it. The quantity annually supplied depends on various factors, chiefly the extent of the high-lying outcrop, the rainfall on the area of outcrop, and the capacity of the rock for absorption. Ordinarily the rock does not receive the whole of the rainfall, but permits a part of it to run off in surface streams, while another part escapes from the surface by evaporation.

The amount which can be drawn from a reservoir may depend, in addition, on the ability of the porous stratum to convey water. Where the stratum is thin or contains little interstitial space, the possible delivery of water is correspondingly small.

In the case of imperfect reservoirs the artesian possibilities are further limited by the natural escape of water at lower levels, and to this should be added the loss of water by slow transmission through the covering strata, for no rock is absolutely impervious to water.

From a perfect reservoir the water will rise in a well to the height of the outcropping edge of the stratum which receives the rainfall; from an imperfect reservoir it will not rise so high, and the amount of difference is related to the amount of water which escapes at lower levels, as well as to the resistance to flow encountered in different parts of the stratum. The height to which water will rise in a well depends on the pressure exerted by the water upon the cover of the reservoir, and that pressure is diminished by any draft upon the reservoir. When an artesian well is opened and begins to flow, the pressure from the water of the reservoir is immediately diminished by the flow; in other words, the flowing pressure is less than the static pressure. If the discharge of a well be computed, by the aid of hydraulic formulæ, from the static pressure and the size of the bore, such computed discharge will always exceed the actual discharge, and the difference will usually be great. The difference is caused by the frictional resistance which the water experiences in moving through the porous stratum.

In this way the mutual interference of wells is occasioned. The boring of each well reduces the static pressure of the water of the reservoir all about it, the reduction diminishing outward in all directions. Any well bored within the range of this reduction meets with a relatively small water pressure and secures a relatively small flow. Reciprocally the boring of the second well diminishes the flow of the first.

If a series of neighboring wells be bored at the same level, the individual discharge of all the wells is progressively diminished, and the total discharge is at first progressively increased, but the limit of discharge for the locality is finally reached, and then the boring of additional wells gives no advantage. If two wells in the same vicinity head at different levels the one at the lower level discharges more water than the other, and the flow of a well or of a group of wells may be entirely destroyed by the sinking of new wells at a lower level. The same effect is produced by pumping water from wells, which is equivalent to a discharge at lower level.

There is, moreover, in the case of most wells, a certain amount of waste through the escape of water from the well to porous strata lying above the impervious cover of the reservoir. Such waste is apt to increase with time, and it manifestly increases with the multiplication of wells. It is therefore possible in most artesian districts to destroy absolutely the artesian head by the boring of numerous wells.

Temporary flow.—Where the exposed outcrop of the artesian stratum covers a broad area and the rainfall is ample, it is usually the fact that the amount of water supplied to it is more than can be transmitted through its buried portion ; but, if the outcropping edge is narrow and lies in an arid region, it may happen that the stratum has capacity for the transmission of more water than is delivered to it. If these latter relations subsist in the case of a perfect or nearly perfect reservoir and that reservoir is tapped by numerous artesian wells, the initial discharge of water from the wells is greater than the permanent discharge. The wells in such case draw upon a body of water which may have required years for its accumulation, and their conditions of permanent flow are not reached until this accumulation has been exhausted. Thus in another and independent way the flow of artesian wells is liable to be diminished.

The following data, selected from the records of various artesian districts of the United States, illustrate chiefly the phenomena of interference, but they doubtless include also phenomena of temporary flow.

Denver Basin.—Artesian water was first obtained in the Denver Basin in 1883. The flow yielded by the first well was so large and the water was of such superior quality for domestic use that other wells were put down with great rapidity. There are now in the city and its vicinity about three hundred wells. Many of the first wells had sufficient pressure to force the water into tanks in the tops of the highest buildings in the city, but as the number of wells was increased the pressure and flow of the older wells began to diminish, and finally, in the region where they are most closely grouped, they have failed to furnish water without the aid of pumps. Outside the region of closest grouping pressure and flow have been diminished, but not to so great extent. Deep wells are still bored at Denver, but not with the expectation of obtaining artesian flow.

Dubuque, Iowa.—The first well at this point for artesian purposes was headed nearly 200 feet above the level of the Mississippi River. Water was obtained in great volume and rose nearly to the surface. A few years later another well was put down at a lower level, approximately 100 feet above the river. A good flow was obtained, and this led to the boring of numerous wells. At first all were successful, but it was observed that with the multiplication of wells the flow from the older diminished, particularly when the new wells were headed at lower levels. Finally an exceedingly large bore was headed in the lower part of the city, but a few feet above the river level, and through this an unprecedented flow was developed ; but within a few hours the flow from the other wells diminished, and within a few days all of those at the higher levels ceased to flow. Eventually the flow from the last-bored well dwindled to not more than twice or thrice that of the first well at the 100-foot level, and it is said to be still slowly diminishing.

Chicago.—The city of Chicago lies over an artesian reservoir, and it was hoped that it could be supplied therefrom with water for domestic purposes. But experimentation proved that while a few good wells could be secured a great number was impossible, and that the pumping necessary to derive a large supply of water would deprive the entire group of its artesian head.

Rockford, Ill.—The municipality of Rockford obtains its water supply through five artesian wells which were bored in succession, and the supply was measured after the addition of each well.

Flow of wells for twenty-four hours.

	Gallons.
No. 1	1,000,000
Nos. 1 and 2	2,000,000
Nos. 1, 2 and 3	2,600,000
Nos. 1, 2, 3 and 4	3,000,000
Nos. 1, 2, 3, 4 and 5	3,500,000

The fifth well thus increased the supply only half as much as did the second. A private well was afterwards drilled at a distance of 1 mile and at a level 17 feet lower than the city wells, when the flow from the city wells immediately fell to 2,500,000 gallons.

Williams County, Ohio.—For the last thirty years it has been known that artesian water may be obtained from reservoirs in the drift in the northwestern portion of Ohio. In Bryan, the county seat of Williams County, an artesian well was bored in the public square, causing the village to be popularly called the "Fountain City." As the reservoir lay but a short distance beneath the surface, wells were easily produced, and their number was rapidly increased; but it soon became apparent that their source could be overtaxed. The force of the flow was abated; the highest wells began to fail altogether; a pump was introduced into the public square fountain; and at the present time a sluggish flow is obtained only in the lowest portion of the village.

Toledo, Ohio.—The conditions are similar at Toledo. When the wells were first bored the water rose to a height of 14 feet above the level of Lake Erie, and this head was gradually lowered as the number of wells was increased. At the present time water is pumped from wells by the corporation and by private owners, and the head has fallen to 40 feet below the lake level.

Ohio Valley.—In the vicinity of Pomeroy, Ohio, and Mason City, W. Va,, brine for the manufacture of salt has been obtained from artesian wells for the last thirty or forty years. When first tapped the brine flowed freely, and it continued to do so for many years; but in 1865 the number of wells was greatly increased and the water head was thereby lost, so that pumping became necessary. Year by year the pumps have been lengthened, and now they are placed about 600 feet below the surface of the ground.

Alabama.—Although the lowlands skirting the Atlantic and Gulf slopes everywhere belong to what may be classed as an artesian district, artesian boring for supplies of water for domestic purposes was first inaugurated extensively in Alabama, and the history of interference is best known there. A representative locality is Finch's Ferry, where the bad quality of the surface water led the people to seek an artesian supply about fifty years ago. The first well obtained a strong flow of water from a depth of several hundred feet, and other wells followed. With the boring of each new well the flow from the older wells diminished, and this tendency became particularly noticeable when a well was bored at a lower level than any of the others on the bank of the Tuscaloosa River. In order not to destroy the older wells, it was found necessary to pipe the new well up to a height corresponding to the level at which the old wells were located. Even then the flow from the wells was so far diminished that some of them were unable to clear the casing of sand and débris, and so became clogged and ruined. At the present time but three wells continue to flow at the surface.

ECONOMIC LIMIT TO UTILIZATION OF ARTESIAN WATER FOR IRRIGATION.

There is a certain economic relation between the cost of an artesian well designed for irrigation and the amount of land which can be redeemed by the water it furnishes. If the value added to the land is less than the cost of the well, the boring of the well is unprofitable. The conditions determining this problem are numerous and can not be fully discussed in a quantitative manner, but it will be advantageous to consider some of the simpler cases. First will be taken the general case in which the permanent conditions of flow are realized at once.

Let us assume that the value added to an acre of land by irrigating it is $50; that for the accomplishment of this result there must be applied to each acre of land a quantity of water amounting in an irrigation season of seventy days to one acre-foot; and that by means of storage reservoirs it is possible to save for irrigation purposes 70 per cent of the water flowing from a well during the remainder of the year.

It follows from these assumptions that an artesian plant, including cost of storage reservoir if storage is employed, must not cost more than $1,000 for each 20 acres of land reclaimed.

It follows also that a certain daily flow must be realized. In case the water is not stored and is used only during the irrigating season of seventy days, a well, to be profitable, must yield perennially 65 gallons per minute for each $1,000 of cost of plant. The cost of plant in this case includes the boring, casing, etc., of the well and the construction of main ditches for the distribution of the water. If the water of the nonirrigating season (295 days) is stored, a well, to be profitable, must yield perennially 21 gallons per minute for each $1,000 of cost of plant. The cost of plant in this case includes also the cost of constructing storage reservoirs, headworks, etc.

These estimates of running gallons per minute must be increased if the value added to the land is less than $50 per acre, if the irrigation season is greater than seventy days, if the duty of an acre-foot of water is less than one acre of land, or if less than 70 per cent of the water flowing in the nonirrigating season can be saved by means of storage reservoirs; and in the contrary cases they must be diminished.

The estimates are based upon assumptions of a general nature intended to represent the average conditions of the arid region. While they require modification when applied to individual localities, the necessity for such modification is limited by certain compensations among the conditions. These arise from the fact that the value added to land by furnishing it with water for irrigation is less in those localities where the duty of water is greater, and from the further fact that the value added to land is in general greater for those crops for which the irrigation season is longer.

Up to a certain limit, determined by the waste through leakage, the amount of water derived from an artesian basin in any limited locality is increased by increasing the number of wells, but the average flow per well is invariably diminished, and the economic limit is reached when the gain in land value from the total flow is equal to the total cost. This limit is reached before the maximum supply has been derived from the reservoir, and it is thus economically impracticable to approximate closely the natural limit of artesian supply.

If we take into account the slope of surface, which exists in all artesian districts, and the advantage enjoyed by the wells heading on low ground, it is evident that the last wells bored in a district will usually be at low levels, and that these will impair the value of those at higher levels. Profitable low-level wells may be bored after the limitation indicated above has been reached. Though each well of a district may be profitable at the time it is bored, the wells in the aggregate may cost more than the aggregate value of the water.

If the supply of water, impaired by multiplication of wells, is restored by pumping, the capitalization of the cost of pumping must be added to the cost of the plant in making the economic computation, and in such case the investment may be shown to be still more disastrous.

The United States has acquired through its oil and gas industries a large experience in the boring of wells, and the following estimates of average cost are based on this experience.

Passing now to the general case in which the permanent conditions of flow are not realized at the outset, but only after a store of water has been exhausted by means of a relatively large temporary flow, we have an additional factor tending to induce a greater expenditure in the boring of wells than will be ultimately profitable. The total amount of water obtained is in this case greater, but unless a more conservative policy be adopted with reference to the multiplication of wells, the economic result may be far more disastrous.

Test wells, that is, wells in localities where the succession of strata and other conditions affecting cost are unknown, can in general be put down by contract at the following rates:

Depth:	
500 feet	$2,000
1,000 feet	4,500
1,500 feet	7,500
2,000 feet	10,000

Individual wells may in exceptional cases cost much larger amounts. In a region where many wells are bored and the conditions are known the cost tends to fall to the following minimum:

Depth:	
500 feet	$1,000
1,000 feet	2,500
1,500 feet	4,500
2,000 feet	7,000

IRRIGATION BY ARTESIAN WELLS IN VARIOUS COUNTRIES.

The cost of boring wells is so great and the quantity of water thus obtained is so limited that in most localities the special use given to the water must have high value in order to warrant the sinking of wells. Most frequently it is sought for domestic use. It is also sought for manufacturing and medicinal purposes, for the watering of stock, and for the production of salt. In some desert regions wells have been bored from point to point to furnish water for the use of travelers, and the water flowing from such wells is also used for the nourishment of gardens, but the irrigation is in this case an incidental result and not a primary purpose. Such gardens associated with travelers' wells are found in Abyssinia, Upper Egypt, and at various places on the Sahara, and also in Australia.

Artesian water has been successfully sought for the purpose of irrigation in China, Italy, Spain, the Sandwich Islands, Algeria, California, and Utah. Details in regard to Chinese wells have not been ascertained. In California they are employed almost exclusively in the cultivation of fruits, and the same is true in Algeria. In Utah they are made to serve vegetable gardens. In Algeria about 4,000 acres have been reclaimed, and it is estimated that the present supply of water is competent to double this acreage. In California the wells are restricted to Los Angeles, San Bernardino, and San Diego Counties, and it is stated by Mr. W. H. Hall, the State engineer, that less than 3,000 acres are irrigated. In Utah about 2,000 acres are irrigated. In each of the other countries named the extent of the irrigated land is very small.

The work in Algeria is peculiarly instructive, because agriculture was there initiated on the face of a desert, and because the institution of wells was scientifically planned. The following facts are selected from the extensive literature of the subject:

Irrigation in Algeria.—The initiative in the search for artesian waters in Algeria was taken by General Desvaux, of the French army, commanding at Batna, in the year 1855. At his request M. Ch. Laurent, a well known artesian expert, was sent to examine that portion of the Sahara Desert lying within and adjacent to the confines of Algeria, with reference to the possibility of artesian waters and the best method of securing them.

The work of boring was under the immediate direction of M. Jus, C. E., assisted by Lieutenant Lehaut of the army. The first well was sunk at Tamerna, in the oasis of Oued Rir'; begun early in May, 1856, completed June 19. Its flow was 4,010 litres (141 cubic feet, or 1,059 gallons) per minute; its depth, 60 metres (197 feet). From this date to 1860 fifty wells were sunk in the province of Constantine (Algeria), with a delivery of 36,000 litres (1,271 cubic feet, or 9,510 gallons) per minute.

Subsequent to 1860, records of wells are traced with difficulty, excepting for the oasis of Oued Rir', and it is probable that the information that follows is somewhat incomplete.

According to the best accounts at present available, the number of flowing wells now amounts to about 125, tubed with iron, and 500 native, tubed with wood; total, 625. Their yield is 240,000 litres (8,475 cubic feet, or 63,400 gallons) per minute. A well of 3,000 to 4,000 litres per minute (105 to 140 cubic feet) will irrigate from 100 to 200 acres, according to the nature of the soil. This gives a duty of from 42 to 84 acres per cubic foot per second, the former being nearer the average. With the present supply of water between 6,000 and 9,000 acres can be irrigated. At present not more than 4,000 acres are under cultivation, of which 3,706 are in the oasis of Oued Rir'.

It is stated that in the thirty years of well usage in this country the wells tubed with iron, with rare exceptions, due to defective tubing, have not varied in the amount of their delivery.

The following table is based on one by M. Rolland, printed in the report of the Société Agricole et Industrielle de Batria et du sud Algérien, made in connection with the society's exhibit at the Paris Exposition of 1889:

Principal groups of artesian wells.	Maximum depth of wells.	No. of wells.	Average flow per minute.
	Feet.		*Gallons.*
Group of Ourir Ensira, Mraier, and Dendouga	269	12	640
Group of Sidi Khelil	318	4	260
Group of El Berd and Tinedla	321	3	560
Group of Zaouiet R'hab and Mellaah	256	2	340
Great group of Mazer, Ourlana, Chria Saiah and Tala-em Mouidi, Ariana-Djama and Tiguedi-din, Couidiat Sidi Yahia and Sidi Amran	372	18	1,125
Group of Tamerna Khedina and Tamerna Djedida	252	10	750
Group of Moggar, Sidi Sliman, Bou Rekhis and El Kessour	292	9	750
Lateral group of Sidi Rached, Bram, Ghamra and El Harihira	387	14	300
Great group of Megarin Khedima and Meggarin Djedida, of Zaouia Tebeshest and Tougourt, of Nezla and Coudiat el Koda	340	8	525
Terminal group of Temassin-Tamelath and Bledet Ahmar and El Gong	278	8	525

GEOLOGIC CONDITIONS AND STATISTICS OF ARTESIAN WELLS ON THE GREAT PLAINS.

Artesian water is now obtained in the region of the Great Plains from Cambrian, Carboniferous, Triassic, Cretaceous, Tertiary, and Pleistocene formations.

Three wells in the Red River basin give water from Cambrian Strata, but this water is saline and the flow is moderate. It is not available for irrigation.

Carboniferous strata yield artesian water in eastern Kansas, eastern Nebraska, and at numerous points in Texas. This water is chiefly saline, and therefore unavailable for irrigation.

In Kansas, artesian water has also been derived from Triassic sandstones and found to be saline and unfit for irrigation. From what is known of this formation in many parts of the country it is believed that no pure water will be obtained from it.

Water has been obtained from several horizons in the Cretaceous, which is a great formation covering a large portion of the Plains. Its principal water-bearing stratum is a sandstone at the base, known as the Dakota sandstone. The water derived from this is usually suitable for irrigation and its yield is exceptionally large. It has been successfully explored in North Dakota, South Dakota, Nebraska, Kansas, and Texas.

Artesian basins in the Tertiary are comparatively limited. Those thus far discovered lie in Colorado, Kansas, and Texas.

In a single basin Pleistocene strata have yielded water by numerous wells. This is the Red River Valley of North Dakota and Minnesota. The water is mainly of a quality suited for irrigation, but it rises in a region where the need of irrigation is not felt, and its quantity is, moreover, too small to permit of extensive use for that purpose. In a second basin a little water has been found, and it is possible that yet other artesian basins may be discovered in this formation, but there is no reason to anticipate that they will afford a water supply of great value.

In the following tables are assembled such data as I have been able to gather with reference to the location, depth, flow, etc., of the artesian wells now existing on the eastern portion of the Great Plains, and thereto are added corresponding data for the wells of the Red River basin. As will be observed, they are arranged by States:

Wells of the Red River Valley.

MINNESOTA.

Location.	Depth.	Strata penetrated.	Water supply.
Traverse County:	*Feet.*		
Near Wheaton	119-182	Glacial drift (till) with included seams of water-bearing sand and gravel.	Fresh, abundant.
Tintah	55	....do	Do.
Do	45	....do	Do.
Do	67	....do	Do.
Near Tintah	35-160	....do	Do.
Wilkin County:			
Champion Township, many wells.	50-66	....do	Fresh, very copious.
Atherton	11	....do	Fresh.
Do	37	....do	Do.
Do	45	....do	Do.
Clay County:			
Near Barnesville	35	All these go through thin lacustrine and alluvial beds, then are for most of their depth glacial drift (till), with seams of water-bearing sand and gravel.	All fresh, with copious supply.
Near Sabin	180		
Near Morehead	100-228		
Kragnes	155		
Near Georgetown	180		
Becker County:			
Hamden	75		
Do	110		
Norman County:			
Perley	200		
Halstad	250		
Eight miles northeast of Halstad.	165		
Do	219		
Ada	217		
Lockhart	140		
Lockhart vicinity	125-150		
From Ada to Crookston, many wells.	100-200		
Polk County:			
Near Kittson	80-112		
Do	140		
Carman	190		
Near Crookston	180		
Do	190	Alluvium and lacustrine beds, then glacial drift (till) in which are water-bearing seams of sand and gravel.	Fresh, copious.
Do	205	....do	Do.
Do	236	....do	Do.
Vicinity of Crookston, probably one hundred wells.	165-240	....do	Do.
Fisher	285	....do	Alkaline and saline, copious.
Near Angus	45	....do	
Do	70	....do	
South Angus	253	....do	Do.

Wells of the Red River Valley—Continued.

MINNESOTA—Continued.

Location.	Depth.	Strata penetrated.	Water supply.
Marshall County:	*Feet.*		
Argyle	150	Alluvium and lacustrine beds, then glacial drift (till) in which are water-bearing seams of sand and gravel.	Alkaline and saline, copious.
Do	285	...do	Do.
Tamarack and vicinity	74	...do	Do.
Do	95	...do	Do.
Do	218	...do	Do.
Stephen	220	...do	Do.
Do	240	...do	Do.
Kittson County:			
Donaldson	45	...do	Do.
Near Kennedy	95	...do	Do.
Near Hallock	119	...do	Fresh, copious.
Near Northcote	30	...do	Do.
St. Vincent	165	...do	Saline, copious.

NORTH DAKOTA.

Richland County:	*Feet.*		
Farmington	93	Thin alluvial and lacustrine beds; then the principal thickness consists of glacial drift (till) in which are water-bearing seams of sand and gravel.	Fresh, copious.
Dwight vicinity (ten wells)	85-110		
Colfax	85		
Do	125		
Do	128		
Do	135		
Walcott	110		
Do	120		
Walcott vicinity	104		
Do	131		
Do	227		
Cass County:			
Durbin	160		
Everest	160		
Argusville	157		
Do	158		
Argusville vicinity	130		
Do	153		
Gardner	125		
Gardner vicinity (many wells)	96 200		
Grandin (within an area of 50 rods).	105 158 187 248		
Traill County:			
Quincy	213		
Kelso	109		
Do	110		
Kelso vicinity	110		
Do	175		
Blanchard (ten wells)	175-404	Partly in Cretaceous	Brackish, copious.
Hillsboro	105	Thin alluvial and lacustrine beds; below these a great thickness of glacial drift (till), in which are water-bearing seams of sand and gravel.	All in this northern part of the valley are brackish and alkaline.
Do	125		
Do	175		
Do	198		
Grand Forks County:			
Grand Forks	265		
Do	270		
Manvel	165		
Do	175		
Walsh County:			
Ardoch	164		
Minto	196		
Do	200		
Grafton	156		
Auburn	175		
Pembina County:			
St. Thomas	175		
Glasston	200		
Hamilton	179		
Bathgate	143		
Bathgate vicinity (eleven wells)	130-160		
Neche vicinity	220		

Wells in North and South Dakota deriving water from the Dakota sandstone.

Locality.	Depth.	No. of wells.	Diameter of bore.	Temperature.	Pressure (per square inch).	Elevation (surface above sea).	Surface of Dakota (above sea).	Character of water.
	Feet.		*Inches*	°*Fah.*	*Pounds.*	*Feet.*	*Feet.*	
Vermilion	350	......	......	......	....	1,150	....	
Yankton	610	15	6	62	32	1,196	616	Slightly hard; drinkable; used in boilers.
Do	165	......	......	......	140	1,196	....	
Yankton vicinity	......	15	......	......	....	1,196	....	
Tyndall	600	......	......	......	122	1,418	....	
Mitchell	1,300	......	......	......	....	1,301	....	
Plankinton	1,500	......	......	......	140	1,528	....	
Kimball	1,100	......	......	......	95	1,788	....	
Chamberlain	......	......	......	......	....	1,363	....	
Letcher	600	......	......	......	....	1,300	....	
Woonsocket	1,300	......	......	......	250	1.308	....	
Artesian City	......	......	......	......	....	1,313	....	
Vilas	......	......	......	......	....	1,480	....	In process.
Huron	863	......	6	60	170	1.285	422	
Brookings	900	......	......	......	....	1,636	....	Said to end in granite.
Miller	1,148	......	5	80	125	1,587	438	Excellent.
Highmore	1,552	......	6	68	25	1,890	338	Soft, and of good quality.
Harold	1,300	......	......	......	80	1,801	....	
Hitchcock	965	......	3½–4½	......	186–218	1.139	....	Used for irrigation.
Redfield	......	......	......	......	....	1,300	....	
Frankfort	......	......	......	......	....	1,296	....	
Faulkton	1,300	......	......	......	....	1,595	....	Abandoned; drilling another.
Gettysburg	1,300	......	......	......	....	2,082	....	
Ashton	915	......	6	55	50	1,296	381	
Andover	1,070	......	4½	64	90	1,476	406	
Groton	960	......	5	......	187	1,301	341	
Aberdeen	908	Many.	5$\frac{3}{16}$	60	140–160	1,300	396	
Columbia	965	......	4⅝	60	176	1,304	339	Soft.
Ipswich	1.270	......	6	65	70	1,530	260–300	Soft; slightly brackish.
Ellendale	1,087	......	4–5–6	65	175	1,453	366	Soft; not pleasant to the taste.
Jamestown	1,476	2	6	70	95	1,400	50	
Jamestown vicinity	1,321	......	......	......	....	....	....	Abandoned.
Devil's Lake	1,511	......	3½	......	....	1,470	39	

Locality.	Artesian head (above sea).	Water supply (per minute).	Area that can be irrigated, allowing 6 inches of water (estimate for average year).		Area that can be irrigated, allowing 12 inches of water (estimate for dry year).	
			With storage.	Without storage; irrigating season of 70 days.	With storage.	Without storage; irrigating season of 70 days.
	Feet.	*Gallons.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
Vermilion	....	80	196	50	98	25
Yankton	1,270	3,000	7,333	1,857	3,667	929
Woonsocket	1,885	8,000	19,550	4,952	9.775	2,476
Huron	1,678	1,400	3,422	866	1,711	433
Miller	1,876	1,000	2,444	619	1,222	310
Highmore	1,948	14	34	9	17	4
Ashton	1,411	60	147	37	73	19
Aberdeen	1,670	300	733	186	367	93
Columbia	1,708	3,500	8,557	2,167	4,279	1,084
Ellendale	1,742	600	1,467	371	733	186
Jamestown	1,690	375	917	232	459	116
Devil's Lake	1,575	60	147	37	73	19

Other Wells in the Dakotas.

Location.	Depth.	Strata penetrated.	Water supply (per minute).
	Feet.		*Gallons.*
Grafton	915	Passed through stratified rocks to granite.	1,000
Tower City	670	Fort Pierre shales in Niobrara horizon.	9¼; rises 33 feet.
Casselton and vicinity	317-000	Passed through the Drift into Cretaceous rocks.	Brackish, alkaline, copious.
Amenia and vicinity	250-215	do	
Blanchard and vicinity (six wells)	300	do	Do.
Mayville	395	do	Do.

Wells west of the Dakotas.

Location.	Depth.	Strata penetrated.	Water supply.
	Feet.		
Glendive		Laramie or Box Hills	
Miles City (fourteen wells)	180-550	Laramie (?)	
Billings	1,000		Not flowing.
Bozeman			
Helena	160	River gravels	200 gallons per min.

Wells of Nebraska.

Geological horizon.	Location.	Depth.	Delivery.	Remarks.
		Feet.		
Dakota	St. Helena, Cedar County	466	Copious.	Pure.
Carboniferous	Omaha, Douglas County	750	Good	Do.
	Lincoln, Lancaster County	985	Copious.	(1) Brine from 244′ (Dakota) cased off. Mineral from 544′ Carboniferous.
	Brownville, Nemaha County.	1,001		(2) No other data.
	Beatrice, Gage County	1,200		(3) No flow.

Wells of Kansas.

Geological horizon.	Location.	Depth.	Caliber.	Delivery per minute.	Remarks.
		Feet.	*In.*	*Galls.*	
Tertiary	Edward's well, Meade Co	155	....	36·00	Pure.
Do	do	165	....	32·4	Do.
Do	do	185	....	29·6	Do.
Do	Mart's well, Meade County	140	....	66·6	Do.
Do	Bower's well, Meade Co	125	....	37·3	Pure; waters rise 15-20 feet above surface. Temperature Meade Co. wells 60° F.
Do	Norman's well, Meade Co	127	...	37·3	
Do	Cox well, Meade County	175	....	9	Pure.
Do	do	142	....	9	Do.
Do	60 other wells, Meade Co	50-175	...	1-30	Do.
Tertiary ?	Norton, Norton County	......	....	....	No data; may be Dakota; depends on depth.
Do	Hoxie, Sheridan County	......	....	....	
Dakota	Smith Centre, Smith Co	......	....	....	No data; may be Tertiary; depends on depth.
Do	Great Spirit Spring, Mitchell County.	......	....	....	Natural artesian flow.
Do	Miltonvale, Cloud County	......		....	No data as to water.
Do	Wa Keeney, Trego Co	......	....	....	Do.
Do	Hays City, Ellis County	......	....	....	Do.
Do	Great Bend, Barton Co	344	....	6·75	Saline; well bored to 1,400 feet, but water from 344 feet; rises 30 feet above surface.
Do	Kinsley, Edwards County	......	....	....	No data as to water.
Do	Dodge City, Ford County	......	....	....	Do.
Do	Santa Fé, Haskell County	......	....	....	Do.
Do	Ulysses, Grant County	......	....	....	Do.
Do	Opera House, Coolidge, Hamilton County.	239	....	45	Pure; water rises 15-20 feet above surface; now choked owing to opera house fire. Temperature 61° F.
Do	Peck's well, Coolidge, Hamilton County.	298	6	100	Pure and medicinal; water rises 15-20 feet above surface; medicinal properties slight. Temperature 61° F.
Do	Border's well, near Coolidge, Hamilton County.	200	....	8	Pure; water rises 15-20 feet above surface; used for irrigation. Temperature 61° F.
Do	Burt's well, near Coolidge, Hamilton County.	275	....	35	Do.
Do	Nolan's well, near Coolidge, Hamilton County.	240	....	53	Do.
Do	Rich's well, near Coolidge, Hamilton County.	240	....	50	Do.
Do	Syracuse, Hamilton Co	1,000	....	......	Water rose only to 90 feet below surface.
Do	Ashland, Clark County	......	....	......	No data as to water.
Triassic	Richfield, Morton County	600	....	6·3	Pure and medicinal; mineralization slight. Temperature 66° F. Dakota furnished no flow; penetrated Trias 265 feet; water from 570 feet.
Do	Larned, Pawnee County	750	....	250	Saline and medicinal; water spouts 10-15 feet high. Temperature 65° F.
Carboniferous	Russell, Russell County	977	....	Good.	Saline; may be Triassic.
Do	Winfield, Cowley County	1,200	....	..do..	Saline; rises 6 feet above surface.

Wells of Texas.

Geological horizon.	Location.	Depth.	Caliber.	Delivery.	Remarks.
		Feet.	*In.*		
Tertiary	Carrizo Springs, Dimmit Co	175	4	Good	Pure.
Lower Cretaceous (probably Dakota).	Cotulla, La Salle County	1,008		..do..	Medicinal; jets above surface 6 ft.; water alkaline-saline. Temperature 86° Fah.
Do	San Antonio, Bexar County	225		..do..	Pure.
Do	San Antonio (near), Bexar County.	450		..do..	Pure and medicinal; could be used for medicinal purposes.
Do	Dallas, Dallas County	750		..do..	Pure.
Do	Fort Worth, Tarrant Co	350		..do..	Do.
Do	Weatherford, Parker Co				No data as to water.
Do	Canadian, Hemphill Co				
Do	Tascosa, Oldham County				
Do	Armstrong, Armstrong Co				
Do	Mobeetie, Wheeler County				
Do	Clarendon, Donley County				
Do	Childress County				
Do	Cottle County				
Do	Floyd County				
Do	Margaret, Hardman Co				
Do	Crosby County				
Do	Pepper's Ranch, Kent Co				
Do	Haskell, Haskell County				
Do	Anson, Jones County				
Do	Roby, Fisher County				
Do	Snyder, Scurry County				
Do	Dawson County				
Do	Trent, Taylor County				
Do	Sweetwater, Nolan County				
Do	Colorado, Mitchell County				
Do	Big Springs, Howard Co				
Do	Marienfeld, Martin County				
Do	Midland, Midland County				
Do	Glasscock County				
Do	Coke County				
Do	San Angelo, Tom Green Co				
Do	Centralia, Tom Green Co				
Do	Aroya, Ward County				
Do	Toyah, Reeves County				
Do	Wild Horse, El Paso County				
Carboniferous	Wichita Falls, Wichita Co				
Do	Archer, Archer County				
Do	Henrietta, Clay County				
Do	Montague, Montague Co				
Do	Throckmorton, Throckmorton County.				
Do	Jacksborough, Jack Co				
Do	Palo Pinto, Palo Pinto Co				
Do	...do				
Do	Albany, Shackleford Co				
Do	Abilene, Taylor County				
Do	Tebo, Taylor County				
Do	Baird, Callahan County				
Do	Eastland, Eastland County				
Do	Eastland County				
Do	...do				
Do	Stephenville, Erath Co				
Do	Comanche, Comanche Co				
Do	Coleman, Coleman Co				
Do	...do				
Do	Runnells, Runnells Co				
Do	San Saba, San Saba Co				

Dakota sandstone.—As already stated, this sandstone is the most important source of artesian water in the region of the Great Plains. It is believed that it has greater importance as a storehouse of water for irrigation than all of the other formations of the same region from which it is possible to derive supply by artesian wells. Its discussion and investigation must constitute the chief part of the discussion and investigation of the artesian problems of the Great Plains.

The formations of the northern part of the plains were early investigated by Dr. F. V. Hayden, who gives the following section:

Name.	Character of strata.	Thickness.
		Feet.
Loup River bed	Fine loose sand, with some layers of limestone	300-400
White River group	White and light drab clays, with some cavities of sandstone and local layers of limestone.	1,000
Wind River deposits	Exposed principally in Nebraska	1,500-2,000
"Fort Union," Laramie.	Sandstone with shale	2,000-10,000
Fox Hill	Gray ferruginous and yellow sandstone and arenaceous clays.	500
Fort Pierre	Dark gray plastic clays above; dark beds of very fine unctuous clay, containing much carbonaceous matter with veins and seams of gypsum, etc., below.	700
Niobrara	Lead gray calcareous marls above; light yellowish and whitish limestones below.	200
Fort Benton	Dark gray laminated clays, sometimes alternating near the upper part with layers of light gray limestone.	800
Dakota	Yellowish, reddish, and occasionally white sandstone with alternations of various colored clays and beds of lignite.	400

From this section it appears that the sandstone has such depth as to constitute it a large reservoir, and that it is covered by deep deposits of clay or clay-shale admirably calculated to prevent the escape of the water. Farther south the data in regard to its thickness are less precise, but there is reason to believe that it underlies a very large portion of the plains from the Canadian boundary to Mexico and from the foothills of the Rocky Mountains eastward to near the eastern border of the Dakotas and Nebraska and to the middle of Kansas and Indian Territory. In Texas it probably extends still farther eastward, but is divided by erosion midway. In North and South Dakota its eastern margin is concealed beneath Pleistocene deposits, but it is believed to terminate against the older rocks of that region and to be overlapped by the clay of the Cretaceous in such a way as to prevent the rapid escape of water from its margin. In Nebraska, Kansas, and Indian Territory it reaches the surface along its eastern margin. In Texas these relations are not well known.

Its water supply is received along the foot of the Rocky Mountains, where it exhibits a nearly continuous outcrop. It is believed that there is a continuous discharge from its eastern margin, at least where that margin is not protected by heavy deposits of Upper Cretaceous clays. It therefore constitutes what has been styled an imperfect reservoir, but the conditions for artesian flow are more favorable in the Dakotas than in the States immediately south, and it is not improbable that they are again favorable in some parts of Texas. The above tables show that the wells of the James River Valley exhibit higher pressure and a greater discharge than those of Nebraska and Kansas, where the eastern outcrop is uncovered, and further indication of the eastward movement of its water is found in the fact that the hydraulic head, as measured in the Dakotas, rises from east to west. The hydraulic head, or the height to which a column of water would rise under the static pressure, is 1,948 feet at Highmore, 1,876 feet at Miller, and 1,678 feet at Huron, reckoning in each case from sea-level. From Highmore to Huron the distance is 62 miles, giving an average fall of 4⅓ feet per mile.

The sandstone reaches the surface at the west by an upward curve, and thus presents but a narrow belt of exposed surface. This belt is estimated to occupy an average width of about 800 feet for the region from Colorado to the northern boundary, and not enough is known of the border of the formation south of Colorado to form an estimate. The outcropping edge pursues a sinuous course and thereby increases the exposed area. Taking this into account, the feeding ground for the reservoir is estimated as the equivalent of a belt one-third of a mile wide from the northern to the southern boundary of the United States. If the rainfall of this belt be taken at 15 inches, and one-half of this be estimated as lost by running away from the surface and by evaporation, the remainder that goes into the sandstone, if it could all be brought up again by artesian wells, would cover a belt one-fifth of a mile wide from boundary to boundary with 12 inches of water. This may be regarded as the outside limit of the permanent water supply derivable from the sandstone.

In order to estimate the land which may be irrigated let us assume that but half of this supply escapes at the eastern edge of the formation; that the other half can all be brought to the surface through wells; that all the water flowing from the wells through the year can be stored without waste and applied to crops in the season of their growth, and that 6 inches of water will suffice to nourish the crops. We then have as the limiting area which can perpetually be served by the artesian water from the Dakota sandstone the equivalent of a belt one-fifth of a mile wide and extending from boundary to boundary, or about 175,000 acres.

But the permanent supply is not all which can be drawn from the Dakota sandstone. There is an accumulated store of water competent to produce a temporary flow of importance. This is indicated by the phenomenal flow of some of the wells of the James River Valley. The wells already sunk here and there over the valley furnish nearly half as much water as is annually received by the outcrop of the formation along the Rocky Mountains west of the Dakotas, and there can be no question that the flow in this valley can be increased several times by boring additional wells at points properly distributed and selected. The yield of such wells in excess of the permanent supply must draw upon an exhaustible store, and must, therefore, be only temporary, but it may nevertheless prove sufficient to compensate for the outlay, at least if the number of wells bored be not excessive. The determination of the quantity of water thus temporarily available is a problem for the geologist and the engineer. The geologist can ascertain the extent, thickness, and porosity of that portion of the Dakota sandstone which lies sufficiently above the level of the James River Valley and is otherwise related to it so as to afford a reservoir delivering water under pressure; the engineer can carefully measure the static pressure and the volume of existing and new wells from time to time, and thus get the data for estimating the rate at which the supply is diminishing. When this has been done it will be possible to give intelligent advice as to the exploitation of the formation in that region for purposes of irrigation.

The general character of the geologic data can be indicated by the information already at hand, but the result is necessarily very crude. At its outcrop along the foot of the Rocky Mountains and about the circumference of the Black Hills the Dakota sandstone dips steeply beneath other rocks, and it is deemed probable that at all points it passes below the level of the James River Valley within 3 miles of the outcrop. This gives as the maximum possible extent of efficient reservoir lying west of the Dakotas 1,200 square miles. Assuming the average thickness of the sandstone as 400 feet, and that the interstices filled with water constitute one-tenth of its volume, we have stored a body of water equivalent to a lake 1,200 square miles in area and 40 feet deep. Such a maximum could only be attained if the reservoir was of the perfect type, and in that case the static pressure at Huron in the James River Valley would be about 850 pounds to the square inch. As a matter of observation it is only 170 pounds to the square inch, and we are thus informed that the reservoir of water has a volume far below the possible maximum. If, in view of this consideration, we reduce our estimate 75 per cent, we still have a most important body of water—a body competent to serve, with a layer 6 inches deep, 24,000 square miles of land for one year, or 1,000 square miles for twenty-four years. The assumption that the feeding ground for the artesian water to be raised in the Dakotas is limited by the same parallels of latitude which limit the Dakotas is arbitrary and crude. If the Dakota sandstone is a continuous formation, then a portion of the supply thus derived must be drawn off through Nebraska at the exposed edge in the eastern part of that State, where it is probable that the water finds free escape. On the other hand it is possible that the Dakotas may draw from the sandstone water supplied to it beyond our northern boundary; while it is equally possible that a portion of the water absorbed along the outcrop of the formation in Montana flows northward rather than eastward, so as to contribute to the artesian supply of our Canadian neighbors.

The moderate yield of artesian wells penetrating the Dakota sandstone in Nebraska and Kansas does not warrant the belief that an accumulated store of water is there drawn from, and full data in regard to Texas wells are not yet at hand.

SUMMARY AND CONCLUSIONS.

It has been shown that the supply of water to be obtained through artesian wells is narrowly limited, the limitation arising from natural conditions of reception by reservoirs, transmission through them, and leakage from them, and being expressed practically through the interference of wells one with another. The permanent flow is in some cases much less than the initial flow.

Owing to the cost of well boring it is not economic to bore wells for the purpose of reclaiming land by artesian water unless the flow obtained exceeds a certain minimum. The economic limit is quickly reached in any district upon the multiplication of wells, and unless well systems are wisely planned there is great danger that the economic limit will be exceeded, and especially that new wells at lower levels will have the effect of destroying wells previously sunk at higher levels. Disappointment is also incurred when the temporary flow resulting from antecedent storage is mistaken for permanent flow. For these reasons exploitation with a drill should be guided by the results of surveys—geologic surveys to determine the stratigraphy and geologic structure, and engineering surveys to determine the limitation of discovered reservoirs. While the Dakota sandstone is one of the most important of the known artesian reservoirs, the amount of land which can be redeemed to agriculture through its aid is yet so small that disastrous results might follow if great expectations were aroused in regard to it.

It is estimated that if all the water received by the Dakota sandstone could be brought to the surface by artesian wells it would cover to the depth of 1 foot an area of land equivalent, at the utmost, to a belt one-fifth of a mile wide and extending from the Canadian boundary to the Mexican.

This is the outside limit for permanent flow. The temporary flow may be large, but can not be estimated from existing data. Such is the complexity of conditions, and so great is the danger of disaster through expensive exploitation in ignorance of the true conditions that the subject demands the most skillful investigation which can be bestowed.

Mr. Chairman, I have laid before you somewhat fully this question of artesian wells, because the people from time to time in the United States have sought to obtain waters for irrigation on the Great Plains from this source. Many years ago Captain (afterwards General) Pope, of the Army, attempted to discover artesian waters on the Staked Plains, and he commanded a military expedition to the country and bored for water, but he failed to find it. Some years ago appropriations were made by Congress to have artesian wells sunk in Colorado and Wyoming, and the work was continued for two years under the direction of the Agricultural Department. I believe that altogether $50,000 was expended, but no artesian waters were discovered. Still the people, now here, now there, from time to time, hope to obtain an artesian water supply sufficient for agriculture; and believing that this supply must always be inadequate, I have presented my views of the matter somewhat in full. It is manifest that the people of that region must resort in times of need to irrigation, and the question arises, Is there an adequate source of supply to meet their wants? I think the answer to this question is plain. There are supplies which can be used, and the attention of the people should be called to them. A very small supply can be obtained from artesian wells, as I have shown; but there are other sources of vastly more importance, and I wish to point them out.

I shall call your attention next to the use of pump-wells for irrigation. This source is far greater than that of overflowing wells. The valley sands in all the region of the plains where irrigation is necessary are great reservoirs of water. I mean that not only the sands of the valleys where great rivers run but the sands which accumulate in all the small valleys are storehouses of water. The experience of mankind shows that this supply is worthy of consideration. There is one district in India where 400,000 wells draw water from such reservoirs, and by them an area of more than 1,250,000 acres is irrigated. This, then, is a supply of some real importance that ought not to be neglected. The wells which can be sunk in the sands along the great river valleys are exceedingly important, and the waters can be pumped from them at a comparatively small expense. The sinking of the well itself costs but a trifle and the pumping is done with great economy. A pump which will irrigate one or two hundred acres of land will cost but $200 or $300, and they are now constructed so simply that they can be operated with little expense and at little cost for fuel to produce the necessary power. These wells are being rapidly developed in some parts of the country, not only on the Great Plains but in Arizona and elsewhere. If the attention of the people of the sub-humid region is called to this source of supply some good may be done and valuable results may be accomplished.

But yet pump-wells do not constitute the chief source of supply, nor are they the most economic. Irrigation in this sub-humid region will ultimately be practiced in the main by the construction of storm-water reservoirs, or "tanks," as they are usually called. Little valleys or ravines in the hills are dammed, and tanks are constructed in this manner, to be filled with water which is held in ponds or small artificial lakes to be poured over the lands below for their fertilization in times of need. Much more than one-half of the lands of the world are dependent upon irrigation, and of this amount I estimate that about one-third is dependent upon the utilization of storm-waters in this manner. It is the great source of supply, and to it the farmers of the sub-humid region should be directed.

I have brought, to place before you, a little map of a district of country in India similarly situated on a plain, where the people irrigate a vast extent of country, to show you how they store the storm-waters in that region. The little valleys are well situated for the storage of storm-waters, and they build dams across them and across the running streams, where there are small streams, and store the water in what they call tanks. The sub-humid country, from the British line to the Mexican line, along the one hundredth meridian and eastward, will ultimately have to depend for irrigation chiefly upon the storage of storm-waters, and these can be stored with economy. You can get an acre-foot of water by storing the storm-waters very much cheaper than by getting it from artesian wells, for which you have to bore 300 or 400 feet; so that the general resource of water is from the storage of storm-waters. That is true not only in theory but is abundantly shown by the experience of mankind throughout the world. In New South Wales $27,000,000 have been expended for the construction of tanks for the storage of storm-waters.

The CHAIRMAN. While on the tank system I want to ask you a question. This Missouri River here—from a point about here, I think it is, to this point here—has nearly 1,000 feet fall?

Maj. POWELL. Yes.

The CHAIRMAN. There is a splendid opportunity, it seems to me, to establish a tank system through this country here in this regiou and obtain the torrential flow from that river, and thus relieve the Lower Mississippi from floods.

Maj. POWELL. I am going to speak of this other source. Across the plains in this sub-humid district some great rivers flow, and a portion of these rivers can probably be used in the region under consideration, but not all of them. It is my opinion that the South Platte will ultimately be all used in the arid region of Colorado. The Arkansas will also be used in Colorado; but I do not believe that the Missouri will ultimately be wholly used in the arid region. I think a part, and a very considerable part, can be used in the sub-humid region of which we are now speaking, and that North and South Dakota will ultimately be benefited thereby to a large extent. It seems probable that the waters of the Missouri can be taken out at the great bend. Here it is on the map, Mr. Chairman.

Mr. HERBERT. About how much is it above the sea level in that arid country there?

Maj. POWELL. Speaking from memory, I should say it is about 2,700 feet.

The CHAIRMAN. I think it is 1,500 feet at Devil's Lake.

Maj. POWELL. Yes, that country is lower.

The CHAIRMAN. That is lower than the big bend of the Missouri.

Maj. POWELL. We now believe that the lands in here can be covered if we can get across or through the divide. It is so narrow we think it can be cut, but that has not yet been determined with certainty. All the water of the Missouri must be taken out on the east side, and for 400 or 500 miles the water can not be taken out because it runs in a deep canyon. So the large body of water must be taken out below, in the Dakotas, or wasted. That much we know.

Mr. PICKLER. Is not the artesian supply the same as that running in the bed of the river?

Maj. POWELL. We do not understand that the artesian supply comes from the river.

Mr. PICKLER. You stated awhile ago that it extended from the British line. Then it must be supplied from the meltings of the snows from the mountains, just as the Missouri River.

Maj. POWELL. From rains and snows on the foothills. The area of supply, so far as we know—and we know it for many miles along the hills—the catchment area, is on an average not more than one-third of a mile in width of exposed surface. That is the edge turned up along the hills.

Mr. PICKLER. Now, for instance, your theory is this water is coming from the Black Hills.

Maj. POWELL. Running from the west, as the Missouri River.

Mr. PICKLER. Where does that come from?

Maj. POWELL. The same way; from the west, but far back in the mountains.

Mr. PICKLER. What is the general direction of that subterranean flow?

Maj. POWELL. Eastward.

Mr. PICKLER. This is the question I asked: Whether or not this flow of subterranean water is as constant as the flow in the bed of the river?

Maj. POWELL. There is no doubt of it at all. This Dakota sandstone supplies it perennially just the same way.

Mr. PICKLER. Is it not your theory that this is an underlying sea of water from the British possessions to Texas?

Maj. POWELL. No, sir; I believe it to be a slow flow through a permeable sandstone which carries the water.

The CHAIRMAN. Has any survey been made to determine the extent of the artesian basins whatever?

Maj. POWELL. We know this one pretty well now, but I am in hopes of finding more.

Mr. PICKLER. Right south of your finger is the greatest well in Dakota.

The CHAIRMAN. What is the depth of that well?

Mr. PICKLER. Seven hundred and some odd feet.

The CHAIRMAN. At this point here we have a well 1,500 feet, which has a great quantity of water. Here there is a well of 1,400 feet. Here is one of 1,300 feet.

Mr. PICKLER. At Faulkton, Faulk County, where I live, there is a good well, opened recently.

The CHAIRMAN. What is the flow?

Maj. POWELL. It is not as much as some of the others.

Mr. HATCH. Where is that tremendous flow?

The CHAIRMAN. At Woonsocket.

Mr. HATCH. Mr. Chairman, it is 12 o'clock, and there is a special order of the House, and the House has been in session since 11 o'clock.

Thereupon the committee adjourned.

SELECT COMMITTEE ON IRRIGATION,
Thursday, April 17, 1890.

The committee met pursuant to adjournment, Mr. Hansbrough in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. POWELL said:

Mr. Chairman and gentlemen of the committee, I want this morning to lay before you the operations of the Irrigation Survey, explaining what has been done up to the present time, and the plan and purposes of the work.

The first appropriation made for the survey was on October 2, 1888, being $100,000. The second appropriation, made for the present fiscal year (which will be expended by the close of the year), was $250,000; making in all an appropriation for the two years of $350,000.

The work of the survey is divided into three parts. I shall take these parts up in order, and try to show the relation of the parts or branches of the work and the outcome of the work.

The statute provides that the survey shall determine the extent to which the arid lands can be redeemed by irrigation. That is the first provision of the statute. The next provides that reservoir sites shall be selected and withdrawn from the market; that canal sites also shall be selected and withdrawn from the market. These canals are of two classes, those which carry the water from streams to reservoirs—the reservoirs in general are not put on the streams themselves, as will appear further on in my remarks—and those that deliver the waters from the reservoirs to the lands. So we have to discover two classes of canal sites, diverting canals—canals by which water is diverted from streams to reservoirs—and canals from the reservoirs to the irrigable lands; and such canal sites and head-work sites or dam sites and reservoirs are nominated in the statute. The next provision of the statute is that the irrigable land shall also be selected, and that all land susceptible of irrigation under the works planned shall be withdrawn from the market except under the homestead act. The President may restore at any time all of this irrigable land to the provisions of the homestead act.

But the statute practically provides that they shall be withdrawn from the operations of the desert-land act, the pre-emption act, and the timber-culture act, but restored the lands to sale under the homestead act. Again, the statute provides that the dams, canals, and reservoirs shall be planned, and the cost thereof determined and reported to Congress. Substantially these are the requirements of the statute.

In order to do this it becomes necessary to make a survey of the country, first for the discovery of the points on the streams where the water can be diverted to the best advantage. This is exceedingly variable along the course of a stream, there being some places where it can be taken out advantageously, and other places where it can not be taken out without great cost, and many other places where it can not be taken out at all. So streams themselves have to be examined to discover points where diverting dams can be constructed and the waters taken out and put into the reservoirs and on the lands.

The next thing is to discover the reservoir sites. Now, in every region of country which we have examined, and of which we have any knowledge, there are more reservoir sites than are needed, but they vary greatly in character, and many good reservoir sites are not sites where the water can be stored cheaply and economically, and the important point is then to discover all the reservoir sites and to make selection of the best, all things considered—where reservoirs can be constructed cheapest, and where the water can be taken to them from the streams with reasonable economy, and where the water can be taken from them to the lands to advantage. Of course a great many reservoir sites could be discovered on low grounds. There is no difficulty in that; but that is where the water can not be taken out on the lands. It goes without saying. But the thing is to discover such sites that water from them can be utilized on the lands below.

It will be noticed, then, we first have to make discovery of places along the streams to divert the water and discover lines of canals from reservoir sites to the lands themselves. Now, it chances that the best reservoir sites are, in the main, far away from the lands. Whenever it is possible, water should be stored high in the mountains, where the evaporation is less. The evaporation on the plains and in the low valleys may be twice as great as in the mountains. The evaporation in the mountains may be 3 or 4 feet annually, and may be 6 or 8 feet annually on the plains, and the difference means a great loss of water. Still, it can not always be stored above, and when we have discovered the principal sites above, we have then to go below into the region occupied for irrigation, the region of irrigable lands, and to discover additional sites there. The waters stored in the mountains are discharged again to the channels of the streams, and flow down the natural channels until they are diverted below. Waters which are stored in the plains and valleys are taken out of the natural streams and stored there, and afterwards taken to the lands themselves. The problem, then, is to discover all these things, and having discovered them, to make accurate, comparatively minute, surveys of the dam sites, reservoir sites, and canal sites, and of the irrigable lands. A general survey of the entire country is necessary to discover these things. A special or specific survey is necessary after the sites and lands are selected, to report upon the cost of the works. For example, there may be from the river to the reservoir site many ways to take the water, and we wish to discover the best. There may be many ways to take the water from the reservoirs to the land, and we wish to discover the best; and having discovered the best line, that one line we survey with greater care, as the general survey is a survey for discovery. This survey for discovery we call a topographic survey, and its purpose is for discovery, as I have briefly stated.

It serves a further purpose, which I shall explain in this manner. In order to plan works, as the statute requires, and in order to discover the extent to which the arid lands can be redeemed by irrigation, it becomes necessary to determine how much water there is. You can not plan reservoirs until you know how much water they are to hold. You can not plan canals until you know how much water they are to carry. You can not discover the irrigable lands and determine their extent until you know what waters are to serve them. The lands being in excess of the water, that is, there being more land than the water will serve, the lands have to be selected, and we do not know how to select the lands until we know how much water can be found to be used upon them.

The question, then, of measuring the waters is the great problem to be solved, and to this problem I have devoted much time and much thought for many years. Fifteen or sixteen years ago I prepared a map of Utah. I was conducting surveys there, and I prepared a map of Utah and reported on irrigation in that Territory, and on that map I delineated the areas which can be redeemed by irrigation during the season of irrigation without storage. At that time people were not thinking of storage, and were not resorting to storage. In order to do that it became necessary to discover how much water the streams would carry; what volume of water was in the several streams simply during the season of irrigation, which lasts from sixty to eighty days in Utah. The survey was not specifically for that purpose, but a topographic survey, and we did not stop to gauge the streams with great care, but to get at some general results, and we gauged in only a rough manner.

The method of gauging streams has been improved from time to time since then, until at last we can gauge streams with considerable accuracy, but it is expensive and takes a long time. To gauge a stream we need first to record its rise and fall during the year. Taking a section of the stream, we determine its rise and fall by means of a nilometer, as we call it, on which is recorded automatically the rise and fall. A float lifts an apparatus which makes a record on a paper, which shows how the river rises and falls from hour to hour, from day to day, from month to month, and from year to year. Then we make an examination and survey of a cross-section of the stream; we find what the cross-section of the water is during each hour and each day and each year, but the water may flow swiftly by or slowly by, as the case may be, and we must know something more; but to know this something more is quite expensive. We must know the velocity of the water passing through the cross-section. This is measured with a current gauge. Then the velocity varies from top to bottom and from side to center, and we must know the velocity of all portions of the section. Then the velocity changes with the rise and fall of the river. When the river is low the velocity is slight, and when the river is high the velocity is great, and it becomes necessary to measure the velocity at different stages of the water from low water to high water with current meters.

We can gauge a stream to-day and find its volume, but that will give us no clew to its volume to-morrow; so this gauging has to be continued until the maximum flow of the stream is found, which may occur once in two, ten, or twenty years, as the case may be. Then the minimum flow of the stream, which may occur at long intervals, must be known. In order to know what that stream will carry from year to year—the mean flow, the maximum flow, and the minimum flow—it becomes necessary to keep up the gauging for a long term of years. If we resort to no other method than that which I have described, on a pretty careful examination of the matter we find that to plan these reservoirs we shall have to make gaugings of this character to determine the quantity of the water at from 16,000 to 20,000 places. I have a map of a little stream here—the Apishapa River, in the Arkansas Basin—giving the reservoir sites, which are marked in blue, and the lands that can be irrigated, which are marked in green. Here is the catchment area in the mountains. Now, there are twenty-two reservoirs there on this little stream. To plan these reservoirs we must have twenty-two gauging stations or measurements of the amount of water. Now, going over the map of the arid region, as we have done with some care in the office, we have found that it will be necessary to have somewhere from 16,000 to 22,000 measurements of this kind, and by the plan which I have given you the measurements would extend over a great length of time and would be quite expensive, varying in expense from $200 or $300 to $2,000 or $3,000 each, and it is believed it would cost from $16,000,000 to $20,000,000 to make these gaugings of the streams.

The CHAIRMAN. Is this a hydrographic survey?

Maj. POWELL. Yes, sir.

Mr. PICKLER. Of the whole arid region?

Maj. POWELL. Of the whole arid region; and the problem was raised whether or not it was possible to adopt some cheaper method. We did devise a cheaper method, and it appears to be satisfactory. I will illustrate what that is. Suppose I wanted to find how much water can be caught on the roofs of the houses of Washington. I could put gauges on the gutters of each house and measure the flow from each one of these houses of the city from day to day, from month to month, from year to year, until I discover the average rainfall and maximum flow from each roof and the maximum and the minimum annual flow from each roof. Suppose, instead of that, I measured two, or three, or ten of these about the city, and then measured the area of all the roofs themselves. I could then compute what the flow would be for all. But in this matter catchment areas of lands are not as simple as catchment roofs. It is very complex, and these complex conditions must be understood. If all the rainfall would flow from the catchment basin then, knowing the rainfall and knowing the number of square miles in the area, we should have the amount of water which would flow from it; but the problem is not so simple. In a region like that of the Hassayampa River, a map of which I had before you one day, and in many other regions of country, a very large portion of the rainfall will flow away, for the declivities are great and the water is gathered into the streams. If the declivities are slight and the country is level, or nearly level, very little water will flow away. In a level country the sands and gravels accumulate, and the rain water sinks into these sands and gravels and evaporates and does not gather in the streams, while on the mountains, where the surface of the country has a great deal of rock, the water gathers rapidly in the streams and can be used.

We might go to a district lying by the side of the Hassayampa district and find practically that all the water would be absorbed by the soil and evaporated and none discharged in the streams, while in the Hassayampa region a very large proportion of the water is gathered into the streams. Now, how can we get at the amount of water that is thus variable? Practically it is a question of declivities. If you increase the declivities, you diminish the amount of sand and gravel which is disposed all along the slopes, and the increased declivities discharge the water more rapidly, and the greater the declivity the greater the amount that is discharged in the streams. The more level the country is the less the amount of water discharged into the streams, until in that region of country probably about one-third of the ground discharges no water in the streams at all. The ground is so level and sandy and the absorption is so great that all evaporates. What we have to do, then, is to determine the declivities. We want to determine the run of water in these sixteen or twenty thousand minor basins. We want, first, to find the catchment area of the water that is to be controlled by the dam and stored by the reservoir; second, we want to find the declivities, the slopes of the ground, and to find what portion of the water will be discharged and how rapidly it will be discharged; and, third, we want to find the rainfall. For the rainfall investigation we found it was not necessary to enter largely into field operations. The rainfall data had been collected in part by the Signal Service and in part by our own observers, but chiefly by the people themselves, many of whom had been interested. Rain-gauges are employed all over that country, and different States and Territories have organized societies for doing the work and they save us the expense of it; so, practically, we are at no expense for determining the rainfall. But it is necessary to do the work of determining the catchment areas and the declivities of the catchment areas, and further than that the gauging of a few typical streams is necessary. By this means we believe the cost will be much less. I made an estimate to Congress two years ago when called on for an estimate of what this work will cost. I believe we can do the gauging for about $1,500,000. Thus it is that a topographic survey which is made for discovering sites is also made for discovering catchment areas and declivities, and is the basis of the hydrographic work.

Mr. PICKLER. What length of time would it take to do it?

Maj. POWELL. That will depend upon the rate of the appropriation, it being a method which does not take a long time. We do it just as rapidly as the appropriations are made.

This method, which combines topographical surveying with the gauging of typical streams, will give the results sooner, will be much cheaper, and will be on the whole more accurate than the method which depends entirely on gauging. Our anticipations in this regard are fully sustained by the experience and outcome of the last eighteen months' work.

Now, the method adopted for doing th ehydrographic work and the necessity for discovering the sites and lands made a double reason for the construction of the topographic map. We could have discovered sites and lands by another method than that of a topographic map. That method is by the use of trial lines. We might, on looking over the ground, suppose we could run a canal from such a point to such a point. In order to prove it we might run a trial line. That is the method generally adopted in this country where surveys are made for lines of railroads. There has been in the United States an enormous experience in trial-line surveying. If a road is to be run from one place to another and they do not know the best way, they run a trial line where somebody thinks it would be a good site, then by other suggested routes, and select the best. Experience shows that the trial lines cost, on a general average for the United States, $25 per mile. To adopt the trial-line system would be to run many lines at a cost of $25 per mile on the general average. To make a topographic survey was to get the same facts in a much more satisfactory way for a much smaller amount. The trial-line system would have cost at least three times as much as to make the topographic map. Let me illustrate that.

The Canadian Government attempted to discover the best line for the Canadian Pacific Railroad by running trial lines, and they spent $3,000,000. After the line had been selected in this manner they discovered they had made a mistake, and had to abandon a large section of the work and to make a new line. It is now discovered that the best line was not selected, and that they could have built that railroad very much cheaper if they had discovered the proper lines. Had they made a topographic map of the whole of that line and of a belt of country about it 150 miles in width, they could have made the map and discovered everything for one-half the money which it cost just to make the trial lines. All this cost of $3,000,000 was for discovery purposes. The line at last found had still to be run with great care as a basis for construction purposes.

You will see on the map before you the extent to which we have made a topographic survey. All marked in blue has been done by the survey under my charge; these other colors represent districts surveyed by Messrs. Hayden, Wheeler, and King. Wherever we have made a topographic survey in the region which you see upon that map no railroad company runs a trial line. They are guided in the selection of these lines by the maps made by the Geological Survey; so that with the whole United States surveyed as we have got that portion surveyed, any engineer of ordinary intelligence can plan any railroad line in the country. Now, the topographic maps which we are making give all the information necessary to locate diverting dam sites, diverting canal sites, reservoir sites, and to select irrigable lands, and give us the catchment areas for every reservoir; give not only the superficial dimensions, but the declivities, and for that reason topography is necessary. To make this survey without a topographic map would increase its cost fivefold, and when made we would never be quite sure we had selected the best. When made in this manner we are sure we have got the best lines and the best sites and the most available lands; and, more than that, we can present those facts graphically to the people who are to construct these works and use the waters, these engineers and farmers. We can present the facts to them in such a manner as to show them no mistakes have been made. It gives all the contour lines and presents all the facts satisfactorily to everybody. It is for this reason, Mr. Chairman and gentlemen of the committee, that a topographic survey is made.

When called upon by a resolution of the Senate to report a plan to Congress, I reported, among other things, that a topographic map was necessary, a topographic survey, and a hydrographic survey, and so on. When the act was passed creating the survey, it was formulated in terms authorizing and directing a topographic survey. The law itself directed that the survey should be made, and it directed it in the same language in which the original law directed that the map should be made for the geological survey.

The irrigation survey was created by an act approved March 20, 1888. Thereupon the Senate, by resolution, called upon the Secretary of the Interior for an estimate of the work, including the making of a map or maps. In reply the Secretary transmitted a letter from myself. In this letter I formulated the plan of the survey, explaining the topographic work and the hydrographic work and other things necessary to its completion. In that letter I stated, among other things, the following:

> To determine for a given stream, or for a given group of streams treated collectively, first, the maximum area of farming land and its most advantageous selection; second, the best selection of sites for reservoirs and their proper size; and, third, the best system of headworks and canals, there are three general requisites, as follows:
>
> (*a*) The construction of an accurate topographic map, with grade curves at such intervals as will properly represent the configuration of the ground.
>
> (*b*) The determination of the total annual discharge of water from the catchment basins, or where there are more than one, from each catchment basin, and the distribution through the year of that discharge.
>
> (*c*) An examination of the soils in the area from which, under existing topographic conditions, the selections of lands for irrigation must be made.
>
> (See Senate Ex. Doc. No. 163, Fiftieth Congress, first session, p. 3.)

And I made an estimate for the beginning of the work in the following language:

> Impelled by these considerations, I respectfully recommend that an appropriation of $250,000 be made for the first year's work, and would suggest the following clause for the appropriation bill:
>
> "For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation, and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation, and to make the necessary maps, including the pay of employés in field and in office, the cost of all instruments, apparatus, and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of two hundred and fifty thousand dollars." (Ibid., p. 6.)

It will thus be seen that, having plainly stated that a topographic survey would be necessary, I made estimates for it in these words: "and to make the necessary maps." The clause which I thus drafted was incorporated in the bill. Additions were made to it, increasing the work and causing the sites to be withdrawn from sale, and the lands susceptible of irrigation to be withdrawn from market except under the provisions of the homestead laws. This plan, with the estimates, was referred to the Appropriations Committee of the Senate, and the chairman of that committee called on me to explain the plan and estimates. This I did, and such statement was published in the report of the committee. (See Senate Report No. 1814, Fiftieth Congress, first session, pp. 112-119.) The bill became a law October 2, 1888, and immediately work was begun. On the last of December following, my report on the inauguration of the work was transmitted to the Congress and published. (See Senate Ex. Doc. No. 43, Fiftieth Congress, second session.) In this report I set forth the fact that topographic surveys had been begun in New Mexico, Colorado, Nevada, California, and elsewhere. Thus, I fully explained to the Congress how the work was proceeding, and that it embraced the topographic survey in accordance with the plan and in obedience to the statute. An estimate to continue the work was then sent for, and again I was called before the Appropriations Committee to explain the estimate, and presented to the committee a specimen of the work, which was a topographic map. On all of these occasions I explained to the committee, not only that I was doing topographic work under the appropriation, as directed, but that the larger part of the cost was involved in this work. Then a second appropriation was made in the same terms as the first. And so the work has proceeded to the present time. Thus it was that the original plan embraced the topographic survey, and the matter was fully explained to the Congress, and the appropriation act specified that the surveys should be made.

Mr. Chairman, let me again call your attention to the map. There is quite an area of country [illustrating on the map] where we do not have to make a topographic map, because we have already made maps for geological purposes that serve for the irrigation survey. We make for the irrigation survey the same map we make for the geological survey, with the one exception that for the irrigation survey we make a careful determination of the gradients of the streams, the declivities of the streams. These have to be determined with more accuracy for the irrigation survey than for the geological survey. So all that topographic survey work which had already been done for the geological survey is available for the irrigation survey, and the topographic map was authorized primarily for the use of the geological survey. It was reauthorized for the use of the irrigation survey. It must be remembered that two maps are not necessary; only one survey is necessary. Whatever maps are made in the arid region for the geological survey are used for the irrigation survey, and whatever maps are made for the irrigation survey are used for the geological survey. These regions of country which you see indicated in dark blue have been surveyed as a part of the irrigation work. The districts are in Colorado, New Mexico, California, Nevada, and Montana, and there is a small district in Idaho.

The work of the Survey has been divided, then, practically into three branches: First, the topographic survey, which is the basis of all the work. It discovers all the sites and lands, and it discovers all the catchment areas, and also gives the means for determining the amount of water supply for each reservoir and for each diverting dam. It also gives a basis for the determination of the total amount that can be redeemed in the arid region, as called for in the first section of the act, which requires us to determine to what extent the arid lands can be redeemed by irrigation.

The second work of the Survey relates to hydrography, and I have already explained a part of it. We have a hydrographic corps now engaged in gauging typical streams, the results to be used in our computations after the topographic work is completed. That hydrographic corps is also charged with certain other duties: wherever we have a station we have a rain gauge; wherever our work is going on we have a rain gauge, as that can be done without additional expense; so that to collect all the data relating to rainfall is part of the duty of this hydrographic branch. We rely chiefly on the records of rainfall kept by the people and made by the Signal Service.

But there are other things of very great importance in the irrigation survey which are relegated to this branch of the work. In order to select the land we have to know how much water it requires to serve an acre of land. Some 12 or 14 years ago I commenced that investigation in Utah, and with the methods then in vogue there were examined a little over 100,000 acres of land, and I discovered that a cubic foot of water per second would irrigate during one season of irrigation from 80 to 100 acres of land. But we must know more accurately than that, and we are going on with this investigation, and it is carried on by the hydrographic branch.

Then the life of the reservoir is an important thing. There are some portions of the course of a stream where it carries an enormous quantity of sediment, as I have already explained to the committee, and there are other sections of the channel where it is clear, pure water, and we want to determine the amount of sediment which the stream carries where it must be taken out, in order to determine the life of the reservoir. If a stream carries a great deal of sediment it will fill up the reservoir and destroy it, and in order to determine its life, and whether it is worth while to construct it or not, we must determine the amount of the sediment. To get this is not a very expensive part of the work, but it is important.

Mr. HATCH. Can not you test that with filters? Take a barrel of that water and filter it and see how much sediment there is in 10, 20, 40 gallons?

Maj. POWELL. We have various ways of determining the question, but the best method is by evaporation. We let it evaporate and weigh the amount of deposit.

There is still one other point, and that is the necessity of determining the amount of evaporation, which I have already explained.

Mr. PICKLER. One question right there. In what part of the arid country is evaporation most rapid?

Maj. POWELL. Probably in southern California and southern Arizona. It amounts to 100 inches in this region [illustrating on the map]. That is the lower Colorado. The evaporation is very great there, and of course we could not store water without an enormous waste where there are a hundred inches of evaporation annually.

The next branch of the work relates to the dams, lines, reservoir sites, and irrigable lands. Having discovered the sites, lands, and quantities of water, then the engineering branch can step in and plan works. In order to plan the works, a site for a dam must be examined and surveyed, so as to know how long and how high, and how wide it must be constructed, and the amount of material which must go into its construction, etc., and to know the ground which furnishes the foundation of the dam. The site then is surveyed and the dam planned, and the elements of its cost examined, and report is made upon it. The reservoirs have to be discovered by a topographic survey for reservoir sites, and the engineer studies these sites from data placed before him by the topographers and selects the best, and having made his selection, he then goes to a particular site and makes a careful survey, a much more elaborate survey of that special site, to determine its capacity and the cost of its construction.

The canal lines having been selected from the great body of possible lines discovered by the topographic survey, the engineers make a selection, and then make minute surveys for the purpose of determining how much cutting is necessary here, or filling is necessary there, to find what the cost will be, as the statute provides. The engineers having selected specific waters, specific dam sites, specific reservoir sites, specific diverting canals, and specific delivery or surface canals, and knowing how much water they can get, and how much water it takes to irrigate an acre of land, they are enabled to determine what lands can be served. About 43,000 square miles have already been surveyed in the places I have mentioned. We had previous to that about 300,000 square miles already surveyed, of which we had a topographic map and to which had to be added only a more elaborate examination of the streams.

Mr. PICKLER. What is the immediate object of the survey in Missouri?

Maj. POWELL. It is a geological survey that has been going on for years. Hence much of it is in mining regions. All that work was planned to meet the wants of the mining districts, just as the work of the irrigation survey is planned to meet the wants of the irrigation districts. So we have been working in the great Appalachian Mountains, in this vast field of iron and coal. Under the Irrigation Survey we are pushing the work in the agricultural or irrigable lands. Here is one of the sheets. It is a sheet unpublished, just as it comes from the table of the draughtsman. Here is Arkansas Valley. This is in longitude 98° 30′, on the plains. Here is the Arkansas River. See how beautifully that great reservoir site is shown. That point is 1,800 feet above the level of the sea, on the Arkansas River. Following that contour line here from the river, you see it runs along the margin of this basin, where a lake can be made. Thus you see how a reservoir site is shown on the map. This is what all these maps mean. We have lines of level, or contour lines, by which any engineer or any farmer even could plan works. [Hereupon various topographic maps were exhibited, showing the character of the work done; then plans of canals, reservoirs, and dams were shown and explained.]

Director Powell then continued:

Mr. Chairman, the outcome of the work, then, will be an atlas of each of the great irrigation districts. This atlas will contain topographic maps of the region, in contour lines or grade curves, representing, quantitatively, the topographic elements. The courses of all streams will be shown; the valleys, plains, hills, and mountains will be delineated in grade curves, so as to show their relative heights and shapes. On these maps will appear the sites of all head-works, canal lines, reservoirs, and irrigable lands. In the atlas of each district there will also be plans of the reservoirs, canals, and head-works, such as you have seen. Then with each atlas there will be a descriptive text explaining the character of all the structures, the amount of material entering into their building, and the cost of the work.

Mr. Chairman, it will be noticed that the statute under which the irrigation survey is conducted provides that the extent to which the arid lands can be redeemed must be determined. It also provides that the sites for works shall be reserved for the people. And, finally, it provides that the lands under these works, to be cultivated by the waters controlled by the works, shall be reserved for homestead settlement. It seems to me that these provisions are all wise, but whether wise or unwise, as an administrative officer I am bound to carry out in good faith all of these provisions. The law is manifestly in the interest of homestead settlers, and it appeared to me on an examination of the statute that I should conduct the survey in the interest of homestead settlers—that the letter and spirit of the statute demanded this, and hence in planning my work I have had these ends in view. Immediately on the passage of the statute individuals and companies applied to me to make surveys for plans and schemes which they had devised, desiring thereby to get official indorsement of such schemes. From many districts throughout the arid lands promoters of schemes urged upon me the consideration of their plans, and requested official examination of the same.

After mature consideration I decided that such examinations were no part of my work, that I could not consistently under the law make the Survey an agency for the indorsement and advertising of the plans of promoters; that it was my duty to enter into each basin and make a complete examination of the same, and report the best system of works for that basin, and to reserve the sites and lands for homestead settlers. The course thus adopted has led in very many cases to disappointment. The promoters are active, vigorous men, standing between the capitalists and the farmers, who by all these irrigation schemes reap the chief reward. I deemed that the law was in the interest of the settlers, the actual farmers, who were making homes, and that I could do no act in compliance with the letter and spirit of the law that did not consider their ultimate interests. Under this theory of administration I have conducted the work. But the promoters are disappointed, and the hue and cry is raised that the survey does not aid the development of the country, and that it is not practical. And this is true so far as such development and such practical benefit are to come from the advancement of irrigation schemes by which lands and waters are aggregated in the possession of individuals and corporations. If this is a fault it is a fault of the law itself, as I act only in harmony with the statute.

Mr. Chairman, I have thus set before you the plans of the survey, the methods of the survey, and the underlying principles which have guided me in the administration of the trust, and now submit the subject to the judgment of the committee. For the patient hearing you have given me through many days, involving questions both of fundamental importance and of collateral interest, I must sincerely thank you.

Thereupon the committee adjourned to meet at the regular hour next Thursday.

SELECT COMMITTEE ON IRRIGATION OF
ARID LANDS IN THE UNITED STATES,
April 24, 1890.

Committee met pursuant to adjournment, Mr. Vandever in the chair.

STATEMENT OF MAJ. J. W. POWELL—continued.

Maj. POWELL said:

Mr. Chairman and gentlemen of the committee, when last before the committee I failed to call attention to a provision of the statute relating to the segregation of lands, and have returned this morning for that purpose. In the act creating an irrigation survey there are the following words:

> And all the lands which may hereafter be designated or selected by such United States surveys for sites for reservoirs, ditches, or canals for irrigation purposes, and all lands made susceptible of irrigation by such reservoirs, ditches, or canals, are from this time henceforth hereby reserved from sale as the property of the United States, and shall not be subject, after the passage of this act, to entry, settlement, or occupation until further provided by law: *Provided*, That the President may at any time in his discretion by proclamation open any portion or all the lands reserved by this provision to settlement under the homestead laws.

This act was passed October 2, 1888. In December, three months following, I made a report of the organization of the work and the progress made at that time to Congress, and in that report I called attention to this special clause and its effect in this language:

> I respectfully invite your attention to the clause of the act providing for an irrigation survey which withdraws from "sale, entry, settlement, or occupation" the lands selected for reservoir sites and those segregated as irrigable tracts.
>
> It is apparent that the reservation from sale of the lands necessary for the sites of reservoirs is eminently wise, as no restriction or burden should be placed upon the development of agriculture by irrigation in arid lands, but some provision should be made by which such reservoir sites can be permanently useful for the purposes for which they are designed. It is shown that further legislation is contemplated from the fact that the reservation is made to extend only "until further provided by law." * * *
>
> The propriety of preserving the irrigable lands from sale, settlement, and occupation until restored under the homestead laws through proclamation of the President, is worthy of further consideration. If the selections are wisely made—and this must be assumed—the best land, all things considered, that belong to the valley or plain of a given stream are segregated from the general domain, and peculiar restrictions are placed upon their disposal; that is, they can be settled only under the homestead provisions, and that after proclamation by the President, while titles to other lands can be secured under the homestead laws, the pre-emption laws, the desert-land laws, and the timber-culture law.
>
> The individual wishing to obtain title to lands will prefer to take up lands under the more liberal provisions, so that the selected lands will be neglected and the non-selected lands will be entered; and, as the statute now stands, the waters of the stream will be taken to the non-selected or poorer lands. It must in this connection be further understood that the difference between the good and the bad land will usually be very great. It may often be the case that the water necessary to irrigate a square mile of the poorer non-selected lands would, if taken to the selected lands, irrigate 2, 3, 4, 5, or more square miles. The individual making the selection can not be supposed to have the general good in view, but only his personal interests, and he will not consider the facts here represented.

The CHAIRMAN. Is that your report?

Maj. POWELL. That is from my report made to Congress a year ago last December.

The CHAIRMAN. If you have a copy of that report with you I would be glad to have it.

Maj. POWELL. A copy is here and I can leave it with you. The effect, then, it would seem to me, would be largely to prevent the settlement of the best lands. If the best lands are segregated and put under the homestead law and the other lands left free to all other statutory provisions for the acquisition of lands, it will result in taking the water on the poorer lands instead of on the better lands, as I explained in my report at that time.

There is another question of uncertainty in the statute. The statute says:

> All the lands made susceptible of irrigation by such reservoirs, ditches, or canals are from this time henceforth hereby reserved from sale, etc.

Now, there has not been a formal decision upon the interpretation of that statute. If it means, as I think perhaps it does, that all the lands made susceptible of irrigation are to be reserved, then larger areas will be selected than the waters will serve, but if a reservoir on the side of a plain or the side of a valley——

The CHAIRMAN. Would it be construed in this way, Susceptible of irrigation with reference to the water supply?

Maj. POWELL. That is the very point I wish to bring out. I want to call the attention of the committee to the fact that there is no legal decision of the question, but it will be raised in a few weeks.

The CHAIRMAN. Is it not entirely now in the discretion of the Interior Department to construe what the law is?

Maj. POWELL. The act will be construed in a few weeks. We have been conservative about the segregation of lands and are now making the first recommendations, and a case will now arise. When a decision is reached in this case an interpretation will be given to this clause. Allow me to explain what the effect would be on the lands susceptible of irrigation under that provision. Where a canal or reservoir may be able to irrigate 10,000 acres of land, 20,000 acres of land may be lying under it. Shall we segregate the 20,000 acres of land or the 10,000 acres of land, is the question. I think the question is worthy of consideration, and perhaps the statute needs amendment. I have suggested to another committee that the survey should be directed more definitely how these segregations should be made, and these are the words which I propose should be incorporated in the law as the conditions governing the selections:

> First, the conditions necessary to secure the greatest area of irrigable land.
>
> Second, the conditions necessary to secure the most valuable land for agricultural purposes by reason of climate.
>
> Third, the conditions necessary to secure the most valuable agricultural lands as determined by soil and subsoil.
>
> Fourth, the conditions necessary to secure land that can be irrigated and cultivated with the greatest economy.

I think there should be some legal restrictions placed upon the segregation of land, and that these conditions would meet the case.

The CHAIRMAN. Have you the suggestions in any form?

Maj. POWELL. Yes, sir; I have them in the form I have just read, which is in a bill introduced in the Senate.

The CHAIRMAN. Whose bill is that?

Maj. POWELL. Mr. Reagan's.

Mr. HANSBROUGH. This is an amendment to the Plumb bill?

Maj. POWELL. Yes, sir.

The CHAIRMAN. This would put the matter under the regulations and the ruling of the Interior Department at the present time, and I do not know whether the committee could consider that. I do not know whether it is best to incorporate a provision of that kind or not.

Maj. POWELL. This is the point I wanted to present to you so that you could consider it. The present law I think is defective; it works an injury; and I think something ought to be done to provide that specific lands should be irrigated, and rules provided under which they should be selected. It would be of interest to all the settlers to do that. The effect of the law at present is to withdraw all selected lands from settlement except under the homestead law. I do not know what the action of the President will be, but it is to be presumed that as fast as lands are selected the President will declare them open to homestead settlement. So that a body of land after being selected will not remain out of the market; it will be immediately brought into the market under the homestead law.

The CHAIRMAN. The homesteader would not be able to perfect the title until after the adjustment of the right to the water. The homesteader may go on and take a piece of land on which he thinks he can raise a crop in an ordinary season without irrigation, and he can hold it for a good while, and when the facts turn out he can not do anything with it at all.

Maj. POWELL. I simply wish to state these facts to the committee, so that it may have them before it for consideration. If the better lands are selected for the homestead settlers and the poorer lands are left to be taken up under the desert-land act, the timber-culture act, and so on, in large quantities, companies will acquire title to these poorer lands through the agency of persons employed for that purpose. Then they will get possession of the water by constructing the irrigation works, and the homestead settlers on the good lands will be left without water and powerless. The poor lands will be cultivated and the good lands will r main waste. If all of the lands which can be irrigated under the works planned are withdrawn from sale except under the provisions of the homestead act, then the companies will plan other lines and reservoir sites not so good and will take other lands not so valuable, leaving the reserved sites for works and the reserved lands to be managed by homestead settlers, who, not being capitalists, will not be able to command the situation, and thus the purpose of the law will be defeated. If the best sites for works are to be selected and the best lands under them selected, and then these sites for works and these lands are to be given to homestead settlers, they should be protected in their settlements by providing that the waters to supply the lands shall belong to their lands, and that they can not be used elsewhere. I suppose that it is well known to the committee that the desert-land privilege and the timber-culture privilege are the two great agencies by which the public domain passes from the possession of the Government into the hands of capitalists and corporations.

REPORT OF MR. A. H. THOMPSON,

SHOWING THE WORK OF THE

TOPOGRAPHIC BRANCH OF THE IRRIGATION SURVEY.

REPORT OF PROF. A. H. THOMPSON.

Department of the Interior,
United States Geological Survey,
Topographic Branch,
Washington, D. C., July 1, 1890.

Sir: I have the honor to submit the following report of the work of the Topographic Branch of the Irrigation Survey during the fiscal year ending June 30, 1890.

TIME AND LOCATION OF WORK.

The work was continued throughout the fiscal year in the States of California, Nevada, Colorado, Idaho, Montana, the Territory of New Mexico and in office at Washington, D. C., on plans approved by you.

GENERAL ORGANIZATION AND PERSONNEL.

For convenience of supervision and administrative management five divisions for the prosecution of work were organized; California and Nevada constituting the first; Colorado the second; Idaho the third; Montana the fourth, and New Mexico the fifth. The California-Nevada Division was assigned to Mr. E. M. Douglas, assisted by Messrs. A. F. Dunnington, R. H. McKee, R. H. Chapman, H. E. C. Feusier, and G. H. Verrill, as assistants in charge of parties, Mr. P. V. S. Bartlett and Mr. Paul Holman as general assistants. The Colorado Division was assigned to Mr. Willard D. Johnson, with Messrs. C. H. Fitch, John W. Hays, R. C. McKinney, A. C. Barclay, R. A. Farmer, S. P. Johnson, W. S. Post, and R. B. Marshall as assistants in charge of parties. The Idaho Division was assigned to Mr. W. T. Griswold, with Mr. E. T. Perkins, jr., as assistant in charge of a party. The Montana Division was assigned to Mr. Frank Tweedy, with Mr. Jeremiah Ahern as assistant in charge of party and Mr. Frank E. Gove as general assistant. The New Mexico Division was assigned to Mr. Arthur P. Davis, with Messrs. C. C. Bassett and J. B. Lippincott assistants in charge of parties.

In California and Nevada the organization consisted of one triangulation and four topographic parties; in Colorado of one triangulation, one plane-table control and six topographic parties; in Idaho of one triangulation and topographic and one topographic party; in Montana of one triangulation and two topographic parties; in New Mexico of one triangulation and two topographic parties.

The work of these divisions being in a sparsely settled or entirely uninhabited region, it was necessary for the parties to subsist in camps. The organization for this purpose was nearly the same in all localities. The means of transportation usually being one large four-mule wagon for camp equipage and supplies, and buck-boards or saddle animals for the persons engaged in the map work.

Usually each party employed, in addition to the regularly appointed assistants, one or two persons as traverse or rod men to assist in the field work. One cook, one teamster, and one laborer generally furnished sufficient force for camp duties.

In all divisions the work proceeded, when practicable, by atlas-sheet areas, bounded by degree, quarter or half degree lines of latitude and longitude.

These atlas sheets are named from some town or prominent natural feature within their limits and conform in scale and area to the system adopted by the Geological Survey, viz, atlas sheets when published on the scale of $\frac{1}{62500}$ to represent 15 minutes of latitude and longitude each way; when on the scale of $\frac{1}{125000}$ to represent 30, and on the scale $\frac{1}{250000}$ 1 degree.

In Colorado the boundaries of a number of the atlas sheets were determined by the outlines of the drainage basin of the Arkansas River.

The field work was done on twice the horizontal scale intended for publication, the relief being represented by contour lines having equal intervals, but differing on different sheets.

The following table shows the locality of work, scale, contour intervals, areas surveyed, and present condition of office work at the end of the fiscal year:

Locality.	Scale field work.	Contour interval.	Surveyed.	Condition of office work.
		Feet.	*Sq. miles.*	
California	1 inch to 1 mile	100	3,250	Completed.
Colorado	do	25 50 100	9,900	Four-fifths completed.
Idaho	do	50 100	1,900	Completed.
Montana	do	50 100	1,600	Do.
New Mexico	do	50 100	2,600	Do.
Nevada	do	100	1,600	Do.
Total			20,850	

DETAIL REPORT OF DIVISIONS.

CALIFORNIA-NEVADA.

The work in the California-Nevada Division as organized in my last report was in full progress on July 1, 1889. To Mr. Feusier was assigned charge of the triangulation party. To the topographic party of Mr. Dunnington was assigned the Truckee atlas sheet, an area west and north of Lake Tahoe. To Mr. McKee's party was assigned an area lying south of that surveyed by Mr. Dunnington and called from its most striking feature, a sharp granitic mountain, the Pyramid Peak sheet. To Mr. Chapman's party was assigned the quarter degree lying east of Mr. McKee's work and called from a town of the same name the Markleeville sheet. To Mr. Verrill's party was assigned the quarter degree including the Carson Valley and called from the city of that name the Carson sheet. Early in August Mr. Verrill resigned and Mr. Bartlett was placed in charge of this party during the remainder of the year.

All these parties completed their assigned work by November 15, and in addition the party under Mr. Chapman surveyed 340 square miles on what was named the Reno sheet, and Mr. Dunnington's party 380 square miles on the Sierraville sheet.

On November 15 work in the California-Nevada Division was closed, the parties disbanded, camp equipage and field material stored, and the animals placed in winter quarters. The chief of the division, with the heads of the parties and their principal assistants, were then ordered to Washington, D. C., for office work.

Topography.—The area mapped lies between longitude 109° 30′ and 110° 30′ west and latitude 38° 30′ and 40° north. It may be said to present three great natural features: The Sierra Nevada Range, the Lake Tahoe Basin, and the Carson Valley. The Sierra Nevada Range occupies the southern and western, the Tahoe Basin the central, and the Carson Valley the eastern and northern parts.

The crest of the Sierra Nevada Range stretches from southeast to northwest across the whole area surveyed, forming a sharp line between the waters flowing into the Valley of California and those flowing into the Great Interior Basin. West of the divide the slopes are gentle and below 8,000 feet in altitude, usually forest clad.

This region receives an abundant rainfall and is drained by branches of the Yuba, American, Cosumne, Mokelumne, and Stanislaus Rivers. Near the eastern edge of the Pyramid Peak and Truckee sheets and at an elevation of 5,000 feet, these streams begin to cut the canyons through which they debouch into the Valley of California, but between the heads of these canyons and the divide is a region of gentler slopes descending into narrow mountain valleys through which the streams course with but comparatively little fall.

East of the dividing ridge the mountain slopes are steeper, the precipitation less, the draining streams fewer, the mountain sides unusually bare, and grow steeper and steeper until they plunge almost precipitously down into the Carson Valley. These slopes are drained by the Truckee, Carson, and Walker Rivers, all rising near the crest and flowing through valleys near the eastern edge of the work.

Near the northwest corner of the Markleeville sheet a spur, breaking from the main range of mountains, bears more to the east than the general trend. This spur, when near the northern edge of the Carson sheet, sweeps round to the west, becomes lower, more confused and broken, and finally, just beyond the limits of the area surveyed, merges again into the main range. Between this curving spur and the main range is an oval-shaped depression called the Tahoe Basin, having the same trend as the greater range.

In its southern portion is Lake Tahoe, a body of water 21 miles in greatest length by 13 in greatest width, and having a water surface of about 190 square miles. It is surrounded on all sides by rugged mountains and high peaks; those on the west rising to 9,500 feet in altitude. The small streams draining these mountains are numerous and flow near the surface, but after the melting of the snows, decrease greatly in volume.

The outlet of the lake is by the Truckee River. This stream flows first along the axis of the Tahoe Basin, then turns sharply to the north, then more to the east, and finally, after a course of 125 miles through a succession of narrow cañons and wider valleys, empties into Pyramid Lake.

The northern portion of the Tahoe Basin is of lower altitude and less rugged than the southern and western, but yet not having, except in the extreme northwestern part of the region surveyed, any considerable areas of level lands. It is drained by the Little Truckee River and other branches of the main stream. In this region are three small lakes, Donner, Webber, and Independence, the former draining into the main Truckee, and the two latter into the Little Truckee Rivers. The only valleys are the wider openings spoken of along the main stream and its principal branch. Of these the Martis and Reno, the latter being properly the northern extension of the Truckee meadows, are the larger.

The Carson Valley occupies the northern portion of the Markleeville and the central portion of the Carson sheets. It is separated from the Tahoe Basin by a narrow range of mountains, the highest peaks of which reach an elevation of 9,000 feet. The valley itself has a length perhaps of 30 miles by 8 in width and ranges in elevation from 5,500 feet at its southern extremity to 4,500 feet at its northern. To the northward it is separated by a low divide from the Washoe Valley. This valley in turn continues northward into the Truckee Meadows or the Reno Valley of the Truckee River.

The mountains to the east of these valleys are of the characteristic Great Basin type—short detached barren ranges giving rise to no permanent streams, but eroded into numberless waterless canyons and washes.

The Sierra Nevada Range occupies the southern portion of the Markleeville sheet, its highest peaks reaching to an altitude of

10,000 feet. This area is drained by the Carson and Walker Rivers and has, at its lower altitudes, many narrow valleys through which the smaller tributaries of the draining streams wind. Its mountain forms are less rugged than those farther west and north and are often forest clad.

Forests.—A large portion of the region surveyed west of the dividing Sierra Nevada Range is forest clad. On the Pyramid Peak sheet, at least three-fourths of the area is covered by timber valuable for milling purposes, the remaining area, except in the valleys, having usually a bare, rocky surface devoid of all vegetable growth. The principal varieties are firs at the higher altitudes, and pines on the lower slopes. On the Truckee sheet one-half of the area is covered by milling timber, principally firs. This is especially the case around the western shore of Lake Tahoe, in the northern portion of the Tahoe Basin, and along the Truckee River. Perhaps one-third of the area of this sheet is covered by timber fit only for firewood and domestic purposes, the remainder being bare granite mountains nearly destitute of any vegetation whatever.

In the western and southern portions of the Markleeville sheet are many detached areas, making one-half the whole, of timber fit for milling purposes, but it is usually not so dense nor in so large bodies as on the Pyramid Peak sheet. The mountains in the eastern part of the Markleeville sheet are usually sparsely covered by a growth of cedar and piñon pines, fit only for fuel and other domestic purposes.

The range directly east of Lake Tahoe on the Carson sheet was formerly covered by a dense growth of pine and fir, but this has been cut off for the use of the inhabitants of the country, and now there remains little else than a scrubby growth, serviceable for domestic uses only. Most of the mountains in the eastern part of this sheet are completely bare of timber, either originally so or cut off for the use of the mining camps of this region.

On that part of the Sierraville sheet surveyed small bodies of milling timber are found, but the greater portion of the area has only a scrubby growth.

No milling timber of any extent is found in that portion of the Reno sheet surveyed.

Throughout the whole area mapped the valleys are usually bare of forest growth. This is especially the case in the larger, such as the Carson, Washoe, and Truckee.

Reservoir sites.—Sixty-six possible reservoir sites were reported by the topographers of this division, not counting the grandest of all, Lake Tahoe. Eleven of them are already occupied, being natural lakes across whose outlets dams have been constructed, raising the water surface; but all these could be very much increased in capacity by larger works.

In area these reservoirs range from 160 acres to several square miles, and are situated at elevations varying from near the crest of the main range to the lowest altitudes represented on the maps. They are usually in the valleys of the streams by which they would be filled, and would be formed by dams built across their channels. In but few cases have reservoirs been reported where it would be practicable to construct settling ponds and then conduct the waters to storage reservoirs. The notes made of these sites seem to be explicit enough to furnish sufficient data to determine their relative importance.

The following table shows the number of reservoirs now occupied, the number of existing lakes now occupied or which could be converted into reservoirs, the additional number which could be constructed, and the total number of reservoirs reported on each sheet:

Reservoirs.

Name of sheet.	Reservoirs occupied.	Natural lake reservoirs.	Could be constructed.	Total reported.
Pyramid Peak	3	7	10	17
Markleeville	4	4	24	28
Carson	2	2	8	10
Truckee	3	3	8	11
Total	12	16	50	66

Classifying these reservoirs by the drainage basins in which they are situated, there are in the—

Walker River Basin	5
Carson River Basin	24
Truckee River Basin	12
Mokelumne River Basin	13
American River Basin	12
Yuba River Basin	1

The last three rivers are on the west side of the Sierra Nevada Range.

Irrigable lands.—No considerable bodies of irrigable lands are reported within the limits of the area surveyed except upon the Markleeville and Carson sheets, though small areas occur upon the Truckee sheet in the valley of the Truckee River.

The work on the Sierraville and Reno sheets has not progressed sufficiently to determine the location of the irrigable land, though large bodies are known to exist. The limit in altitude for successful cultivation of the soil in this region seems to be about 6,000 feet. In favorable locations it may be higher.

The irrigable lands reported on Walker River lie at an altitude of about 5,000 feet; in the Carson, Washoe, and Truckee meadow valleys they range from 4,500 to 5,600 feet. The soil of all these valleys is reported fertile and productive wherever water is applied and the irrigable lands far in excess of any probable supply of water.

COLORADO.

At the beginning of the fiscal year the work of this Division, under Mr. Willard D. Johnson, was organized into one triangulation, one plane-table control, and six topographic parties. Mr. Hays was given charge of the triangulation party, Mr. Barclay of the plane-table control, and Messrs. Fitch, Bien, McKinney, S. P. Johnson, Farmer, and Post were given charge of topographic parties.

Mr. Hays was directed to extend the triangulation from located Coast Survey points southeast through the Nepesta, Catlin, Las Animas, Higbee, and Twin Butte sheets.

Mr. Barclay was directed to extend the plane-table control eastward on a line south of Mr. Hays's triangulation and through the Apishapa, Timpas, Higbee, and Springfield sheets.

To the topographic party in charge of Mr. Bien, assisted by Mr. Corse, was assigned the work on the Leadville and Buena Vista sheets.

To Mr. S. P. Johnson was assigned the work on the Trinidad and the Culebra sheets.

To Mr. Fitch, assisted by Mr. Fuller, was assigned work on the Huerfano Park and the southern part of the Cañon City sheets.

To Mr. McKinney, assisted by Mr. Kendall, was assigned first the completion of unfinished work on the Twin Butte and Springfield sheets and after completing this the northern part of the Cañon City sheet.

To Mr. Post, assisted by Mr. Marshall, were assigned the Pike's Peak, Colorado Springs, Big Spring, and Suffolk sheets.

To Mr. Farmer was assigned the completion of the work on the El Moro and Trinidad sheets.

Later in the season it was found necessary to change the allotment of areas to these parties and to suspend the work of Mr. Hays's triangulation and assign him to the completion of the topography of the Arroyo and Sanborn sheets. It was also found necessary to change the assignment of personnel to a considerable extent. The field organization of these parties varied with the character and difficulty of the work assigned.

The work assigned to this division was completed about November 1, when the parties were directed to proceed to Pueblo, Colorado, and were there disbanded. The camp equipage and field material were securely packed and stored and the animals placed in winter quarters near Pueblo.

Mr. Johnson, with his assistants, was then directed to proceed to Washington, D. C., for office work.

Topography.—The area surveyed by the Colorado Division lies in the drainage basin of the Arkansas River and entirely within the limits of the State of Colorado.

The topography varies from rough, rugged mountains, through broken foothills, to level plains, and naturally divides into two distinct regions, presenting two distinct types of geographic forms—mountains and plains—each about equal in area. The dividing line is sharp. Some atlas sheets present both forms, with all the variations through which the one passes to the other. The most prominent feature is the Arkansas Valley, stretching, an ever widening area, from the sources of the river in the northern part of the Leadville sheet, through both mountain and plains area, to the eastern line of the work.

The Leadville, Buena Vista, Arkansas Hills, Pike's Peak, Rito Alto, Canyon City, Huerfano Park, Culebra, and Trinidad atlas sheets are all in the mountain region. The Colorado Springs, Pueblo, Walsenburg, and El Moro sheets are on the dividing line, and present the topography of both mountains and plains. The Twin Buttes, Springfield, Suffolk, and Sanborn sheets are wholly in the plains area.

In the mountain region the great western rim of the Arkansas Valley is formed by three of the highest ranges in Colorado, the Sawatch, Sangre del Cristo, and Culebra, each having summits reaching over 14,000 feet in altitude, and scarcely a pass is below 10,000. These ranges stretch in an irregular segment of a great circle from Tennessee Pass on the north through the Leadville, Buena Vista, Rito Alto, and Culebra sheets to Boundary Mountain, just below the dividing line between Colorado and New Mexico on the south.

The northern rim of the valley is less imposing by contrast with its western rival, and is less regular in its course.

Having the same point of origin as the western rim (Tennessee Pass), it first curves northward round the head of the East Fork of the Arkansas River, then down the crest of the Park Range round the Arkansas Hills by the Chalcedony Buttes to the Rampart Range, and out onto the plains divide between the Arkansas and the South Platte Rivers, having crossed the Leadville, Buena Vista, Arkansas Hills, and Pike's Peak sheets.

The eastern rim is formed by the Rampart Range, the irregular mass of Pikes Peak, standing like a sentinel, the Wet Mountain, or Greenhorn Range, and the Spanish Peaks, all rising directly from the plains, and forming a wall perhaps more distinct and imposing than either of the others. The area included by these walls is in the shape of an irregular triangle, its apex toward the west, its base opening toward the east. It is almost bisected by the river. On the western side of the valley the mountains rise higher, their slopes steeper, the draining streams are more numerous and have cut deeper channels than on the eastern, where the country presents more the broken character of the foothills.

The sources of the Arkansas River are among mountains rising to an altitude of 14,000 feet. At Canyon City, where it leaves the mountain region, its bed has descended to an altitude of 4,400 feet. Its upper course is in a narrow valley lying—except at its lower extremity—at too great an altitude for successful cultivation. Its lower course is through close canyons having walls sometimes rising nearly 3,000 feet above the water's edge. The whole mountain region is one of great precipitation, and is the principal, almost the only, source of the water which the river bears to the plains.

The Colorado Springs, Pueblo, Walsenburg, and El Moro sheets present a varied topography. The eastern part of the Colorado Springs sheet is of the plains type, but the western part is mountainous, rising 14,140 feet to the summit of Pike's Peak. In the southern part of this sheet the mesa form of topography begins to show. The most of the Pueblo sheet, as well as the Walsenburg and El Moro sheets, is of this character. The Springfield, Twin Buttes, Sanborn, and Suffolk sheets are entirely within the plains region and present but little relief, and that of the low rolling plains type.

Forests.—The area of forest growth containing merchantable timber or that fit for lumber is found entirely within the mountain region, and occurs in bodies of considerable extent on the slopes of all the higher ranges included in the Leadville, Buena Vista, Rito Alto Arkansas Hills, Pike's Peak, Colorado Springs, Canyon City, Culebra, and Trinidad sheets. These areas have all been carefully noted by the topographers, and comprise about 25 per cent of the whole. The forest growth is principally of pines and spruces, not covering the ground densely, as in a more humid region, but scattered. Considerable areas of a forest growth, largely composed of cedar and pinon pine, and available only for firewood, fencing, and other farming purposes, occur throughout the mountain region, usually at lower altitudes than the merchantable timber, and extends partly over the areas embraced by the Pueblo, Walsenburg and El Moro sheets. About 20 per cent of the area is thus covered. The immediate valleys of the streams in both mountain and plains areas often have a scattered growth of cottonwoods.

Reservoir sites.—One hundred and ten possible reservoir sites are reported by the topographers of this division, including those on sheets where the field work was done in 1888 but the office work in 1889. Six of these are existing lakes.

In area these reservoirs range from 40 acres to several square miles, and are situated at elevations varying from 4,500 to 11,000 feet. They are usually situated in the valleys of the streams by which they would be filled, and would be formed by dams built at eligible locations across the channels.

Quite a number of cases are reported where settling reservoirs might be first constructed, and the waters conducted to other reservoirs having smaller drainage area and where the danger of silting up would be less, but, as in the case of the California-Nevada Division, the topographers probably failed to note many of these auxiliary sites. The field notes made by the topographers will furnish sufficient data to judge of the relative importance of the sites reported.

Few reservoirs have been constructed throughout this region, the waters of the streams used for irrigation having simply been turned from their channels by diverting dams.

In the plains region quite a number of sites are reported which would be filled by storm-waters only.

The following table shows the number of possible sites reported on each sheet:

Reservoir sites reported.

Name of sheet.	No.	Name of sheet.	No.
Leadville	14	Saguache	1
Buena Vista	6	El Moro	4
Pike's Peak	7	Apishapa	5
Colorado Springs	2	Nepesta	1
Pueblo	10	Catlin	4
Canyon City	9	Timpas	1
Huerfano Park	7	Higbee	10
Walsenburg	4	Las Animas	5
Trinidad	13		
Culebra	7	Total	110

Classifying these reservoir sites by the drainage basins in which they are situated, and counting all the small creeks having but one site each and flowing directly into the Arkansas. and also reservoirs which would be filled by canals from the Arkansas as of the Arkansas drainage, there are in the—

South Platte River Basin	4
Grand River Basin	2
Arkansas Basin	39
Fountain Basin	2
St. Charles Basin	3
Huerfano Basin	6
Sangre del Christo Basin	2
Cuchara Basin	3
Greenhorn Basin	3
Purgatoire Basin	28
Apishapa Basin	9
Filled by storm waters	9
Total	110

Irrigable lands.—No considerable bodies of lands susceptible of successful cultivation were noted in the mountain region except in the immediate neighborhood of steams in the lower portion of the Arkansas Basin.

In the plains area large bodies are reported, the amount being far in excess of the water supply. The general topographic conditions and probable source of water supply were noted in my last report.

IDAHO.

As no topographic work had ever been prosecuted in Idaho, Mr. Griswold, in charge, was directed to first measure a base line near Boise City to form a linear basis for his operations.

This work was successfully accomplished in July. The location chosen for the line was on the mesa near the railroad station south of Boisé City. The ground selected was first cleared of sagebrush and all undergrowth, stakes were driven at regular intervals of 100 feet, their tops carefully leveled, and the distance measured both forward and backward by a steel tape under a constant strain of 20 pounds, the temperature being noted at every stretch of the tape and the contacts accurately made.

These measurements, after being adjusted for error in length of tape, temperatue, and catenary curve, and reduced to sea level, give a result of 25,066.3 feet for the first measurement and 25,065·9 feet for the second. The mean of this, or 25,066·1 feet, was adopted for the correct length of the base, a system of triangles expanded from the base and extended over the whole region surveyed between latitudes 43° and 43° 30′ north and longitudes 115° and 116° west, and comprising two atlas-sheet areas, which were named Mountain Home and Camas Prairie sheets. Owing to certain topographic peculiarities it was found impracticable to assign complete atlas sheets to either party, so the triangulation and topography were carried on jointly by both Mr. Perkins and Mr. Griswold.

The field work proper of the survey of the area assigned was completed November 1. The parties then proceeded to Boisé City, were disbanded, their camp equipage and field material stored at that place, and the animals placed in winter quarters.

This duty performed, Mr. Perkins was ordered to proceed to Washington, D. C., for office work, but Mr. Griswold was instructed to remain and assist in the determination of the latitude, longitude, and azimuth of the base line. For this work, Prof. R. S. Woodward, chief geographer of the Survey, has been detailed. He was assisted on the determination of the longitude by Prof. H. S. Pritchett, of the Washington University, St. Louis. Through the courtesy of the Western Union Telegraph Company the use of their line between Boisé City and Washington University, St. Louis, was obtained for the exchange of time signals. Prof. Woodward arrived at Boisé City on November 10 and immediately proceeded to work.

Owing to unfavorable weather either at one or the other end of the line exchanges were possible only on three nights between November 12 and December 1. Good results were, however, obtained, the final determination of the longitude being 116° 13′ 04.04″, with a small probable error. The latitude of Boisé City was determined by the method of zenith distances, observations being made on twenty-six pairs of stars on three different nights, giving a resulting latitude of 43° 35′ 57.98″, with a probable error of 16″. The azimuth of the base line was determined at the same time, giving a result west-east base of 307° 27′ 17.16″ with a small probable error.

Upon the completion of the astronomical observations, Prof. Woodward proceeded to Cisco, Texas, for the purpose of making a latitude and longitude determination at that place, and Mr. Griswold was directed to proceed to Washington to take charge of the office work.

Topography.—The region surveyed lies wholly within the drainage basin of the Snake River, and presents topography of both mountains and plains type. The southern part of the Camas Prairie and the southwestern part of the Mountain Home sheet areas are on the Snake River plain, while the north and east parts of these sheets are mountainous, the higher peaks rising to an altitude of 7,500 feet. These mountains spring abruptly from the plain, are arid and barren, and drained by the Boisé River and smaller tributaries of the Snake, the latter generally cutting into the flanks of the mountains in deep, narrow, rock-walled canyons, dry except during the winter months.

The most striking features of the mountain area are the Boisé River Canyon and the high circle-like valleys called Smith, Little Camas, and Camas Prairies. The Boisé River flows in a semicircle through the northern part of each sheet, and has vertical walls sometimes rising nearly 2,000 feet above the water. The valley is narrow, but the fall of the river is gentle. The "prairies" lie at an elevation of about 5,000 feet, an altitude too great in this latitude for successful cultivation. The plains region presents a generally level surface, gently sloping to the southwest and cut by shallow lines of drainage.

Forests.—The forest area of this region is confined entirely to the mountains. Only two small bodies of merchantable timber are found on the area of both atlas sheets, but perhaps 10 per cent of the area is covered by a shrubby growth of cedar and pine, fit only for firewood and domestic purposes. Hardly a single tree grows on the plains, the exception being here and there a single cottonwood; but wherever the rock is covered by a sufficient depth of soil these plains are covered by an abundant growth of sagebrush.

Reservoir sites.—Only two reservoir sites are reported by the topographers within the area surveyed, and these are small, the narrow canyons with steep grades furnishing but few opportunities for the storage of water.

Irrigable lands.—No irrigable lands are reported in the mountains, though nearly the whole of the plains area is susceptible of cultivation if a supply of water can be obtained.

MONTANA.

The organization under Mr. Frank Tweedy at work in Montana at the beginning of the fiscal year was composed of one triangulation and topographic party under Mr. Tweedy and one topographic party under Mr. Ahern.

The region assigned this division was that lying between latitude 43° 30′ and 46° north and longitude 109° and 110° west. The two atlas sheets which include this area were named respectively Big Timber and Stillwater, from the most prominent towns within their limits.

In addition to the work on these atlas sheets, Mr. Tweedy organized a party, placing it under Mr. Gove, for the revision and survey, in more detail, of the shores of the Yellowstone Lake from the water line to an elevation of 8,000 feet. As it was impracticable to use animals for this work, two boats were purchased in Chicago, transported to the lake, and used by Mr. Gove to convey his party and supplies to points necessary in the prosecution of his work. By November 15 all parties had completed the areas assigned them, and they were directed to proceed to Livingston, Montana, where they were disbanded, the camp equipage stored, and the animals placed in winter quarters.

Mr. Tweedy, with his assistants, Mr. Ahern and Mr. Gove, was then directed to proceed to Washington, D. C., for office work.

Topography.—The general character of the area surveyed is that of an eroded mesa, with the canyon of the Yellowstone River cutting nearly through its center from east to west, though the extreme southwestern portion of the Big Timber sheet presents a more mountainous character.

The Yellowstone River enters the Big Timber sheet at its western boundary at an altitude of 3,900 feet and leaves at the eastern limit of the Stillwater sheet at an altitude of 3,900 feet. The canyon is narrow, averaging hardly 2 miles in width, and its precipitous walls rise abruptly from its level floor to the flat surface of the mesa above. North of the river the country is drained by the Otter, Sweet Grass, and Beaver Creeks, small tributaries to the Yellowstone.

The area south of the Yellowstone is drained by the Boulder, Stillwater, and Bridger Creeks, which enter the larger valley through narrow, vertically walled canyons, smaller than but similar to the canyon of the Yellowstone. The northeastern corner of the Stillwater sheet is within the drainage basin of the Musselshell River and presents gentler slopes than the area drained by the tributaries of the Yellowstone.

Forests.—The immediate valleys of the Yellowstone and its larger tributaries have a park-like appearance, due to the frequent occurrence of groves of cottonwood. South of the river 50 per cent of the mesa on both sheets is covered by a growth of small pines, spruces, and firs, sometimes furnishing trees of sufficient size to be used for lumber. The lake basin in the watershed of the Musselshell, in the northeastern part of the Stillwater, is almost bare of forest growth.

Reservoir sites.—But two reservoir sites are reported by the topographers of this division; both are on the Big Timber sheet, one being on Otter Creek, and the other on Sweet Grass Creek.

Irrigable lands.—The irrigable lands reported by the topographers of this division are all in the immediate valleys of the rivers and the Lake Basin on the drainage of the Musselshell. Along the Yellowstone River the area of irrigable lands averages perhaps 2 miles in width, and the water can be taken from the river by simply constructing diverting dams, and can be conducted almost to the walls of the valley, so gentle and regular is the slope. In the Lake Basin the lands appear far in excess of the probable water supply.

NEW MEXICO.

The area assigned to the division of New Mexico was that lying between latitudes 35° 30′ and 36° north and longitude 105° 30′ and 106° west, comprising three atlas sheets, which were named respectively, from the larger towns within their limits, the Sante Fé, Las Vegas, and Watrous sheets. The organization under Mr. Arthur P. Davis consisted of one triangulation party under his own immediate charge, and two topographic parties under charge of Messrs. Bassett and Lippincott. This organization was continued till the close of the field season.

These parties had completed their outfit and were ready to take the field at the beginning of the fiscal year, and they prosecuted their work until November 15, when the area assigned them was finished, the parties disbanded, the camp equipage stored at Las Vegas, and the animals placed in winter quarters.

Mr. Davis, with his assistants, was then directed to proceed to Washington, D. C., for office work.

In May, 1890, it was decided to determine the latitude and longitude of some point in Texas for the purpose of locating the place where the one hundred and fifth meridian of west longitude crosses the Rio Grande River. Prof. R. S. Woodward, chief geographer of the survey, was instructed to take charge of this work, and Mr. Arthur P. Davis was detailed to assist him.

For the purpose of determining longitude it was decided to exchange time signals with St. Louis, and the services of Prof. H. S. Pritchett of the Washington University were procured to conduct the necessary observations and exchanges at that place.

Sierra Blanca, a small town at the junction of the Texas and Pacific and the Southern Pacific Railroads, was selected as being the place nearest the meridian where the necessary telegraphic facilities could be obtained, and the Western Union Telegraph Company, with its usual courtesy, placed its line at our disposal for the work.

Prof. Woodward commenced operations at Sierra Blanca May 16, and by May 29 had completed the necessary observations. He was able to exchange time signals with Prof. Pritchett at St. Louis on four nights, giving to the observation pier at Sierra Blanca the resulting longitude of 105° 21′ 24·96″ west. During this time Prof. Woodward also made latitude observations by the method of zenith distances on 28 different pairs of stars for two nights, giving as the latitude of the pier 43° 35′ 57·98″ north. The astronomic observations being concluded, Prof. Woodward returned to Washington, leaving Mr. Davis to locate the position of the one hundred and fifth meridian.

To accomplish this, Mr. Davis first measured a short base line, connected it with the pier of the astronomic station, and then expanded a series of triangles to the eastward, computing his positions as he proceeded until the meridian was reached. The point thus determined was indicated by permanent marks and an azimuth line laid out, which was extended by the local authorities south to the Rio Grande River.

Upon the completion of this work Mr. Davis was directed to return to Washington, D. C.

Topography.—The topography of the area surveyed by the New Mexico division is of both the mountain and plains type, nearly the whole of the Santa Fé and the west half the Las Vegas sheets being of the former, the east half of the Las Vegas and all of the Watrous sheets of the latter.

The mountain area, which is really the southern continuation of the Culebra Range of Colorado, though known locally as the Santa Fé and Vegas Mountains, is drained by the tributaries of the Rio Grande, Pecos, and Canadian Rivers. It presents the general features of two short ranges united at the northern edge of the Santa Fé and Las Vegas sheets, terminating separately near their southern boundary and inclosing a segment of an oval basin drained by the Pecos River.

The western rim of the Pecos basin, or the Santa Fé Mountains, rises to an altitude of over 12,000 feet. Its slopes are comparatively smooth and gentle, descending from the summits into the valley of the Rio Grande River on the west, and on the east into the valley of the Pecos. The southern extremity of this rim is more broken, often presenting mesa-like forms. The draining streams of the western slope are all small, flow in valleys rather than canyons, and furnish but little water except during the melting of the snows. The streams of the eastern slope flowing into the Pecos River are of the same character but have a more permanent flow of water.

The eastern rim of the basin, or the Vegas Mountains, though rising only to an altitude of a little over 10,000 feet, is more broken and presents somewhat the character of a double range, with draining streams having their sources in the higher interior range and cutting through the front or outer one in narrow canyons. This is an especial feature of the northern portion, where the branches of the Mora River have cut the front range into a maze of mesa-like forms. The plains area presents the general features of a level region bearing mesas and crater-like masses of volcanic rock on its surface. The draining streams in the eastern part of the Watrous sheet have cut narrow canyons with comparatively straight vertical walls.

Forests.—A large part of the mountain area on the Santa Fé sheet is covered by a forest growth suitable for milling or lumber purposes, pine and fir being the principal varieties.

This growth is not dense, but thinly scattered over nearly the whole region between the altitude of 8,000 feet and the timber line, which is here about 11,000 feet.

Below 8,000 feet the hills and mesas are usually scantily covered by a growth of cedar and piñon pine, fit only for firewood and other domestic uses.

The plains area is destitute of trees, except a few cottonwoods along the immediate valleys of the streams.

Reservoir sites.—Eight possible reservoir sites of considerable area were reported by the topographers within the limits surveyed. Two of these are in the plains region on the Watrous sheet, four in the foothills on the Las Vegas sheet, and two in the mountains on the Santa Fé sheet. Four are in the drainage basin of the Mora River and furnish sufficient capacity to store all the waters of that stream during the entire year. The others are on smaller streams and have but limited catchment areas.

All over the plains region are numerous depressions that are usually converted into ponds during the winter months, but are dry in summer. It often happens that a number of these could be easily connected by canals, and so furnish storage for considerable bodies of water. The contour interval of the maps is too great to show more than the principal of these depressions.

Irrigable lands.—Within the mountain region considerable areas of irrigable lands are reported along the valley of the Mora and Pecos Rivers. At least 75 per cent of the area of the plains region is reported good fertile land, lying at such altitudes and slopes as permit irrigation, the only question being the limited water supply.

SUMMARY.

The following table shows the locality of each atlas sheet, the scale upon which the final drawing was made, the intended scale for publication, and the contour intervals:

State or Territory.	Name.	Scale of drawing.	Public scale.	Contour interval
				Feet.
California	Truckee	1 m = 1 inch.	1:12500	100
Nevada.	Pyramid Peak	do	1:12500	100
	Markleeville.	do	1:12550	100
	Carson	do	1:12500	100
	Sierraville	do	1:12500	100
	Reno	do	1:12500	100
Colorado	Leadville.	do	1:12500	25, 50, and 100
	Buena Vista	do	1:12500	25, 50, and 100
	Arkansas Hills	do	1:12500	25, 50, and 100
	Rito Alto	do	1:12500	25, 50, and 100
	Colorado Springs	do	1:12500	25, 50, and 100
	Pueblo	do	1:12500	25, 50, and 100
	Canyon City	do	1:12500	25, 50, and 100
	Huerfano Park	do	1:12500	25, 50, and 100
	Walsenburg	do	1:12500	25, 50, and 100
	Trinidad	do	1:12500	25, 50, and 100
	Culebra	do	1:12500	25, 50, and 100
	Pike's Peak	do	1:12500	25, 50. and 100
	El Moro	do	1:12500	100
	Higbee	do	1:12500	25 and 50
	Timpas	do	1:12500	25 and 50
	Saguache	do	1:12500	50
	Suffolk	do	1:12500	25
	Sanborn	do	1:12500	25
	Catlin	do	1:12500	25
	Springfield	do	1:12500	25
	Las Animas	do	1:12500	25
	Nepesta	do	1:12500	25
	Arroya	do	1:12500	25
	Twin Butte	do	1:12500	25
	Apishapa	do	1:12500	25
Idaho	Mountain Home	do	1:12500	50
	Camas Prairie	do	1:12500	100
Montana	Big Timber	do	1:12500	50
	Stillwater	do	1:12500	50
New Mexico	Santa Fé	do	1:12500	100
	Las Vegas	do	1:12500	50
	Watrous	do	1:12500	50
	Las Cruces	do	1:12500	50
	La Union	do	1:12500	50

RESERVOIR SITES.

The following table shows the number of possible reservoir sites reported by each division, the atlas sheet area, and drainage basin within which each is situated:

Division.	Atlas sheet area.	Number sites.	In drainage basin of—	Number sites.
California	Pyramid Peak	17	Walker River, Nev	5
Nevada	Markleeville	28	Carson River, Nev	24
	Carson	10	Truckee River, Cal	12
	Truckee	11	Mokelumne River, Cal	13
			American River, Cal	12
			Yuba River, Cal	1
Colorado	Leadville	14		
	Buena Vista	6		
	Pike's Peak	7	South Platte River	4
	Colorado Springs	2	Grand River	2
	Pueblo	10	Arkansas River	39
	Canyon City	9	Fountain	2
	Huerfano Park	7	St. Charles	3
	Walsenburg	4	Huerfano	6
	Trinidad	13	Sangre del Cristo	2
	Culebra	7	Cuchara	3
	Saguache	1	Greenhorn	3
	El Moro	4	Purgatoire	28
	Apishapa	5	Apishapa	9
	Nepesta	1	Filled by storm waters	9
	Catlin	4		
	Timpas	1		
	Higbee	10		
	Las Animas	5		
Idaho	Mountain Home	2	Lucky Tom Creek	2
Montana	Big Timber	2	Otter Creek	1
			Sweet Grass Creek	1
New Mexico	Santa Fé	2	Santa Fé River	1
	Las Vegas	4	Mora	4
	Watrous	2	Guttenas	2
	Las Cruces	....	Escondido	1
	Total	188		

FIELD METHODS.

CHARACTER OF THE WORK.

The character of work deemed essential for the requirements of the maps of the Irrigation Survey was set forth in my last annual report. It embraced the correct determination of the drainage areas of all streams and the correct representation of all hypsometric features by means of contour lines representing equal vertical intervals and showing absolute and relative altitude as well as the slope of all surfaces. Certain features of culture were also added, such as the correct location of towns, wagon-roads, railroads, and the larger water-ditches.

No attempt has been made to make these maps cadastral in character, though where the scale is sufficiently large they are admirably adapted to serve as a base for such maps. Neither have the maps been made with the expectation that they would give the engineer all the details necessary for the estimates for the construction of his works. To make maps with that degree of accuracy would be to increase their cost to a prohibitory amount. Nor does the constructing engineer require such maps except for a narrow area along the immediate line of his work.

But the irrigation engineer does require, for any systematic or comprehensive investigation of the problems of irrigation, maps which in their construction shall show the areas of the drainage basins of the steams, the slopes of the declivities of their watersheds, the location of all possible reservoir sites, the practicable routes for canal lines, locations for their headworks, and the situation of irrigable lands. It is hardly conceivable that an investigation worthy of the claim to be scientific and comprehensive, or worthy of the patronage of a great Government, could be made without these data.

Experience has shown that the maps constructed by the topographic branch of the Irrigation Survey do furnish just such information, and the fact that they are the very first material to be called for by the irrigation engineer is ample proof that their value is appreciated.

The field work of all the divisions was conducted essentially by the same methods, though the manner of its execution varied with the local conditions. It consisted in the determination of linear distances, or horizontal control; of altitudes, or vertical control; and of the conventional representation of topographic forms after the methods explained in my last annual report.

In the California-Nevada and Colorado divisions the horizontal control was still derived from the primary stations of the transcontinental triangulation of the Coast and Geodetic Survey; in the Idaho division, from the base line measured the present season near Boisé City; in the Montana division, from the stations derived from the base measured by the U. S. Geological Survey near Bozeman; and in the New Mexico division, from stations derived from a base line measured by the U. S. Geological Survey near Fort Wingate.

Plane-table traverses, using the compass for directions and some form of odometer for distances, were extensively used in addition to regular triangulation and plane-table work from stations. All public roads, streams, cliff-edges, valleys, and frequent lines across the country were thus traversed and the whole area surveyed covered by a network of accurately determined and adjusted distances.

VERTICAL CONTROL.

The altitudes of points in the area surveyed were determined by horizontal or angular leveling or by the use of aneroid or mercurial barometers. In all cases a number of bench-marks were accurately located on each atlas-sheet area by leveling, and to these were referred all other level or barometric observations, thus reducing the vertical element of the work to a few accurately determined points.

REPRESENTATION.

The representation of topographic forms was obtained by plane-table sketching from all the stations occupied either in traverse or area work. This sketching was done in contours having a prescribed vertical interval. In some cases the topographer performed his computations in the field and located the contours with accuracy. In other cases they were approximately located and their true position determined by the office reduction of the observation.

OFFICE WORK.

Immediately on the disbandment of the field parties all persons belonging to the permanent force were directed to report at the office of the Geological Survey in Washington, District of Columbia, for office work. This force was organized by divisions, as in the field. Each person who had there had charge of a division retained it in the office work, thus securing in the construction of the maps all knowledge gained by personal observation in the field.

Before the close of the fiscal year maps of the areas surveyed by the California-Nevada, Idaho, Montana, and New Mexico divisions were completed ready for the engraver, and in addition the New Mexico division completed the office work of the La Union and Las Cruces sheets, situated on the Lower Rio Grande, the field survey of these atlas-sheet areas having been made the previous year.

The Colorado division had all the office work of what was practically two field seasons to do. By the close of the year, however, maps of all the full atlas-sheet areas in which the field survey was entirely made were completed ready for the engraver.

Upon the completion of the office work the permanent force of all the divisions, with the exception of the Montana division and Messrs. Bien and McKinney of the Colorado division, were directed to proceed to the field and organize parties for work. This duty is now being performed, except in Colorado, where the force was directed to suspend organization temporarily and make the final drawing of the fractional portions of those atlas-sheet areas of which the field work was completed.

I herewith transmit a map showing areas surveyed by the different divisions during the year.

DISBURSEMENTS OF MONEY.

The disbursement of money allotted to this branch was under charge of Mr. H. C. Rizer during the entire fiscal year. His duties were performed at the field office established at Topeka, Kansas, and in Washington, District of Columbia.

I am, very respectfully, your obedient servant,

A. H. THOMPSON,
Geographer.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk U. S. Geological Survey, during the first quarter of 1890.

[Appropriation for U. S. Geological Survey—Irrigation.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889				
July 31	17	Pay roll of employés	Services, July, 1889	$1,431.29
31	20	Richard J. Hinton	....do	150.00
Aug. 6	31	J. S. Topham	Material	9.00
21	39	Pennsylvania R. R	Transportation of assistants	29.00
31	64	Richard J. Hinton	Services, August, 1889	150.00
31	73	Pay roll of employés	....do	1,259.07
Sept. 12	86	Denver and Rio Grande R. R	Transportation of assistants	103.70
12	87	Colorado Midland R. R	....do	7.05
12	90	Northern Pacific R. R.	....do	56.30
13	94	Baltimore and Ohio R. R	....do	29.50
30	107	Northern Pacific R. R.	....do	192.60
30	110	Pennsylvania R. R	....do	29.00
30	113	C. A. Kenaston	Pay, August and September, 1889	260.00
30	119	Richard J. Hinton	Pay, September, 1889	150.00
30	127	Pay roll of employés	....do	1,196.55
30	135	Utah Central Ry	Transportation of assistants	9.70
		Total		5,062.76

Abstract of disbursements, made by Mark B. Kerr, disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

[Irrigation—Immediately available, 1889–'90.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount
1889.				
June 4	1	Pay roll	Services, May, 1889	$235.20
4	2	....do	....do	604.90
4	3	....do	....do	409.20
4	4	....do	....do	117.10
4	5	A. J. Newman	Two horses	275.00
4	6	J. & J. Ragcraft	....do	250.00
4	7	Pay roll	Services, May, 1889	281.40
4	8	E. M. Douglas	Field expenses	48.21
4	9	....do	....do	87.05
4	10	R. H. Chapman	....do	45.60
4	11	....do	....do	6.10
4	12	H. M. Wilson	Traveling expenses	141.75
6	13	John W. Hays	Field expenses	193.26
6	14	....do	....do	283.53
6	15	....do	....do	36.46
6	16	Pay roll	Services, May, 1889	158.38
6	17	H. M. Wilson	Field expenses	54.00
6	18	G. E. Verrill	....do	28.75
6	19	James Meadows	Services, May, 1889	15.00
6	20	Ah Lawk	....do	12.00
6	21	G. F. Allen	....do	4.25
7	22	Nephi Johnson	Services, April, 1889	21.00
7	23	Isaac N. Hager	Pasturage	52.50
7	24	W. H. Hyde	Wagons	152.50
7	25	H. C. Daugberg	Pasturage, etc	99.50
7	26	Thomas Clements	Storage	10.00
7	27	A. T. Kyle, jr	Pasturage	75.40
7	28	Jacob Klein	Storage, etc	10.00
7	29	Charles Smith	Board and lodging	47.50
7	30	P. V. S. Bartlett	Field expenses	13.75
7	31	G. T. Davis	Field subsistence	147.08
7	32	P. H. Peterson	Forage	68.77
7	33	E. B. Rail	Field supplies	37.05
7	34	D. G. Kitzmeyer	Repairs	29.55
7	35	W. S. Montgomery	Pasturage	55.87
7	36	R. H. Chapman	Traveling expenses	23.50
7	37	J. B. Kendall	....do	15.60
7	38	J. H. Boring	Services, April, 1889	8.33
7	39	W. T. Griswold	Traveling expenses	58.50
7	40	R. Henry Phillips	....do	16.05

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

[Irrigation—Immediately available, 1889-'90.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 7	41	Stuart & McNair	Field subsistence	25.26
7	42	McCutchen, Payne & Co	Field forage	15.32
7	43	Sparks Bros	Public animals	1,501.00
7	44	....do	....do	1,507.00
7	45	R. C. McKinney	Traveling expenses	16.50
6	46	R. Henry Phillips	Field expenses	44.37
7	47	J. H. Boring	....do	16.75
7	48	W. T. Griswold	....do	113.14
8	49	G. E. Verrill	....do	31.28
8	50	W. D. Tarreyson	Field material	75.75
8	51	W. S. Montgomery	Two horses	260.00
8	52	R. S. Swift	....do	300.00
8	53	H. M. Wilson	Field expenses	28.57
8	54	E. M. Douglas	....do	54.34
12	55	Frank Tweedy	....do	167.00
12	56	....do	Traveling expenses	54.60
12	57	Morris Bien	....do	19.00
12	58	R. C. McKinney	Field expenses	110.18
12	59	L. G. Stevenson	Traveling expenses	16.00
12	60	R. B. Marshall	....do	39.15
12	61	Amos Scott	Services, May, 1889	75.00
12	62	Charles E. Ludlow	....do	17.41
12	63	P. W. J. Pefley	Field material	76.00
12	64	Peter Soma	... do	170.00
17	65	Willard D. Johnson	Field expenses	232.97
29	66	Mark B. Kerr	Traveling expenses	149.55
29	67	....do	Services, June, 1889	148.30
30	68	A. H. Thompson	....do	247.25
30	69	R. Henry Phillips	Field expenses	62.72
30	70	....do	....do	36.55
30	71	Julien J. Mason	Services, June, 1889	50.00
30	72	Alan M. Johnson	Services, May and June, 1889	69.35
17	73	Wells, Fargo & Co	Expressage	7.00
30	74	Sparks Bros	Forage	13.50
		Total		9,980.40

Abstract of disbursements made by Mark B. Kerr, disbursing agent U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 13	1	P. V. Bartlett	Field expenses	$9.00
13	2	Frank Tweedy	do	2.73
		Total		11.73

Abstract of disbursements made by P. C. Warman, special disbursing agent U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 30	1	J. W. Powell	Traveling expenses	$135.30
30	2	P. C. Warman	....do	106.70
28	3	....do	Telegrams	3.72
		Total		245.72

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during the first quarter of 1890.

[Irrigation—Immediately available.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 5	1	The Roberts Hardware Co	Field material	$140.25
5	2	Samuel P. Barbee	....do	133.50
5	3	Schroter & Haines	Forage	13.66
5	4	Grover & Ulrich	Subsistence supplies	133.19
5	5	Wall & Pursell	Material and repairs	24.20
5	6	Joseph Werlen	Forage	12.00
July 20	7	J. J. Evans	Stationery	97.65
20	8	Thomas Day & Co	Field supplies	10.00
20	9	Samuel C. Partridge	Photographic material	21.25
20	10	Lyman Bridges	Traveling expenses	87.34
20	11	Neville & Co	Field material	257.40
20	12	John Roach	Instruments	59.70
20	13	....do	....do	38.50
20	14	George H. Fuller	Office furniture	65.00
20	15	Ames & Detrick	Field material	172.80
20	16	W. W. Montague & Co	....do	77.02
20	17	Edward Denny & Co	Stationery	8.50
20	18	J. P. Mighett & Co	Typewriting machine	95.00
20	19	George Sandow	Field expenses	67.55
20	20	W. R. Mayfield	Traveling expenses	15.25
20	21	Goldman & Co	Field supplies	20.28
27	22	Stuart & McNair	Field material	146.12
29	23	W. W. Follett	Traveling expenses	20.00
31	24	....do	Services, July 6 to 31, 1889	167.74
31	25	P. H. Christie	Services, July, 1889	151.60
31	26	O. C. Moorhead	Services, July 7 to 31, 1889	32.25
31	27	Samuel M. Lee	Hire of transportation	52.42
31	28	Harold M. Dyar	Services, July, 1889	50.00
31	29	S. H. Buchanan	Field supplies	24.25
31	30	Alexander McKenzie	Field expenses	22.60
31	31	J. Brown	Instruments	19.40
31	32	Harold M. Dyar	Field expenses	12.75
31	33	Frank R. Coffin & Bro	Field material	275.84
31	34	P. E. Harroun	Traveling expenses	9.40
31	35	....do	Services, July 7 to 31, 1889	48.38
31	36	George T. Quimby	Field expenses	137.99
31	37	Pay roll	Services, July, 1889	175.00
31	38	....do	....do	265.00
31	39	George T. Quimby	Traveling expenses	30.90
31	40	Andrew J. Wiley	Field expenses	84.79
31	41	Frank R. Coffin & Bro	....do	52.36
31	42	Anderson Bros	....do	80.96
31	43	George T. Quimby	....do	110.73
31	44	Pay roll	Services, July, 1889	302.70
31	45	....do	....do	537.50
Aug. 5	46	Sumner H. Bodfish	....do	202.20
5	47	H. M. Wilson	Field expenses	133.18
5	48	W. L. Wilson	Services, July, 1889	50.00
5	49	H. M. Wilson	Field expenses	86.75
5	50	Bach, Cory & Co	Subsistence supplies	79.17
5	51	Sumner H. Bodfish	Traveling expenses	82.53
6	52	L. D. Hopson	Field expenses	57.30
6	53	J. B. Williams	....do	140.18
6	54	....do	Traveling expenses	21.25
6	55	William P. Trowbridge	....do	7.10
6	56	George Sandow	....do	3.50
6	57	Pay roll	Services, July, 1889	239.51
6	58	William Ham Hall	....do	337.00
8	59	P. H. Christie	Field expenses	173.25
8	60	W. A. Farish	Services, July, 1889	75.00
8	61	W. W. Sargeant	....do	40.00
8	62	R. S. Tarr	Traveling expenses	55.35
8	63	P. H. Christie	....do	45.35
8	64	Pay roll	Services, July, 1889	62.90
8	65	....do	....do	462.00
8	66	George E. Curtis	....do	116.66
10	67	Sumner H. Bodfish	Field expenses	287.75
10	68	C. E. Dutton	Traveling expenses	153.00
10	69	Pay roll	Services, July, 1889	401.29
10	70	S. H. Bodfish	Field expenses	41.93
10	71	Robert Robertson	Services, July, 1889	75.00
10	72	W. G. Steel	Services, May 17 to July 20, 1889	200.00
10	73	Arthur D. Foote	Field expenses	33.00
10	74	J. A. Quinlan	Smithing	27.70
10	75	James M. Butcher	Rating station	236.38
10	76	E. Meininger	Stationery	30.55

Abstract of disbursements made by P. H. Christie, etc.—Continued.

[Irrigation—Immediately available.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 10	77	W. H. Lawrence & Co	Stationery	$36.30
10	78	Meguillet & Macrum	Field supplies	42.30
10	79	Denver Transit and Warehouse Co	Rent for storage	20.00
10	80	E. S. Nettleton	Field expenses	79.18
10	81	...do	Traveling expenses	27.40
10	82	Lallie & Bailey	Instruments	409.50
14	83	Frank Harrison	Services, July 1 to 31, 1889	75.00
14	84	F. H. Newell	...do	126.40
15	85	John B. Rogers	Field expenses	84.75
15	86	John Martin	Services, July 22 to 31, 1889	11.29
15	87	Stewart S. McKay	Field expenses	125.43
15	88	Truckee Lumber Co	Field supplies	83.85
15	89	Pay roll	Services, July, 1889	312.70
15	90	W. A. Farish	Field expenses	58.25
15	91	Lyman Bridges	Traveling expenses	4.82
15	92	Pay roll	Services, July, 1889	140.78
15	93	F. H. Newell	Field expenses	14.55
		Total		10,000.00

Abstract of disbursements made by P. H. Christie, etc.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 20	94	A. J. Wiley	Field expenses	$62.96
20	95	Anderson Bros	Field supplies	60.70
20	96	Phil A. Manix	...do	50.92
20	97	F. K. Walker	...do	85.55
20	98	Anderson Bros	...do	39.67
20	99	W. A. Farish	Traveling expenses	20.75
20	100	R. P. Irvin	Services	50.00
20	101	Pay roll	...do	500.00
20	102	T. M. Bannon	...do	75.00
20	103	Goldman & Co	Field supplies	30.14
20	104	Holmes & Lindsley	Field material	22.00
20	105	Robert Robertson	Traveling expenses	40.75
20	106	Wall & Pursell	Material and stock	869.00
20	107	Pay roll	Services	672.23
20	108	Alfred Bacon	...do	13.55
20	109	Pay roll	...do	531.76
20	110	Joslin & Park	Instruments	22.00
20	111	Robert Robertson	Field expenses	174.87
20	112	Samuel P. Barbee	Field material	81.25
20	113	The Mitchell Optical and Instru't Co.	Instruments	28.00
20	114	Joseph Werlen	Forage and stock	70.25
20	115	Samuel P. Barbee	Field material	11.00
20	116	Grover & Ulrich	Subsistence supplies	70.02
21	117	F. H. Newell	Field expenses	54.27
21	118	Robert Robertson	...do	83.80
21	119	George T. Quinby	...do	77.51
22	120	T. M. Bannon	...do	85.37
22	121	George M. Scott & Co	Field material	13.35
22	122	Henry Reppe & Co	...do	14.95
22	123	F. H. Newell	Traveling expenses	67.42
22	124	T. M. Bannon	...do	24.70
22	125	Robert Robertson	...do	50.85
23	126	Walker House	Subsistence	54.00
23	127	George M. Scott & Co	Field material	18.90
26	128	Francis Bridges	Field expenses	11.55
26	129	Charles Imholz	Services	15.48
26	130	L. B. Sheafe	Forage	14.21
26	131	J. M. McKay	Smithing	30.00
27	132	W. G. Irwin	Transportation and forage	76.87
26	133	Truckee Lumber Co	Subsistence supplies	124.38
27	134	...do	...do	215.96
27	135	S. S. Ferguson	Transportation	15.00
27	136	Truckee Lumber Co	Field expenses	283.49

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid,	For what paid.	Amount.
1889.				
Aug. 27	187	William M. Heidenreich	Services, July, 1889	$40.00
27	138	Pay roll	...do	83.69
28	139	L. H. Shortt	Field expenses	39.85
28	140	...do	...do	10.13
28	141	R. H. Cowles	Hire of transportation	101.25
28	142	Nevada House	Subsistence	234.03
30	143	John Raycraft	Transportation	30.50
30	144	M. Harris	Forage and supplies	32.67
29	145	Lemery & Fitzgerald	Subsistence	5.33
31	146	William E. Smith	Forage	27.75
31	147	Stewart & McKay	Subsistence, etc	32.77
31	148	...do	Subsistence	28.95
31	149	Frank Harrison	Field expenses	186.97
31	150	...do	Services, August, 1889	75.00
31	151	William M. Heidenreich	...do	40.00
31	152	P. H. Christie	...do	151.60
31	153	Pay roll	...do	334.95
31	154	...do	...do	285.00
Sept. 3	155	Lawrence Frey	Subsistence supplies	30.00
3	156	Stewart & McNair	...do	70.26
3	157	W. W. Follett	Field expenses	49.87
3	158	Robert Adams	Services, August 1 to 19, 1889	18.39
3	159	C. W. Dake	Field material	12.60
3	160	J. M. Short	Field supplies	6.20
3	161	Pay roll	Services, August, 1889	705.80
7	162	Jacob Radenbah	Subsistence and forage	52.35
7	163	...do	...do	136.30
7	164	M. Harris	Field supplies	120.44
7	165	Ellen Raycraft	Subsistence	13.66
7	166	A. G. Small	Forage and subsistence	239.03
7	167	L. H. Shortt	Traveling expenses	25.50
7	168	...do	Field expenses	26.73
7	169	R. Gelatt	Forage and transportation	18.66
7	170	George A. Brown	Field expenses	86.60
9	171	John Raycraft	Forage and subsistence	33.50
9	172	F. A. Titus	Hire of transportation	185.80
9	173	Pay roll	Services, August, 1889	524.03
9	174	...do	...do	528.54
10	175	C. H. Clapp	Field expenses	9.00
10	176	Pay roll	Services, August, 1889	597.73
10	177	...do	...do	768.49
11	178	E. S. Ritchie & Sons	Instruments	988.50
11	179	E. M. Sleator	Maps	22.00
11	180	Pay roll	Services, August, 1889	496.28
11	181	Electrical Supply Co	Instruments	16.50
11	182	Pay roll	Services, August, 1889	195.00
11	183	Frank P. Thwartes	Services, July 16 to 22, 1889	11.29
11	184	Luther Wagoner	Services, July 27 to 31, 1889	24.19
11	185	Pay roll	Services, August, 1889	117.57
11	186	Rich Shumway	...do	50.00
11	187	Sumner H. Bodfish	...do	202.20
11	188	George B. Stiles	Field expenses	109.75
12	189	William Donaldson	Subsistence	83.52
12	190	Pay roll	Services, August, 1889	490.00
12	191	...do	...do	314.34
12	192	A. J. Wiley	Field expenses	79.78
12	193	Frederick K. Walker	Field supplies	50.26
12	194	Delano & Clay	...do	63.13
12	195	Pay roll	Services, August, 1889	460.00
12	196	William Ham Hall	...do	337.00
12	197	The Bancroft Co	Stationery	11.64
12	198	George Sandow	Field expenses	105.91
12	199	Harold M. Dyar	Traveling expenses	4.75
12	200	Peter Melich	Forage	9.22
12	201	J. B. Williams	Services, August, 1889	100.00
12	202	Pay roll	...do	160.64
13	203	Harold M. Dyar	Traveling expenses	17.30
13	204	...do	...do	30.60
13	205	...do	Services, August, 1889	75.00
13	206	J. W. Mitchell	...do	50.00
13	207	William Ham Hall	Traveling expenses	33.15
13	208	Curt W. Miller	Services, July, 1889	20.00
13	209	...do	Services. August, 1889	20.00
13	210	P. E. Connor, jr	Field expenses	10.17
13	211	Luther Wagoner	...do	197.97
13	212	William P. Trowbridge	...do	27.00
14	213	Josiah Pierce, jr	Traveling expenses	92.75
14	214	James Getz & Bro	Field supplies	91.80
14	215	C. R. Guthiel	Traveling expenses	13.75
14	216	Lyman Bridges	Field expenses	22.21

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 14	217	J. J. Evans	Stationery	$18.22
16	218	E. M. Boyle	Services, August 1 to 17, 1890	41.12
16	219	Luther Wagoner	Field expenses	206.32
16	220	E. M. Boyle	Traveling expenses	3.00
16	221	C. R. Guthiel	Field supplies	8.75
16	222	Francis Bridges	Field expenses	123.99
16	223	William P. Trowbridge, jr	...do	36.63
16	224	Francis Bridges	Traveling expenses	14.00
17	225	George A. Brown	...do	29.25
17	226	...do	Field expenses	119.13
18	227	Burr Jennings	Traveling expenses	3.50
18	228	F. A. Titus	Hire of transportation	60.00
18	229	L. H. Shortt	Traveling expenses	12.50
18	230	Lemery & Fitzgerald	Subsistence	48.66
18	231	L. H. Shortt	Field expenses	20.69
19	232	William B. Hooper	Subsistence	79.75
24	233	J. B. Williams	Traveling expenses	146.05
24	234	...do	Field expenses	43.66
24	235	L. D. Hopson	...do	85.30
24	236	N. Arave	...do	13.04
24	237	Harold M. Dyar	...do	136.40
24	238	W. A. Farish	...do	42.61
25	239	Henry E. Hemp	Field material	74.00
25	240	Goldman & Co	Field supplies	15.79
25	241	W. A. Farish	Field expenses	40.95
25	242	Pay roll	Services, August, 1889	326.40
25	243	H. M. Wilson	Field expenses	17.75
25	244	...do	...do	47.45
25	245	...do	...do	53.80
25	246	...do	Services, August, 1889	202.20
25	247	E. S. Nettleton	...do	337.00
25	248	E. C. Hawkins	...do	125.00
25	249	Pay roll	...do	500.00
25	250	...do	...do	342.70
26	251	George E. Curtis	...do	116.66
26	252	George T. Quinby	...do	75.00
26	253	H. S. Davidson	Services, July 19 to 31, 1889	52.41
26	254	Pay roll	Services, July, 1889	221.26
30	255	P. H. Christie	Services. September, 1889	146.80
30	256	A. D. Foote	...do	244.60
30	257	Pay roll	... do	500.00
30	258	...do	...do	392.99
30	259	E. C. Hawkins	...do	125.00
30	260	E. S. Nettleton	...do	326.00
30	261	William Ham Hall	...do	326.00
30	262	Pay roll	...do	370.32
30	263	...do	...do	281.65
30	264	...do	...do	285.00
30	265	E. C. Hawkins	Traveling expenses	35.30
30	266	J. W. Mitchell	Services, September, 1889	50.00
30	267	Harold M. Dyar	...do	75.00
30	268	F. H. Newell	...do	122.20
30	269	T. M. Baunon	...do	75.00
30	270	W. W. Follett	...do	200.00
30	271	Pay roll	...do	220.00
30	272	...do	...do	135.00
30	273	Josiah Pierce	...do	130.40
30	274	C. R. Rockwood	Field expenses	121.40
30	275	W. W. Follett	...do	67.58
30	276	...do	...do	151.51
30	277	...do	Traveling expenses	14.15
30	278	Edward D. Wickes	Services, September 2 to 9, 1889	14.00
30	279	H. M. Wilson	Services, September, 1889	195.60
30	280	H. Savitree Brady	Servicees, August 24 to September 25, 1889.	64.00
30	281	H. M. Wilson	Field expenses	58.50
30	282	John B. Rogers	...do	53.31
30	283	P. P. Dahl	Field supplies	54.82
30	284	A. McGillis	Transportation	155.00
30	285	L. C. Fraser	Office rent	100.00
30	286	H. M. Wilson	Field expenses	45.70
30	287	John B. Rogers	...do	30.36
30	288	F. H. Newell	Traveling expenses	51.73
30	289	Frank Harrison	Services, September, 1889	75.00
30	290	William M. Heidenreich	...do	40.00
30	291	Robert Robertson	...do	75.00
30	292	R. P. Irvin	...do	50.00
30	293	F. H. Newell	Field expenses	119.82
30	294	T. M. Bannon	...do	55.45
30	295	S. H. Bodfish	...do	211.82

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 30	296	T. M. Bannon	Traveling expenses	22.40
30	297	Columbia Phonograph Co	Rent of phonograph	$10.00
30	298	Buff & Berger	Instruments	32.00
30	299	S. H. Bodfish	Field expenses	75.80
30	300	...do	Traveling expenses	71.66
30	301	Robert Robertson	Field expenses	140.21
30	302	Rich Shumway	Services, September, 1889	50.00
30	303	William M. Fitzhugh	Traveling expenses	46.55
30	304	Hooper & Jennings	Subsistence supplies	64.12
30	305	Campbell & Stebbins	Field supplies	105.82
30	306	Frank R. Coffin & Bro	...do	16.28
30	307	A. J. Wiley	Field expenses	53.69
30	308	Walker House	Subsistence	61.00
30	309	W. W. Follett	Traveling expenses	7.50
30	310	Denver Transit and Warehouse Co	Rent for storage	40.00
30	311	E. J. Hall	Instruments	10.00
30	312	S. H. Bodfish	Field expenses	114.87
30	313	George T. Quimby	Traveling expenses	60.10
30	314	Anderson Bros	Field supplies	26.00
30	315	Harold M. Dyar	Field expenses	141.08
30	316	Pay roll	Services, September, 1889	158.33
30	317	...do	...do	238.00
30	318	H. S. Davidson	Field expenses	16.00
30	319	C. R. Rockwood	...do	9.00
30	320	The Roberts Hardware Co	Field supplies	75.10
30	321	W. & L. E. Gurley	Instruments	14.40
30	322	...do	Expressage	8.25
30	323	G. G. Wright	Forage	15.90
30	324	John T. Oldham	Field supplies	12.00
30	325	Edward S. Snell	Traveling expenses	18.50
30	326	W. & L. E. Gurley	*Instruments*	51.55
30	327	...do	...do	49.60
30	328	W. W. Montague & Co	Field material	48.83
30	329	...do	...do	11.23
30	330	Main & Winchester	...do	50.00
30	331	Edward Denny & Co	Stationery	22.19
30	332	...do	...do	27.12
30	333	W. & L. E. Gurley	Instruments	36.55
30	334	L. Hansel	Subsistence supplies	35.40
30	335	Austin Bros	Field supplies	33.72
30	336	Edward Denny & Co	Stationery	16.68
30	337	L. D. Hopson	Traveling expenses	24.20
30	338	The Roberts Hardware Co	Field supplies	6.40
30	339	E. C. Hawkins	Field expenses	12.15
30	340	John Kinna & Son	Instruments	35.00
		Total		27,981.65

Abstract of disbursements made by H. C. Rizer, disbursing agent U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 8	1	H. C. Rizer	Traveling expenses	$30.35
8	2	E. T. Perkins	...do	104.15
8	3	E. Shaw	...do	10.50
8	4	A. F. Dunnington	...do	133.00
8	5	Ewing Speed	...do	84.00
8	6	Redick H. McKee	...do	126.75
8	7	Robert Muldrow	...do	46.25
8	8	Frank E. Gove	...do	25.25
8	9	L. H. Cooper	...do	80.20
8	10	Jeremiah Ahern	...do	24.50
8	11	MacGregor Jenkins	...do	97.95
8	12	Jeremiah Ahern	Field expenses	13.40
8	13	Pay roll	Idaho party for June	636.48
8	14	...do	Montana party for June	204.99
8	15	W. H. Edwards	Services, May	9.67
8	16	Pay roll	Colorado party for June	377.30
8	17	...do	California party for June	322.40
8	18	H. E. Clermont Feusier	Services, June	26.00

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 8	19	Monroe Sonnichsen	Services, April 27 to May 31	$56.66
8	20	A. Navarrine	Services, May	33.87
8	21	Pay roll	California party for June	777.19
8	22	do	Montana party for June	363.29
8	23	do	Colorado party for June	345.40
8	24	do	Nevada party for June	96.00
8	25	do	do	314.70
8	26	do	New Mexico party for June	59.00
8	27	Nephi Johnson	Services in May	45.00
8	28	Pay roll	New Mexico party, June	224.80
8	29	J. C. McGuire	Traveling expenses	68.40
8	30	Pay roll	Colorado party, June	594.80
8	31	do	do	225.66
8	32	do	New Mexico party, June	232.40
9	33	E. M. Douglas	Field expenses	88.53
9	34	L. Landecker	Supplies	104.26
9	35	James Booland	Board and lodging	20.00
9	36	J. W. Keenan	Material	20.00
9	37	S. G. Beach & Co	do	30.00
9	38	J. W. Deuch	do	107.45
9	39	Eli Williams	do	18.00
9	40	Thomas Alderson	do	19.30
9	41	J. W. Deuch	do	31.84
9	42	N. Wonderly	do	356.35
9	43	L. Landecker	Material and supplies	20.42
9	44	do	Field supplies	166.88
9	45	do	do	100.51
9	46	E. B. Rail	Material	188.60
9	47	E. J. Owenhouse	do	103.15
9	48	Carver Mercantile Co	Supplies and material	185.90
10	49	G. E. Verrill	Field expenses	24.50
10	50	Weatherwax & Morey	Material	40.50
10	51	do	do	30.37
10	52	R. C. McKinney	Field expenses	67.87
10	53	McCutcheon, Payne & Co	Forage	5.47
10	54	W. T. Griswold	Field expenses	104.91
10	55	Warren H. Mooers	Forage	12.00
10	56	S. C. Gallup	Material	179.38
10	57	do	do	473.15
10	58	R. H. Chapman	Field expenses	49.20
10	59	Morris Bien	do	44.95
10	60	do	do	177.16
10	61	Fred Y. Wilson	do	12.40
10	62	George Davis	Pasturage	49.30
10	63	John J. Rogers	Material	89.40
11	64	Frank Tweedy	Field expenses	84.68
11	65	W. T. Griswold	do	19.80
11	66	G. E. Verrill	do	35.86
11	67	Spratlen & Anderson	Supplies	99.27
11	68	do	do	119.45
11	69	W. T. Griswold	Field expenses	340.56
11	70	William A. Korts	Services, June	11.67
11	71	W. H. Ridenbaugh	Material	15.70
11	72	Frank R. Coffin & Bro	do	65.43
11	73	do	do	18.95
11	74	Peter Sonna	do	35.70
11	75	H C. Rizer	Services, June	96.70
11	76	W. S. Parrett	Supplies	28.71
11	77	L. Landecker	do	66.80
12	78	A. P. Davis	Field expenses	62.75
12	79	do	Traveling expenses	79.15
12	80	Cartwright & Griswold	Supplies	47.85
12	81	A. F. Dunnington	Field expenses	58.75
12	82	Redick H. McKee	do	35.99
12	83	R. H. Chapman	do	88.55
12	84	G. E. Verrill	do	104.13
12	85	E. T. Perkins	do	12.80
12	86	Gerald F. Sherman	Services, June	16.00
13	87	J. B. Lippincott	Traveling expenses	41.80
13	88	W. P. Rowe	Material	68.00
13	89	Julien J. Mason	Traveling expenses	21.50
13	90	Alan M. Johnson	do	21.00
13	91	Charles C. Bassett	do	23.60
13	72	Pay roll	Colorado party, June	199.30
13	93	G. E. Verrill	Field expenses	14.75
13	94	A. H. Thompsou	Traveling expenses	106.12
13	95	do	do	88.00
13	96	do	do	156.66
15	97	R. Henry Phillips	Field expenses	61.60

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 16	98	R. Henry Phillips	Traveling expenses	$37.85
23	99	D. G. Kitzmeyer	Material	82.75
24	100	W. D. Torreyson	Labor and material	31.00
24	101	E. M. Douglas	Field expenses	26.25
24	102	L. B. Brett	Material	3.95
24	103	H. C. Rizer	Traveling expenses	17.50
24	104	A. C. Laudenslager	Supplies	53.67
24	105	Cartwright & Griswold	do	56.65
24	106	Charles W. Friend	Services, June	50.00
24	107	E. M. Douglas	Field expenses	84.33
25	108	do	do	36.09
25	109	W. D. Torreyson	Labor and material	22.00
20	110	Paul Pouliot	Boats	63.00
25	111	A. H. Thompson	Traveling expenses	71.25
25	112	P. Henry Phillips	Services, July, 1889	40.76
26	113	J. W. Hayes	Field expenses	602.27
26	114	R. C. McKinney	do	152.76
26	115	J. H. Boring	do	10.50
27	116	H. E. Clermont Feusier	do	59.38
27	117	Pay roll	Colorado party for July, 1889	386 44
31	118	A. H. Thompson	Services for July, 1889	252.70
29	119	Paul Holman	Traveling expenses	5.90
29	120	A. F. Dunnington	Field expenses	54.10
29	121	W. H. Prouty	Supplies	63.53
31	122	H. C. Rizer	Services, July, 1889	185.30
31	123	Pay roll	New Mexico party, July, 1889	799.27
31	124	do	Nevada party, July, 1889	290.60
31	125	do	do	576.15
31	126	do	Montana party, July, 1889	391.60
31	127	do	Idaho party, July, 1889	358.50
31	128	do	do	312.90
31	129	do	Colorado party, July, 1889	391.10
31	130	do	do	228.50
31	131	do	do	270.60
31	132	do	do	100.00
31	133	do	do	211.75
31	134	do	Nevada party, July, 1889	202.20
31	135	do	Colorado party, July, 1889	291.10
31	136	C. H. Fitch	Field expenses	51.55
31	137	J. C. McGuire	Services, July, 1889	24.18
31	138	William A. Kortz	do	25.00
31	139	Paul Holman	do	70.80
31	140	R. H. Chapman	Field expenses	31.45
31	141	George T. Davis	Supplies	66.78
Aug. 1	142	Spratlen & Anderson	do	110.55
1	143	Reaser Bros	Forage	62.30
1	144	S. C. Gallup	Material	238.57
1	145	do	do	172.92
1	146	Simons & Mix	Labor and material	160.70
1	147	Cartwright & Griswold	Supplies	22.25
1	148	Spratlen & Anderson	do	722.09
1	149	Willard D. Johnson	Field expenses	247.41
1	150	do	do	640.20
2	151	do	do	21.45
2	152	do	do	16.95
2	153	Redick H. McKee	do	9.70
2	154	Perry Fuller	do	7.40
2	155	A. F. Dunnington	do	36.15
2	156	G. E. Verrill	do	44.03
2	157	do	do	56.61
3	158	H. E. Clermont Fensier	do	33.41
3	159	do	do	38.16
3	160	Morris Bien	do	196.99
3	161	C. H. Fitch.,	do	49.90
3	162	do	do	80.81
3	163	Spratlen & Anderson	Supplies	57.53
3	164	Pay roll	Montana party for July, 1889	361.10
5	165	Carver Mercantile Co	Supplies	60.23
5	166	Jeremiah Ahern	Field expenses	24.50
5	167	do	Traveling expenses	5.30
5	168	Pay roll	Colorado party for July, 1889	207.90
5	169	do	Nevada party for July, 1889	352.90
5	170	Redick H. McKee	Field expenses	105.92
5	171	Pay roll	Nevada party for July, 1889	296.10
6	172	C. C. Bassett	Field expenses	28.29
6	173	R. C. McKinney	do	62.68
6	174	do	do	189.00
6	175	Frank Tweedy	do	75.15
6	176	William S. Post	do	263.29

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 7	177	H. E. Clermont Feusier	Field expenses	$31.96
7	178	Morris Bien	...do	206.48
7	179	Redick H. McKee	...do	65.05
8	180	R. H Chapman	..do	125.61
8	181	A. P. Davis	...do	37.92
8	182	J. S. Topham	Material	6.00
9	183	George T. Davis	Supplies	59.92
9	184	W. T. Griswold	Field expenses	159.10
10	185	G. E. Verrill	...do	18.90
10	186	...do	...do	55.87
10	187	Carver Mercantile Co	Supplies	126.03
12	188	E. Shaw	Services	23.34
12	189	A. F. Dunnington	Field expenses	33.50
12	190	Reeves & Co	Forage	31.44
13	191	H. E. Clermont Feusier	Field expenses	119.32
14	192	Jacob Klein	Storage	15.00
14	193	Robert A. Farmer	Field expenses	23.12
14	194	A. H. Thompson	Traveling expenses	75.35
14	195	E. T. Perkins, jr	Field expenses	56.97
15	196	D. L. Williams	Services	12.00
15	197	Redick H. McKee	Field expenses	37.70
15	198	...do	...do	26.95
15	199	E. M. Douglas	...do	261.52
17	200	P. V. S. Bartlett	Traveling expenses	4.50
17	201	A. H. Thompson	Field expenses	17.85
19	202	Ewing Speed	Services	50.00
19	203	S. M. Fitzgerald	Transportation	107.00
19	204	E. T. Perkins, jr	Field expenses	92.80
19	205	... do	...do	31.45
19	206	A. C. Barclay	...do	39.83
19	207	H. E. Clermont Feusier	...do	33.47
19	208	G. E. Verrill	...do	47.08
20	209	R. H. Chapman	...do	59.59
21	210	Stuart P. Johnson	...do	214.09
23	211	W. T. Griswold	...do	65.39
24	212	A. F. Dunnington	Services	151.60
24	213	..do	Field expenses	63.40
24	214	H. E. Clermont Feusier	...do	38.80
26	215	Robert A. Farmer	...do	32.49
26	216	E. T. Perkins	...do	26.40
26	217	Spratlen & Anderson	Supplies	50.50
26	218	C. H. Fitch	Field expenses	112.11
27	219	Albert J. Dockwiller	Services	48.00
27	220	Cartwright & Griswold	Supplies	84.66
28	221	William Balander	Material	23.50
28	222	W. A. McKenzie	...do	30.80
28	223	Arthur Bishop	Supplies	21.40
28	224	George Chase	Labor and material	74.70
28	225	G. E. Verrill	Field expenses	173.82
28	226	Morris Bien	...do	166.39
31	227	A. H. Thompson	Services	252.70
31	228	H. C. Rizer	...do	185.30
31	229	Pay roll for August	Nevada party	263.50
31	230	...do	Colorado party	396.60
31	231	...do	Nevada party	202.20
31	232	...do	...do	332.35
31	233	...do	...do	423.70
31	234	...do	...do	326.40
31	235	...do	Idaho party	362.90
31	236	...do	Nevada party	431.60
Sept. 3	237	Redick H. McKee	Field expenses	40.12
3	238	...do	...do	37.90
28	239	E. M. Douglas	...do	11.82
		Total		30,000.00

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889. Sept. 3	1	Pay roll for August	Colorado party	$100.00
3	2	...do	New Mexico party	301.10
3	3	...do	Colorado party	291.10
3	4	...do	...do	270.60
3	5	...do	Idaho party	340.43
3	6	...do	Montana party	419.64
3	7	...do	New Mexico party	518.50
3	8	...do	Colorado party	406.60
3	9	A. F. Dunnington	Field expenses	60.95
3	10	...do	...do	73.00
4	11	John W. Hays	...do	372.04
4	12	Pay roll for August	Colorado party	228.50
4	13	Frank Tweedy	Field expenses	99.87
5	14	Stuart P. Johnson	...do	120.82
5	15	Harry King	Traveling expenses	25.25
6	16	William S. Post	Field expenses	335.15
7	17	John Hatch	Traveling expenses	24.00
7	18	Pay roll for August	Colorado party	215.00
7	19	Reeves & Co	Forage	20.88
7	20	S. C. Gallup	Material	12.00
7	21	P. V. S. Bartlett	Field expenses	48.32
7	22	E. M. Douglas	...do	55.00
7	23	Pay roll for August	Colorado party	244.66
9	24	D. Johnson	Board and lodging	30.00
9	25	A. F. Dunnington	Field expenses	39.00
10	26	R. C. McKinney	...do	64.85
10	27	H. E. Clermont Feusier	...do	77.75
10	28	C. C. Bassett	...do	139.45
10	29	Alex. C. Barclay	...do	24.00
10	30	W. T. Griswold	...do	68.93
10	31	Jeremiah Ahern	...do	49.00
11	32	E. T. Perkins	...do	221.13
11	33	A. Leitz & Co	Material	14.00
11	34	G. E. Verrill	Field expenses	6.40
11	35	Robert A. Farmer	...do	66.06
11	36	Redick H. McKee	...do	48.87
12	37	Morris Bien	...do	321.60
12	38	H. E. Clermont Feusier	...do	63.08
13	39	G. T. Davis	Supplies	73.98
13	40	R. H. Chapman	Field expenses	100.21
13	41	A. H. Thompson	Traveling expenses	143.55
13	42	William A. Korts	Services, August, 1889	25.00
14	43	A. F. Dunnington	Field expenses	46.20
14	44	J. L. Van Arsdell	Forage	8.90
14	45	Reaser Bros	...do	50.80
14	46	A. P. Davis	Field expenses	54.73
16	47	Philip Standley Twells	Services, September 1 to 8, 1889	16.00
16	48	D. L. Williams	...do	12.00
16	49	Pay roll for August	Montana party	361.10
16	50	C. C. Bassett	Field expenses	13.50
16	51	J. A. Edwards	Services, August 8 to 31, 1889	36.00
16	52	John Hatch	Services, August 12 to 31, 1889	30.00
17	53	J. W. Deuch	Material	23.00
17	54	John W. Hays	Field expenses	222.60
17	55	Philip Sawyer	Services, August, 1889	60.06
17	56	R. C. McKinney	Field expenses	20.56
17	57	Arthur Marshall	Services, September 1 to 7, 1889	11.60
17	58	E. E. Handley	Services, September 1 to 14, 1889	18.65
17	59	E. T. Perkins, jr	Field expenses	17.55
17	60	Rogers Bros	Labor and material	12.60
18	61	Gross, Blackwell & Co	Supplies	103.15
18	62	W. H. Hyde	Material	35.35
18	63	Simons & Mix	...do	58.80
20	64	Willard D. Johnson	Field expenses	140.28
20	65	Redick H. McKee	...do	24.20
20	66	Fred A. Schmidt	Material	21.65
20	67	L. Landecker	Supplies	80.90
20	68	E. M. Douglas	Field expenses	89.30
20	69	Robert Muldrow	...do	42.28
21	70	William M. Thompson	Supplies	22.85
21	71	A. H. Thompson	Traveling expenses	115.95
21	72	C. R. Glass	...do	11.25
21	73	P. V. S. Bartlett	Field expenses	80.98
21	74	Perry Fuller	...do	21.65
23	75	H. C. Clermont Feusier	...do	75.24
23	76	A. F. Dunnington	...do	40.50
23	77	R. H. Chapman	...do	37.62
23	78	Willard D. Johnson	...do	94.45

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 23	79	P. V. S. Bartlett	Field expenses	$111.54
24	80	W. T. Griswold	...do	114.97
24	81	Stuart P. Johnson	...do	140.78
24	82	Samuel McDowell	Forage	240.00
24	83	Pueblo Hardware Co	Material	594.37
24	84	...do	...do	57.15
24	85	C. H. Fitch	Field expenses	172.67
24	86	Morris Bien	...do	219.36
30	87	Pay roll for September	Nevada party	268.00
30	88	...do	...do	277.80
30	89	...do	Montana party	357.80
30	90	...do	Colorado party	223.00
30	91	...do	...do	451.80
30	92	...do	...do	147.80
30	93	...do	...do	241.60
30	94	...do	...do	391.80
30	95	...do	...do	278.80
30	96	...do	New Mexico party	463 00
30	97	...do	...do	337.80
30	98	...do	Nevada party	426.80
30	99	...do	...do	299.20
30	100	...do	...do	201.00
30	101	...do	...do	200.00
30	102	...do	Idaho party	722.20
30	103	A. H. Thompson	Services, September, 1889	244.60
30	104	H. C. Rizer	...do	179.40
30	105	Robert Muldrow	...do	58.80
30	106	Paul Holman	...do	68.40
30	107	Pay roll for September	Colorado party	264.20
30	108	Redick H. McKee	Field expenses	74.40
30	109	H. E. Clermont Feusier	...do	33.60
30	110	G. E. Verrill	Traveling expenses	105.63
30	111	Harry King	Field expenses	24.00
30	112	John H. Hughes	Material	43.50
30	113	Jeremiah Ahern	Field expenses	22.73
30	114	R. C. McKinney	...do	238.98
30	115	...do	...do	109.19
30	116	L. B. Kendall	...do	21.37
30	117	John W. Hays	...do	113.63
30	118	C. H. Fitch	...do	28.72
30	119	Pay roll for September	Montana party	466.13
30	120	Reeves & Co	Forage	18.00
30	121	A. F. Dunnington	Field expenses	68.50
30	122	E. T. Perkins, jr.	...do	6 50
30	123	W. T. Griswold	...do	27.51
30	124	Morris Bien	...do	146.99
30	125	Frank Tweedy	...do	229.28
30	126	Redick H. McKee	...do	37.75
30	127	A. F. Dunnington	...do	66.39
30	128	R. H. Chapman	...do	133.27
		Total		17,993.23

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

[Irrigation.]

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 7	3	William B. Gaw	Services, September 1 to 7, 1889	$30.00

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during October and November, 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 15	7	William A. Balch	Services, October 1 to 15, 1889	$39.00
23	20	Colorado Midland Rwy	Transportation of assistants	7.40
23	22	Columbia Phonograph Co.	Rent of phonograph	10.00
23	23	Pennsylvania Company	Transportation of assistants	17.50
24	26	Burlington and Missouri River R. R.	...do	59.30
24	27	Denver and Rio Grande R. R.	...do	103.90
24	28	Baltimore and Ohio R. R.	...do	229.85
28	38	A. L. Hodder	Services, July, 1889	100.00
31	58	Pay roll of employés	Services, October, 1889	1,256.90
31	60	...do	...do	140.32
Nov. 1	63	C. A. Kenaston	...do	135.00
2	74	John C. Parker	Supplies	28.65
2	77	Adams Express Co	Freight charges, July, 1889	249.65
8	82	Colorado Midland Rwy	Transportation of assistants	8.00
8	83	...do	...do	8.00
8	84	Pennsylvania Co	...do	17.50
8	85	Chesapeake and Ohio Rwy	...do	55.65
8	86	Atchison, Topeka and Santa Fé R. R.	...do	218.89
8	87	Hannibal and St. Joseph R. R	...do	12.50
8	88	Ohio and Mississippi Rwy	...do	8.09
11	94	Adams Express Co	Freight charges	33.70
14	100	Alvah Bushnell	Irrigation supplies	24.96
15	103	B. W. Faire	Services, November 1 to 15, 1889	19.50
30	124	R. H. Chapman	Services, November, 1889	114.20
		Total		2,898.46

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during December, 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Dec. 7	2	Pay roll of employés	Services, November, 1889	$1,109.20
7	4	George Ryneal, jr	Supplies	190.92
10	12	Rio Grande Western Rwy	Transportation of assistants	58.00
11	18	Missouri Pacific Rwy	...do	9.65
16	25	Edmund Shaw	Traveling expenses	41.25
16	26	...do	Services, November 1 to 6, 1889	10.00
17	28	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	213.55
17	29	Denver and Rio Grande R. R	...do	35.80
19	35	Wabash R. R	...do	7.50
20	38	E. T. Brooks	Irrigation supplies	17.00
20	39	Gottlieb Spitzer	...do	4.50
23	40	Adams Express Co	Freight charges, September, 1889	40.45
23	41	George W. Knox	Freight, July, August, September, 1889.	36.21
23	47	Denver and Rio Grande R. R	Transportation of assistants	118.35
23	48	Pennsylvania Company	...do	17.80
24	51	L. H. Schneider's Son	Supplies	3.75
31	65	William D. Clark & Co	...do	1.25
31	73	Pay roll of employés	Services, December, 1889	1,134.90
31	88	Cincinnati, Washington and Baltimore R. R.	Transportation of assistants	14.00
31	89	Burlington and Missouri River R. R.	...do	58.65
31	90	Denver and Rio Grande R. R.	...do	34.35
		Total		3,157.08

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 3	1	Pay roll	Services, September, 1889	$495.00
3	2	...do	...do	605.83
3	3	...do	...do	315.00
3	4	Douglas Martin	Services, September 1 to 14, 1889	23.33
3	5	Chris. Baumhoefer	Services, September 16 to 30, 1889	25.00
3	6	Harold M. Dyar	Traveling expenses	41.90
3	7	A. McGillis	Hire of transportation	145.00
3	8	John B. Rogers	Field expenses	72.13
3	9	John Roach	Instruments	170.00
3	10	...do	...do	118.40
3	11	Bull & Grant Farm Implement Co	Field material	296.35
3	12	John T. Oldham	Field supplies	87.97
3	13	Fauth & Co	Instruments	195.00
3	14	Sumner H. Bodfish	Services, September, 1889	195.60
3	15	W. & L. E. Gurley	Instruments	155.00
8	16	William L. Patten & Co	Field material	73.62
8	17	W. & L. E. Gurley	Instruments	140.00
8	18	...do	...do	1,111.00
8	19	J. B. Williams	Traveling expenses	170.50
8	20	...do	Field expenses	142.69
8	21	Pay roll	Services, September, 1889	746.00
8	22	George E. Curtis	...do	116.66
9	23	C. E. Dutten	Traveling expenses	74.02
9	24	C. H. Treat	Instruments	25.53
9	25	W. P. Trowbridge, jr	Traveling expenses	31.42
9	26	George Sandow	Field expenses	52.90
10	27	E. S. Nettleton	...do	54.85
10	28	...do	Traveling expenses	79.00
10	29	E. C. Hawkins	...do	71.60
10	30	William Ham. Hall	...do	62.55
11	31	Windsor Hotel	Subsistence	47.25
21	32	Frank Harrison	Traveling expenses	61.40
21	33	...do	Services, October 1 to 16, 1889	38.70
22	34	J. B. Williams	Traveling expenses	21.35
22	35	Royce & Mareau	Instruments	75.00
22	36	Henry J. Green	...do	30.25
22	37	Guy Sterling	Services, September, 1889	75.00
24	38	E. S. Nettleton	Traveling expenses	37.75
24	39	...do	...do	58.80
24	40	...do	...do	21.60
24	41	W. L. Wilson	Services, September, 1889	50.00
24	42	William M. Heidenreich	Services, October 1 to 9, 1889	11.61
24	43	Goldman & Co	Field supplies	19.76
24	44	H. M. Wilson	Traveling expenses	102.60
24	45	Wheeler & Burdick	Field supplies	15.00
24	46	L. C. Fraser	Office rent	50.00
24	47	William Ham. Hall	Traveling expenses	47.16
24	48	J. W. Mitchell	...do	21.35
25	49	Henry J. Green	Instruments	30.25
25	50	Edward Denny & Co	Stationery	23.90
25	51	Moore & McHarvey	Hire of transportation	44.00
25	52	W. W. Montague & Co	Instruments	12.70
25	53	L. H. Gruwell & Co	Hire of transportation	10.00
25	54	Edward Denny & Co	Instruments	27.25
25	55	William M. Fitzhugh	Traveling expenses	18.25
26	56	Charles R. Rockwood	...do	7.50
26	57	H. S. Davidson	Field expenses	7.50
26	58	Frank D. Tunis	Field supplies	25.97
26	59	W. H. Himes	Field expenses	35.89
26	60	John Roach	Instruments	15.50
26	61	George E. Gresley Jackson	Services, September, 1889	120.00
28	62	P. H. Christie	Field expenses	121.64
28	63	S. H. Bodfish	...do	67.77
28	64	...do	...do	85.89
28	65	...do	...do	87.74
28	66	... do	...do	95.30
29	67	Anson Mills	...do	383.99
29	68	William M. Fitzhugh	... do	281.97
29	69	Isaac Alter	Hire of transportation	220.00
30	70	Luther Wagoner	Field expenses	257.71
30	71	John C. Parker	Office supplies	25.62
30	72	P. H. Christie	Traveling expenses	128.10
31	73	Pay roll	Services, October, 1889	175.00
31	74	...do	...do	201.12
31	75	Robert Robertson	.. do	100.00
31	76	George E. Curtis	...do	116.66
81	77	P. H. Christie	...do	151.60
31	78	Charles Ashton	Rent of office	150.00

Abstract of disbursements made by P. H, Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1883.				
Oct. 31	79	Robert Robertson	Traveling expenses	$72.25
31	80	L. D. Hopson	do	117.80
31	81	Pay roll	Services, October, 1889	324.18
31	82	do	do	95.00
31	83	W. H. Farish	Field expenses	34.25
31	84	Harold M. Dyar	Traveling expenses	36.50
31	85	Pay roll	Services, October, 1889	321.77
31	86	W. W. Follett	do	200.00
31	87	George Sandow	Field expenses	35.15
31	88	L. H. Shortt	do	16.90
31	89	L. C. Fraser	Office rent	50.00
31	90	Thomas Bundy	Hire of transportation	39.50
31	91	C. R. Rockwood	Field expenses	27.50
31	92	Luther Wagoner	do	96.28
31	93	Robert Bucknell	Hire of transportation	10.00
31	94	Frank Harrison	Field expenses	158.12
31	95	E. S. Nettleton	Services, October, 1889	337.00
31	96	do	Field expenses	36.79
31	97	do	Traveling expenses	29.75
31	98	Josiah Pierce, jr	Services, October, 1889	134.80
31	99	Pay roll	do	537.47
31	100	E. C. Hawkins	do	125.00
31	101	R. P. Irving	do	50.00
31	102	T. M. Bannan	do	75.00
31	103	F. H. Newell	do	126.40
31	104	C. W. Taylor & Co	Office furniture	49.00
31	105	James M. Butcher	Field expenses	38.00
31	106	Daniels & Fisher	Office furniture	69.45
31	107	Lewis C. Goldsborough, agent	Office rent	17.50
Nov. 6	108	John B. Rogers	Traveling expenses	114.05
6	109	F. H. Hughes	Services, October 16 to 24, 1889	12.00
6	110	John B. Rogers	Field expenses	127.56
6	111	Lyman Bridges	Services, September, 1889	144.60
8	112	Harold M. Dyar	Field expenses	283.50
8	113	Sumner H. Bodfish	Services, October, 1889	202.20
8	114	W. L. Wilson	do	50.00
8	115	Pay roll	do	335.00
8	116	do	do	370.00
9	117	J. B. Williams	Traveling expenses	220.25
9	118	do	Field expenses	41.92
9	119	Pay roll	Services, October, 1889	297.70
11	120	S. H. Bodfish	Field expenses	83.55
12	121	Luther Wagoner	Traveling expenses	6.50
12	122	Keuffel & Esser	Instruments	33.00
12	123	A. Leitz & Co	Field expenses	27.50
12	124	Isaac Alter	Hire of transportation	80.00
12	125	A. Levy	Field supplies.	205.38
12	126	Ridgely Tilden	Traveling expenses	12.75
12	127	H. S. Davidson	do	8.00
13	128	George E. Curtis	Field expenses	17.75
13	129	C. E. Dutton	Traveling expenses	48.00
13	130	Keuffel & Esser	Instruments	23.90
13	131	N. A. Just	Field supplies.	63.35
13	132	A. J. Wiley	Field expenses	65.31
13	133	Utah Central Rwy	Transportation	.25
14	134	Montana Central Rwy	do	2.16
14	135	Montana Union Rwy	do	1.25
14	136	Denver & Rio Grande R. R	do	122.45
18	137	Denver Transit and Warehouse Co	Rent for storage	20.00
18	138	E. C. Hawkins	Traveling expenses.	11.15
18	139	Anderson Bros	Field supplies.	148.27
18	140	Pay roll	Services, October, 1889	506.61
18	141	Charles Whitney	do	28.38
18	142	William M. Fitzhugh	do	150.00
18	143	Wells, Fargo & Co., express	Transportation	15.95
18	144	W. W. Montague & Co	Field supplies.	20.50
18	145	C. R. Rockwood	Field expenses	100.97
18	146	H. S. Davidson	do	147.20
18	147	do	do	22.52
18	148	Luther Wagoner	do	145.96
18	149	P. McGee	Services, October, 1889	45.00
18	150	Buff & Berger	Instruments	365.45
19	151	Josiah Pierce, jr	Traveling expenses	89.86
19	152	H. M. Wilson	Field expenses	98.45
19	153	do	do	211.80
19	154	do	Traveling expenses	114.05
19	155	Pay roll	Services, October, 1889	399.99
19	156	do	do	534.33

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 20	157	H. M. Wilson	Traveling expenses	$84.00
20	158	T. M. Bannon	Field expenses	100.67
21	159	do	Traveling expenses	69.37
21	160	J. B. Williams	do	101.90
21	161	Thomas Riggs, jr	Supplies	10.00
21	162	S. H. Bodfish	Field expenses	127.75
22	163	do	do	143.14
22	164	do	Traveling expenses	30.00
22	165	Robert Robertson	Field expenses	285.49
23	166	Josiah Pierce, jr	Traveling expenses	206.87
23	167	Harold M. Dyar	do	46.25
26	168	William M. Fitzhugh	do	16.50
27	169	William P. Trowbridge, jr	Field expenses	62.50
27	170	R. S. Johnson	do	12.00
27	171	do	do	40.00
29	172	S. H. Bodfish	do	240.05
29	173	do	do	205.11
30	174	Pay roll	Services, November, 1889	1,086.66
30	175	S. H. Bodfish	do	195.60
30	176	Pay roll	do	210.66
30	177	S. H. Bodfish	Field expenses	80.44
30	178	H. P. Croft	Services, November, 1889	60.00
30	179	Pay roll	do	197.15
30	180	W. W. Follett	do	200.00
30	181	George E. Gresley Jackson	Services, November 1 to 12, 1889	40.00
30	182	F. J. Fernhof	Office fixtures	46.50
30	183	Pay roll	Services, November, 1889	385.00
30	184	do	do	200.00
30	185	do	do	132.50
30	186	William Ham. Hall	Services, October 1 to 31, 1889	337.00
30	187	do	Services, November, 1889	326.00
30	188	W. A. Farish	Field expenses	72.55
30	189	Pay roll	Services, November, 1889	209.00
30	190	John A. Roebling Sons & Co	Field supplies	38.34
30	191	Clot & Meese	do	63.00
30	192	R. S. Johnson	Forage and storage	142.28
30	193	S. H. Bodfish	Field expenses	179.85
30	194	Henry E. Kemp & Co	Field material	84.45
30	195	Go.dman & Co	Field supplies	59.06
30	196	N. F. Hoyt	Services, October, 1889	10.00
30	197	S. H. Bodfish	Traveling expenses	143.35
30	198	Guy Sterling	do	20.10
30	199	E. C. Hawkins	Services, November, 1889	125.00
30	200	Harold M. Dyar	do	75.00
30	201	Denver Transit and Warehouse Co	Rent for storage	20.00
30	202	Lewis C. Goldsborough	Rent of office	35.00
30	203	W. W. Montague & Co	Field material	12.25
30	204	Hooper & Jennings	Subsistence supplies	26.42
30	205	C. Bunting & Co	Field supplies	65.09
30	206	L. C. Fraser	Office rent	50.00
30	207	Hume & Else	Forage	32.50
30	208	L. D. Hopson	Services, November, 1889	75.00
30	209	S. P. McKnight	Services, November 21 to 27, 1889	20.00
30	210	Zero Thomas	Services, November 24 to 30, 1889	9.33
30	211	W. L. Wilson	Services, November 29 to 30, 1889	3.33
30	212	A. D. Foote	Services, November, 1889	244.60
30	213	N. J. Brown	do	45.00
30	214	W. L. Wilson	Traveling expenses	23.30
Dec. 9	215	W. W. Follett	do	41.43
9	216	do	Field expenses	42.66
9	217	Pay roll	Services, November, 1889	75.83
10	218	T. K. Walker	Field supplies	155.47
11	219	James A. Pinney	Stationery	49.85
11	220	Campbell & Stebbins	Field supplies	15.86
11	221	A. J. Wiley	Field expenses	88.32
11	222	Pay roll	Services, November, 1889	445.50
11	223	Harold M. Dyar	Field expenses	93.92
12	224	Luther Wagoner	Traveling expenses	3.00
12	225	C. R. Rockwood	do	28.00
12	226	J. B. Williams	Field expenses	18.70
13	227	Northern Pacific R. R.	Transportation	1.44
13	228	Keuffel & Esser	Instruments	65.00
16	229	William M. Fitzhugh	Field expenses	178.16
16	230	Lallie & Bailey	Repairs to instruments	46.00
17	231	D. H. Burtis	Instruments	36.00
18	232	J. B. Williams	Field expenses	94.65
19	233	W. W. Follett	do	226.76
19	234	W. H. Farish	do	122.39

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 19	235	John C. Parker	Office supplies	$9.65
19	236	Pay roll	Services, November, 1889	135.00
20	237	Henry J. Green	Instruments	60.30
20	238	J. Schultzbach	...do	24.00
31	239	A. D. Foote	Services, December, 1889	252.70
31	240	Pay roll	...do	1,443.86
31	241	W. B. Moses & Son	Office furniture	29.00
31	242	Francis Bridges	Services, Oct. 25 to Nov. 2, 1889	36.56
31	243	H. P. Croft	Services, December, 1889	60.00
31	244	W. W. Follett	...do	200.00
31	245	W. L. Wilson	...do	50.00
31	246	William Ham Hall	...do	337.00
31	247	Pay roll	...do	340.00
31	248	...do	...do	225.00
31	249	...do	...do	125.00
31	250	...do	...do	125.00
31	251	E. C. Hawkins	...do	125.00
31	252	Harold M. Dyar	...do	75.00
31	253	N. F. Hoyt	Services, November, 1889	10.00
31	254	Pay roll	Services, December, 1889	205.80
31	255	William R. Cartwright	Services, November, 1889	7.50
31	256	...do	Services, December, 1889	7.50
31	257	T. M. Bannon	Field expenses	198.90
31	258	Keuffel & Esser Co	Stationery	42.50
31	259	C. R. Rockwood	Services, December, 1889	150.00
31	260	William P. Trowbridge, jr	Field expenses	72.83
31	261	L. C. Fraser	Rent of office	50.00
31	262	Goldman & Co	Field supplies	86.37
31	263	J. J. Lallie	Repairs to instruments	18.30
31	264	Harold M. Dyar	Field expenses	50.00
31	265	A. D. Foote	...do	9.15
31	266	...do	Traveling expenses	64.50
31	267	Lewis C. Goldsborough	Rent of office	35.00
31	268	James M. Butcher	Office furniture, etc.	32.50
31	269	Denver Transit and Warehouse Co	Rent of storage	20.00
31	270	E. C. Hawkins	Field expenses	54.85
31	271	L. D. Hopson	Instruments	7.50
31	272	Library bureau	Office supplies	288.00
31	273	Amos G. Thompson	...do	15.00
31	274	A. J. Wiley	...do	2.75
31	275	W. W. Follett	Traveling expenses	7.65
31	276	...do	Field expenses	39.45
31	277	Samuel McDowell	Forage	20.00
31	278	Luther Wagoner	Field expenses	24.19
31	279	C. R. Rockwood	...do	78.35
31	280	...do	Traveling expenses	30.25
31	281	M. A. Knapp	...do	4.00
31	282	Pay roll	Services, December, 1889	135.00
31	283	William P. Trowbridge, jr	Field expenses	33.17
31	284	William D. Walkup	Office expenses	13.35
31	285	Wood & Turner	Field material	21.30
31	286	Scott & Mills	Office expenses	18.25
31	287	Britton & Ray	Maps	63.00
31	288	W. A. Montgomery	Field expenses	10.00
31	289	O. I. Mairs	Subsistence	44.50
31	290	Edward Denny & Co	Stationery	24.15
31	291	Overland Freight Transfer Co	Storage	10.00
31	292	A. W. Eibeshritz	Hire of transportation	120.00
31	293	H. S. Davidson	Traveling expenses	28.95
31	294	George Sandow	Field expenses	47.66
31	295	F. H. Newell	...do	239.20
31	296	...do	Traveling expenses	79.70
31	297	Rich Shumway	Services, November, 1889	50.00
31	298	...do	Services, December 1 to 17, 1889	27.41
31	299	George E. Curtis	Field expenses	7.35
31	300	E. S. Nettleton	Services, November, 1889	326.00
31	301	...do	Traveling expenses	54.50
		Total		34,491.46

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 15	1	H. E. Clermont Feusier	Field expenses	$61.80
15	2	...do	...do	26.25
15	3	E. M. Douglas	...do	75.45
15	4	A. F. Dunnington	...do	29.45
15	5	Redick H. McKee	...do	104.97
16	6	Robert Muldrow	...do	38.75
16	7	R. H. Chapman	...do	46.88
16	8	H. E. Clermont Feusier	...do	51.20
18	9	E. M. Douglas	...do	90.07
18	10	E. T. Perkins, jr.	..do	29.75
18	11	William M. Thompson	Supplies	58.03
18	12	Alexander C. Barclay	Field expenses	50.85
18	13	...do	...do	80.60
18	14	Robert A. Farmer	...do	38.00
18	15	C. C. Bassett	...do	110.44
18	16	Perry Fuller	...do	42.00
18	17	Robert B. Marshall	...do	34.65
18	18	Morris Bien	...do	40.70
18	19	William S. Post	...do	384.43
18	20	Pay roll for September	Colorado field party	100.00
19	21	S. C. Gallup	Material	6.50
19	22	Silas Parker	...do	27.70
19	23	Sparks Bros	Forage	22.50
19	24	J. L. Van Arsdell	...do	19.00
19	25	Harry King	Traveling expenses	64.80
19	26	L. Landecker	Supplies	15.86
19	27	A. F. Dunnington	Field expenses	63.51
19	28	W. T. Griswold	...do	65.88
21	29	W. P. Powell	Traveling expenses	29.65
22	30	Perry Fuller	Field expenses	58.25
22	31	Stuart P. Johnson	...do	103.03
22	32	...do	...do	123.59
22	32	William H. Anderson	Forage	562.50
22	34	A. H. Thompson	Traveling expenses	117.95
22	35	...do	...do	186.10
22	36	H. E. Clermont Feusier	Field expenses	54.50
22	37	Robert B. Marshall	...do	21.35
22	38	C. C. Bassett	...do	80.47
23	39	P. V. S. Bartlett	...do	47.42
23	40	...do	...do	96.55
23	41	A. P. Davis	...do	52 55
24	42	Alexander C. Barclay	...do	32.35
25	43	C. H. Fitch	...do	66.11
25	44	...do	Traveling expenses	66.40
25	45	John W. Hays	Field expenses	10.45
25	46	...do	...do	148.42
26	47	L. G. Stevenson	Traveling expenses	38.55
28	48	William S. Post	Field expenses	55.45
28	49	R. H. Chapman	...do	47.96
28	50	Redick H. McKee	...do	71.71
31	51	Charles C. Bassett	Services, October 16 to 31, 1889	60.87
31	52	Pay roll for October	New Mexico field party	288.91
31	53	...do	...do	443.80
31	54	...do	Nevada field party	202.20
31	55	...do	...do	307.18
31	56	...do	...do	196.35
31	57	...do	...do	273.50
31	58	...do	...do	250.00
31	59	...do	...do	242.07
31	60	...do	Colorado field party	438.85
31	61	...do	...do	229.49
31	62	...do	Idaho field party	604.58
31	63	...do	Colorado field party	800.87
31	64	J. M. Dikeman	Services October 1 to 24, 1889	34.80
31	65	October pay roll	Colorado field party	131.52
31	66	Paul Holman	Services, October, 1889	70.80
31	67	A. H. Thompson	...do	252.70
31	68	H. C. Rizer	...do	185.30
31	69	October pay roll	Colorado field party	287.54
31	70	J. D. Reeves	Forage	52.79
Nov. 1	71	J. W. Simons	Labor and material	45.85
1	72	B. Freund	Storage	15.00
2	73	W. F. Griswold	Field expenses	48.70
2	74	Roswell G. Wheeler	Pasturage	20.59
2	75	E. T. Perkins, jr.	Field expenses	22.45
2	76	...do	Traveling expenses	3.25
4	77	William T. Post	Field expenses	142.08
4	78	William A. Korts	Services, September 1 to October 1889.	50.00

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 4	79	Samuel A. Foot	Traveling expenses	$69.10
4	80	R. C. McKinney	Field expenses	94.76
8	81	D. Johnson	Board and lodging	55.16
4	82	John R. Morton	Services, October 16 to 19, 1889	5.80
4	83	Benjamin K. Hays	Services, October 24 to 31, 1889	15.48
5	84	R. H. Chapman	Services, October 16 to 31, 1889	60.87
5	85	Robert Muldrow	Services, October 23 to 31, 1889	22.01
5	86	H. E. Clermont Feusier	Field expenses	122.00
5	87	H. D. Reinken	Supplies	32.08
5	88	Robert A. Farmer	Field expenses	60.75
5	89	Jeremiah Ahern	...do	140.07
5	90	October pay roll	Montana field party	630.51
6	91	J. B. Lippincott	Field expenses	56.43
6	92	S. M. Fitzgerald	Hire of teams	54.00
6	93	E. M. Douglas	Field expenses	135.69
7	94	Oppenlander, Rehm & Co	Supplies	36.16
7	95	L. F. Spratlen	Material	45.00
7	96	George A. Newton	Labor	13.50
7	97	Spratlen & Anderson	Supplies	54.42
7	98	Pueblo Hardware Co.	Material	15.12
7	99	A. F. Dunnington	Field expenses	42.40
7	100	A. H. Thompson	Traveling expenses	140.75
7	101	Daniel M. Adams	...do	24.55
7	102	C. C. Bassett	...do	76.00
7	103	...do	Field expenses	67.24
7	104	P. V. S. Bartlett	...do	58.50
8	105	Frank Tweedy	...do	241.56
9	106	W. B. Corse	Services, October, 1889	60.00
11	107	Stuart P. Johnson	Traveling expenses	62.90
11	108	E. T. Perkins, jr	Services, October 16 to 31, 1889	69.57
11	109	William S. Post	Field expenses	39.92
11	110	Alan M. Johnsou	Traveling expenses	50.25
11	111	Willard D. Johnson	Field expenses	97.24
11	112	...do	...do	102.75
12	113	Newton Lumber Company	Material	20.35
14	114	W. T. Griswold	Field expenses	125.99
14	115	Jeremiah Ahern	Services, October 16 to 31, 1889	60.87
15	116	William H. Otis	Services, November 1 to 15, 1889	20.00
15	117	Samuel McDowell	Pasturage	40.00
15	118	Robert A. Farmer	Field expenses	51.27
15	119	E. M. Douglas	...do	130.79
16	120	R. S. Woodward	...do	108.92
18	121	Redick H. McKee	...do	57.76
18	122	A. F. Dunnington	Traveling expenses	125.25
18	123	Philip Sawyer	...do	29.00
18	124	...do	...do	94.50
18	125	...do	Services, September 1 to 30, 1889	60.00
19	126	John W. Hays	Traveling expenses	67.65
19	127	Paul Holman	...do	132.00
19	128	Arthur P. Davis	...do	75.75
19	129	Julien J. Mason	...do	75.75
19	130	Perry Fuller	...do	91.10
19	131	Robert Muldrow	...do	133.30
20	132	H. E. Clermont Feusier	Field expenses	94.05
20	133	...do	...do	42.50
19	134	R. B. Marshall	...do	77.65
21	135	A. H. Thompson	Traveling expenses	54.25
21	136	R. C. McKinney	Services, October 26 to 31, 1889	22.83
21	137	...do	Traveling expenses	68.15
21	138	Morris Bien	...do	68.15
21	139	Robert J. Breckinridge	...do	68.90
21	140	Louis William Mohun	...do	68.90
21	141	Willard D. Johnson	...do	68.90
22	142	William S. Post	...do	61.60
22	143	E. T. Perkins, jr	...do	69.50
22	144	Ewing Speed	...do	69.50
22	145	William A. Earl	...do	9.50
23	146	Alexander C. Barclay	Field expenses	56.42
25	147	L. B. Kendall	Traveling expenses	66.40
25	148	Morris Bien	Field expenses	111.87
26	149	Frank Tweedy	Traveling expenses	110.45
26	150	Frank E. Gove	...do	101.45
30	151	Pay roll for November	Colorado party	1,143.80
30	152	...do	...do	100.00
30	153	...do	Nevada party	177.00
30	154	...do	New Mexico party	299.49
30	155	...do	Idaho party	180.40
30	156	Robert A. Farmer	Services, November, 1889	60.00

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 30	157	A. F. Dunnington	Services, November, 1889	$146.80
30	158	Robert Muldrow	...do	73.40
30	159	Paul Holman	...do	68.40
30	160	R. B. Marshall	...do	60.00
30	161	Julien J. Mason	...do	50.00
30	162	A. H. Thompson	...do	244.60
30	163	Charles C. Bassett	...do	114.20
30	164	J. W. Dobbins	...do	50.00
30	165	William H. Otis	Services, November 16 to 30, 1889	12.50
30	166	H. C. Rizer	Services, November	179.40
Dec. 2	167	W. T. Griswold	...do	163.00
2	168	...do	Field expenses	106.50
2	169	Gross, Blackwell & Co	Supplies	24.90
2	170	Alexander C. Barclay	Field expenses	11.22
2	171	...do	...do	12.90
2	172	P. V. S. Bartlett	Traveling expenses	125.00
2	173	Redick H. McKee	...do	128.35
2	174	H. E. Clermont Feusier	...do	129.35
2	175	R. B. Marshall	...do	78.80
2	176	P. V. S. Bartlett	Services, November, 1889	60.00
Nov. 26	177	Western Union Telegraph Company	Messages	2.57
Dec. 7	178	Frank Tweedy	Field expenses	10.46
3	179	A. F. Dunnington	Telegrams	.80
7	180	J. B. Lippincott	Traveling expenses	95.25
7	181	Frank E. Gove	Services, November, 1889	60.00
9	182	R. S. Woodward	Field expenses	153.75
9	183	...do	Traveling expenses	112.70
9	184	H. C. Rizer	...do	45.50
9	185	Robert A. Farmer	...do	67.15
9	186	W. B. Corse	...do	76.55
10	187	Jeremiah Ahern	...do	93.20
10	188	R. C. McKinney	...do	16.75
10	189	MacGregor Jenkins	...do	104.75
10	190	R. H. Chapman	...do	131.00
10	191	E. M. Douglas	...do	123.50
3	192	R. H. Chapman	Field expenses	1.45
11	193	Charles W. Powell	Services, November, 1889	60.00
11	194	James Moore	Services, November 1 to 18, 1889	29.95
11	195	Frank Tweedy	Services, November, 1889	146.80
12	196	Jeremiah Ahern	...do	114.20
12	197	H. C. Danberg	Foraging stock	85.05
12	198	H. E. Clermont Feusier	Services, November, 1889	60.00
12	199	...do	Field expenses	3.26
12	200	Arthur P. Davis	...do	40.25
12	201	P. V. S. Bartlett	...do	165.10
13	202	E. M. Douglass	...do	97.71
16	203	Wade Lenington	Services, December 1 to 12, 1889	15.48
14	204	L. H. Cooper	Traveling expenses	85.25
14	205	Redick H. McKee	Services, October 16 to November 30, 1889.	199.97
16	206	...do	Field expenses	24.25
18	207	W. T. Griswold	Traveling expenses	19.95
18	208	...do	...do	177.61
3	209	...do	Telegrams	2.20
19	210	Amos Scott	Services, November, 1889	60.00
3	211	J. W Hays	Telegrams	8.18
31	212	H. C. Danberg	Forage of stock	90.00
28	213	Alexander C. Barclay	Traveling expenses	67.15
31	214	J. W. Dobbins	Services, December, 1889	50.00
31	215	William H. Otis	...do	25.00
31	216	A. H. Thompson	...do	252.70
31	217	Paul Holman	...do	70.80
31	218	Pay roll for December	Colorado party	1,298.10
31	219	...do	New Mexico, Idaho, and Montana parties.	1,079.20
31	220	...do	Nevada party	954.10
31	221	E. M. Douglas	Field expenses	44.14
31	222	Alexander C. Barclay	...do	20.17
31	223	Fauth & Co	Material	3.00
31	224	John C. Rogers	...do	5.25
		Total		25,447.34

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during January, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 11	2	Wash B. Williams	Supplies	$142.50
17	12	Pennsylvania Co	Transportation of assistants	35.00
17	13	Denver and Rio Grande R. R	...do	50.20
17	16	Colorado Midland Rwy	...do	12.85
21	28	United States Express Co	Freight	27.40
21	29	Wyckoff, Seamans & Benedict	Irrigation supplies	2.20
21	30	Melville Lindsay	...do	2.25
21	34	Newman & Son	Repairs to typewriter	2.50
21	37	E. E. Jackson & Co	Miscellaneous supplies	9.00
25	40	Oregon Railway and Navigation Co	Transportation of assistants	13.88
24	43	Department of the Interior	Irrigation supplies	62.88
31	55	George Ryneal, jr	Supplies	119.00
31	56	C. C. Willard	Office rent, January 7 to 31, 1890	215.00
31	73	Pay roll of employés	Pay for January, 1890	1,161.62
		Total		1,856.28

Abstract of Disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during January, 1890

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 17	1	A. B. Ely	Stock	$75.00
17	2	Henry J. Green	Instruments	3.15
22	3	T. M. Bannan	Field expenses	10.00
22	4	...do	Traveling expenses	56.55
27	5	Gore, Janey & Co	Office furniture	85.00
27	6	Anson Mills	Field expenses	199.22
28	7	The Columbia Phonograph Co	Office expenses	3.35
28	8	W. A. Farish	Field expenses	130.98
31	9	H. P. Croft	Services, January, 1890	60.00
31	10	Harold M. Dyar	...do	75.00
31	11	A. D. Foote	...do	258.30
31	12	Pay roll	...do	240.00
31	13	E. S. Nettleton	...do	344.40
31	14	John B. Rogers	...do	125.00
21	15	Sumner H. Bodfish	...do	206.70
31	16	Pay roll	...do	292.80
31	17	...do	...do	630.86
31	18	W. L. Wilson	...do	50.00
31	19	W. W. Follett	...do	200.00
31	20	Library Bureau	Office supplies	5.52
31	21	F. H. Newell	Field expenses	65.83
		Total		3,117.66

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during January, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 9	1	Charles W. Howell	Services, December 1 to 31, 1889	$60.00
9	2	William Kronig	Forage	72.45
11	3	Monroe Sonnichsen	Traveling expenses	30.25
14	4	E. M. Douglas	Field expenses	38.22
31	5	Pay roll for January	Office force	1,338.20
31	6	...do	...do	1,868.70
31	7	Julien J. Mason	Services, January, 1890	50.00
31	8	Ewing Speed	...do	50.00
31	9	Louis William Mohun	...do	60.00
31	10	H. C. Rizer	...do	189.40
31	11	J. W. Dobbins	...do	50.00
31	12	William H. Otis	...do	25.00
31	13	A. H. Thompson	...do	258.30
31	14	C. H. Fitch	...do	155.00
		Total		4,245.52

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during February, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 12	1	Robert Boyd	Supplies	$19.23
12	3	W. H. Lowdermilk & Co	Publications	25.00
14	16	Newman & Son	Supplies	1.70
14	17	Julius Lansburgh	...do	2.55
17	20	...do	...do	17.48
17	22	W. B. Moses & Son	...do	106.23
25	26	Adams Express Co	Freight charges	51.15
26	27	E. E. Jackson & Co	Irrigation supplies	19.30
26	28	George Ryneal, jr	Supplies	79.43
27	29	Chicago, Burlington and Northern R. R.	Freight	1.71
28	31	George W. Knox	Freight charges	70.00
28	32	C. C. Willard	Office rent, February, 1890	266.66
28	38	Wash. B. Williams	Supplies	24.32
28	39	Adams Express Co	Freight charges, November, 1889	246.68
28	40	The Texas and Pacific Rwy	Transportation of assistants	59.25
28	46	James J. Seymour	Services, February, 1890	50.00
28	54	Pay roll of employés	...do	1,106.40
		Total		2,147.09

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during February, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 4	22	Anson Mills	Field expenses	$5.00
4	23	Pay roll	Services, January, 1890	190.00
4	24	...do	.. do	225.00
5	25	M. A. Knapp	Services, January 1 to 27, 1890	43.55
5	26	C. R. Rockwood	...do	116.13
5	27	William Ham Hall	Services, January, 1890	344.40
6	28	W. W. Follett	Field expenses	144.80
6	29	Pay roll	Services, January, 1890	20.00
10	30	L. C. Fraser	Office rent	50.00
10	31	M. H. Jones	Subsistence supplies	25.29
10	32	E. C. Hawkins	Services, January, 1890	125.00
10	33	Lewis C. Goldsborough	Office rent	35.00
10	34	Denver Transit and Warehouse Co	Rent of storage	20.00
10	35	J. L. Armstrong	Services, July 1 to December 31, 1889	79.50
11	36	George Glover	Drawing table	16.00
11	37	A. J. Wiley	Field expenses	7.75
11	38	Pay roll	Services, January, 1890	207.50
11	39	W. H. Farish	Field expenses	177.43
13	40	W. & L. E. Gurley	Instruments	125.00
13	41	...do	...do	1.58
15	42	William P. Trowbridge, jr	Field expenses	32.85
15	43	...do	Traveling expenses	7.50
17	44	J. B. Williams	Field expenses	28.65
17	45	Fauth & Co	Instruments	100.00
17	46	John C. Parker	Office supplies	5.12
18	47	E. W. Woodruff	.. do	3.00
28	48	H. P. Croft	Services, February, 1890	60.00
28	49	A. D. Foote	...do	233.40
28	50	Pay roll	...do	618.26
28	51	...do	. do	264.40
28	52	John B. Rogers	...do	125.00
28	53	Sumner H. Bodfish	. do	186.60
28	54	E. S. Nettleton	..do	311.20
28	55	Standard Thermometer Co	Instruments	120.00
28	56	Pay roll	Services, February, 1890	240.00
28	57	Harold M. Dyar	...do	75.00
28	58	W. W. Follett	...do	200.00
28	59	W. L. Wilson	...do	50.00
28	60	F. H. Newell	Field expenses	67.00
		Total		4,686.91

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during February, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 8	1	Atchison, Topeka and Santa Fé R. R.	Material	$8.10
8	2	Spratten & Anderson	...do	4.80
8	3	...do	...do	3.00
10	4	H. C. Danberg	Feed, and care of stock in January	90.00
10	5	Alexander C. Barclay	Field expenses	12.00
12	6	Charles W. Howell	Services in January	60.00
28	7	H. C. Danberg	Feed, and care of stock in February	90.00
28	8	Amos Scott	Services in December	60.00
28	9	...do	Services in January and February	120.00
28	10	Charles W. Howell	Services in February	60.00
28	11	J. W. Dobbins	...do	50.00
28	12	William H. Otis	...do	25.00
28	13	Ewing Speed	...do	50.00
28	14	Julien J. Mason	...do	50.00
28	15	Louis William Mohun	...do	60.00
28	16	Pay roll for February	Office employés	1,208.60
28	17	...do	...do	1,065.40
28	18	...do	...do	1,026.80
28	19	C. H. Fitch	Services in February	140.00
		Total		4,183.70

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey, during March, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Mar. 6	3	Julius Lansburgh	Supplies	$14.25
11	16	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	26.90
11	17	William D. Clarke & Co	Supplies	8.45
14	20	Office Specialty Manufacturing Co	...do	17.50
14	21	Pennsylvania R. R	Transportation of assistants	59.00
18	31	John C. Parker	Supplies	2.00
22	40	Belt & Dyer	...do	78.00
25	43	Julius Lansburgh	Irrigation supplies	8.74
29	50	George Ryneal, jr	Supplies	67.52
31	60	Pay roll of employés	Services, March, 1890	1,218.30
31	74	Atlantic and Pacific R. R	Transportation of assistants	5.75
31	75	Chicago and Northwestern R. R	...do	12.50
31	76	C. C. Willard	Rent of office, March, 1890	266.66
		Total		1,785.57

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during March, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Mar. 3	61	Pay roll	Services, February, 1890	$176.78
3	62	Lewis C. Goldsborough	Rent of office	35.00
3	63	Denver Transit and Warehouse Co	Rent of store room	20.00
3	64	E. C Hawkins	Services, February, 1890	125.00
3	65	Pay roll	...do	20.00
3	66	J. B. Williams	Field expenses	12.60
3	67	George Sandow	...do	14.99
3	68	...do	Services, February 1 to 18, 1890	96.43
3	69	Wm. Ham Hall	Services, February, 1890	311.20
3	70	B. F. Groves	Traveling expenses	35.60
4	71	Keuffle & Esser Company	Instruments	15.00
4	72	W. W. Follett	Traveling expenses	22.85
4	73	...do	Field expenses	92.25
6	74	L. C. Fraser	Rent of office	50.00
6	75	Frank M. Smith	Traveling expenses	51.50
6	76	Anson Mills	Field expenses	5.00
8	77	Gerald F. Sherman	Services, February 10 to 22, 1890	34.82
8	78	Pay roll	Services, February, 1890	207.50
8	79	Harold M. Dyar	Field expenses	50.80
13	80	L. D. Hopson	...do	44.85
13	81	...do	Traveling expenses	38.50
13	82	W. A. Farish	Field expenses	57.36
15	83	F. Daugle	Field supplies	29.23
17	84	Wm. P. Trowbridge, jr	Services, February 22 to 28, 1890	25.00
17	85	Frank P. Thwaites	Field expenses	11.75
17	86	Frank R. Coffin & Bro	Field supplies	69.25
18	87	R. P. Irving	Traveling expenses	34.15
18	88	Robert Robertson	...do	74.85
20	89	B. F. Groves	...do	14.94
24	90	L. D. Hopson	Field expenses	59.10
25	91	F. H. Newell	...do	105.55
26	92	J. B. Williams	Traveling expenses	117.60
31	93	Wm. Ham Hall	Services, March, 1890	344.40
31	94	Pay roll	...do	210.48
31	95	...do	...do	144.68
31	96	L. D. Hopson	...do	75.00
31	97	Pay roll	...do	75.00
31	98	Curt. W. Miller	...do	20.00
31	99	Pay roll	...do	150.00
31	100	...do	...do	143.38
31	101	W. W. Follett	...do	200.00
31	102	W. L. Wilson	...do	50.00
31	103	Pay roll	...do	292.80
31	104	...do	...do	295.86
31	105	Sumner H. Bodfish	...do	206.70
31	106	Jno. B. Rodgers	...do	125.00
31	107	A. D. Foote	...do	258.30
31	108	J. B. Williams	...do	100.00
31	109	E. S. Nettleton	...do	344.40
31	110	Main & Winchester	Field material	20.50
31	111	Clot & Meese	...do	90.00
31	112	B. F. Groves	Traveling expenses	4.25
31	113	F. M. Smith	Field expenses	63.88
31	114	H. P. Croft	Services, March, 1890	60.00
31	115	Harlen Pefley	Field material, etc	77.00
31	116	A. D. Foote	Traveling expenses	66.00
31	117	Lewis C. Goldsborough	Rent of office	35.00
31	118	Denver Transit and Warehouse Co	Rent of store room	20.00
31	119	L. C. Rice	Electrical supplies	43.55
31	120	E. C. Hawkins	Services, March, 1890	125.00
31	121	J. L. Armstrong	Services, January 1 to March 31, 1890.	27.00
31	122	Hendrie and Bolthoff Manufacturing Company.	Field material	29.40
31	123	J. J. Lallie	Repairs to instruments	61.65
31	124	W. E. Scott & Co	...do	16.45
31	125	N. F. Hoyt	Services, January 1 to March 31, 1890.	80.00
		Total		5,865.13

Abstract of disbursements made by H. C. Rizer, disbursing agent U. S. Geological Survey, during March, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Mar. 4	1	Wm. Kronig	Feed and care of stock	$64.67
4	2	...do	...do	62.50
5	3	Isaiah Rendell	...do	12.00
6	4	P. E. Harroun	Labor	3.00
18	5	E. T. Perkins, jr	Telegrams	.87
24	6	John H. Hughes	Material	30.00
31	7	C. L. Walker	Storage	6.00
31	8	John Hartmann	...do	6.00
31	9	Spratlen & Anderson	Material	2.40
31	10	...do	...do	3.00
31	11	H. C. Dangberg	Feed and care of stock	90.00
31	12	J. W. Dobbins	Services, March, 1890	50.00
31	13	Wm. H. Otis	...do	25.00
31	14	Chas. W. Howell	...do	60.00
31	15	Amos Scott	...do	60.00
31	16	Julien J. Mason	...do	50.00
31	17	Ewing Speed	...do	50.00
31	18	Lewis William Mohun	...do	60.00
31	19	C. H. Fitch	...do	155.00
31	20	Pay roll	Office force, March, 1890	1,179.80
31	21	...do	...do	1,136.60
31	22	...do	...do	1,338.20
		Total		4,445.04

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk U. S. Geological Survey, during April, 1890—Irrigation.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
April 9	2	E. E. Jackson & Co	Supplies	$9.60
9	3	George Ryneal, jr	...do	10.00
11	10	Adams Express Co	Freight, December, 1889	7.40
11	11	...do	Freight, January, 1890	.60
11	12	...do	Freight, February, 1890	4.15
15	13	Richard J. Hinton	Services, April 1 to 15, 1890	75.00
19	21	United States Express Co	Freight, November, 1889, to February 28, 1890.	99.40
30	32	Columbia Phonograph Co	Services	12.00
30	33	C. C. Willard	Rent of office, April, 1890	266.66
30	43	Pay roll of employés	Services, April, 1890	1,032.50
		Total		1,517.31

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during April, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
April 3	1	John A. Roebling's Son's Co	Field material	$64.43
3	2	Fred A. Daugle	Field supplies	30.24
3	3	Harlen Petley	Field material	41.00
3	4	Frank R. Coffin & Bro	...do	232.88
4	5	George E. Curtis	Field expenses	10.25
4	6	Ott, Mergenthaler & Co	Instruments	17.00
8	7	L. C. Fraser	Office rent	50.00
8	8	Harold M. Dyar	Services, March, 1890	75.00
8	9	William B. Lane	Services, March 7 to 31, 1890	48.38
9	10	E. C. Hawkins	Field expenses	44.60
9	11	Harold M. Dyar	...do	93.60
9	12	...do	Traveling expenses	81.30
9	13	W. W. Follett	...do	17.25
9	14	...do	Field expenses	138.54
9	15	A. J. Wiley	Services, March 1 to 14, 1890	56.45
16	16	W. R. Cartwright	Services, March, 1890	7.50
16	17	William P. Trowbridge, jr	Field expenses	43.16
16	18	Frank P. Thwaites	...do	8.75
16	19	Clot & Meese	Instruments	10.00
16	20	W. A. Farish	Field expenses	71.05
17	21	F. M. Smith	...do	27.94
17	22	William P. Trowbridge, jr	...do	22.21
18	23	T. M. Bannon	...do	177.89
18	24	Robert Robertson	...do	99.50
18	25	L. D. Hopson	...do	60.62
19	26	J. B. Williams	...do	54.40
21	27	Robert Robertson	Traveling expenses	74.85
23	28	T. M. Bannon	Field expenses	186.47
25	29	William P. Trowbridge, jr	...do	61.26
25	30	...do	Traveling expenses	10.25
25	31	G. F. Wakefield	...do	12.00
25	32	T. M. Bannon	...do	77.00
25	38	J. B. Williams	...do	64.55
25	34	...do	...do	171.85
28	35	...do	Field expenses	114.15
28	36	Robert Robertson	...do	177.50
31	37	Pay roll	Services, April, 1890	280.20
31	38	...do	...do	210.00
31	39	...do	...do	290.26
31	40	John B. Rogers	...do	125.00
31	41	Sumner H. Bodfish	...do	197.80
31	42	Pay roll	...do	150.00
31	43	...do	...do	150.00
31	44	...do	...do	165.00
31	45	...do	...do	173.66
31	46	...do	...do	210.00
31	47	A. D. Foote	...do	247.25
31	48	T. M. Bannon	...do	75.00
31	49	Harold M. Dyar	...do	75.00
31	50	William B. Lane	...do	60.00
31	51	W. W. Follett	...do	200.00
31	52	W. L. Wilson	...do	50.00
31	53	E. C. Hawkins	...do	125.00
31	54	Curt W. Miller	...do	20.00
31	55	Frank P. Thwaites	...do	75.00
31	56	Lewis C. Goldsborough	Rent of office	35.00
31	57	Denver Transit and Warehouse Co	Rent of storeroom	20.00
31	58	Harold M. Dyar	Field expenses	75.21
31	59	...do	Traveling expenses	40.55
31	60	Eugene Lichtenberg	Field expenses	25.00
31	61	Anderson Bros	Field supplies	62.61
31	62	Frank R. Coffin & Bro	...do	31.25
31	63	Fred Daugle	Subsistence supplies	28.16
		Total		5,730.77

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during April, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
Apr. 3	1	John Sunderland	Storage	$9.00
3	2	Gross, Blackwell & Co	Material	14.75
7	3	William Kronig	Feed and care of stock	72.57
8	4	Samuel McDowell	Forage	98.00
16	5	J. W. Dobbins	Traveling expenses	10.05
16	6	....do	Field expenses	54.18
16	7	....do	....do	10.33
16	8	....do	....do	.90
16	9	S. C. Gallup	Material	8.60
21	10	Northern Pacific R. R	Labor and material	20.00
30	11	H. C. Dangberg	Feed and care of stock	90.00
30	12	Charles W. Howell	Services, April, 1890	60.00
30	13	J. W. Dobbins	....do	50.00
30	14	William H. Otis	....do	25.00
30	15	Ewing Speed	....do	50.00
30	16	Julien J. Mason	....do	50.00
30	17	Louis William Mohun	....do	60.00
30	18	C. H. Fitch	....do	148.30
30	19	Pay roll	Office employés	1,087.85
30	20	....do	....do	1,129.10
30	21	....do	....do	1,280.90
		Total		4,329.53

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey, during May, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 8	14	George Ryneal, jr	Material and supplies	$31.14
8	15	L. H. Schneider's Son	....do	.60
13	24	Denver and Rio Grande R. R	Transportation of assistants	6.90
17	29	M. W. Beveridge	Supplies	.50
28	48	E. E. Jackson & Co	Irrigation supplies	8.60
31	70	Pay roll of employés	Services, May, 1890	582.40
31	74	C. C. Willard	Rent of office	266.66
		Total		896.80

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during May, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 5	64	L. C. Fraser	Rent of office	$50.00
5	65	H. P. Croft	Services, April, 1890	60.00
5	66	William Ham Hall	...do	329.70
7	67	W. W. Follett	Field expenses	148.22
10	68	L. D. Hopson	Traveling expenses	9.25
10	69	...do	Field expenses	64.75
12	70	Frank R. Coffin & Bro	Field material	53.50
12	71	Thomas Brinson	...do	105.00
12	72	J. Raycroft	Hire of field transportation	38.00
12	73	J. B. Williams	Traveling expenses	165.60
13	74	...do	Field expenses	46.13
13	75	W. H. Farish	...do	244.72
14	76	F. H. Newell	...do	80.00
14	77	Robert Robertson	...do	158.76
15	78	William P. Trowbridge, jr	...do	62.82
15	79	Frank P. Thwaites	...do	14.70
15	80	...do	Traveling expenses	10.50
17	81	Anson Mills	Field expenses	28.46
19	82	F. M. Smith	...do	116.24
17	83	P. H. Christie	...do	45.55
20	84	R. S. Johnson	...do	33.80
20	85	...do	...do	6.50
20	86	...do	...do	6.50
20	87	Hume & Else	...do	10.00
20	88	Conrad & Conrad	...do	20.75
20	89	J. C. Smith	Forage of stock	55.70
20	90	Overland Freight Transfer Co	Storage	20.00
20	91	M. H. Jones	...do	9.00
20	92	E. S. Nettleton	Services, April 1 to 15, 1890	164.84
23	93	T. M. Bannon	Field expenses	186.52
23	94	...do	...do	149.62
23	95	J. B. Williams	...do	22.89
24	96	Harold M. Dyar	...do	40.33
24	97	...do	Traveling expenses	55.35
26	98	J. B. Williams	...do	94.70
31	99	Pay roll	Services, May, 1890	137.10
31	100	...do	...do	289.60
31	101	Pay roll	...do	294.46
31	102	John B. Rogers	...do	125.00
31	103	Sumner H. Bodfish	...do	204.40
31	104	Harold M. Dyar	...do	75.00
31	105	William B. Lane	...do	60.00
31	106	Frank P. Thwaites	...do	75.00
31	107	William Ham Hall	...do	340.60
31	108	W. W. Follett	...do	200.00
31	109	Curt W. Miller	...do	20.00
31	110	A. D. Foote	...do	255.50
31	111	Robert Robertson	Field expenses	96.60
31	112	Pay roll	Services May, 1890	150.00
31	113	E. C. Hawkins	...do	125.00
31	114	Denver Transit and Warehouse Co.	Rent	20.00
31	115	W. W. Follett	Field expenses	94.90
31	116	...do	Traveling expenses	40.25
		Total		5,311.84

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during May, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 6	1	Asahel Russell	Forage	$30.00
8	2	Robert Cameron	Supplies	12.50
12	3	Bibo & Block	...do	13.94
14	4	A. P. Davis	Traveling expenses	28.30
16	5	Gross, Blackwell & Co	Forage	3.13
31	6	C. H. Fitch	Services, May, 1890	153.40
31	7	Arthur P. Davis	...do	170.40
31	8	Ewing Speed	...do	50.00
31	9	Julien J. Mason	...do	50.00
31	10	Pay roll	...do	953.90
31	11	...do	...do	1,166.80
31	12	...do	...do	1,323.20
31	13	Charles W. Howell	...do	60.00
31	14	J. W. Dobbins	...do	50.00
31	15	William H. Otis	...do	25.00
31	16	H. C. Dangberg	Feed and care of stock	90.00
		Total		4,180.57

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during June. 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 7	13	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	$48.60
18	60	H. M. Wilson	Services, January 1 to April 30, 1890	797.80
21	62	George Ryneal, jr	Supplies	4.65
30	101	C. C. Willard	Rent for June, 1890	266.66
30	114	Pay roll of employés	Services, June, 1890	561.80
		Total		1,679.51

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during June; 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 2	117	Robert Robertson	Traveling expenses	$89.85
3	118	Oliver Roberts	Subsistence	28.00
3	119	W. L. Wilson	Services, May 1 to 10, 1890	16.12
3	120	H. P. Croft	Services, May, 1890	60.00
3	121	Pay roll	...do	195.00
4	122	R. W. Parry	Forage of stock	62.00
4	123	Arcade Hotel	Subsistence	59.62
4	124	T. M. Bannon	Services, May, 1890	75.00
7	125	Pay roll	...do	270.00
16	126	H. M. Wilson	...do	204.40
16	127	L. C. Goldsborough	Rent of office	35.00
16	128	E. C. Hawkins	Field expenses	15.10
17	129	William P. Trowbridge	...do	30.22
17	130	T. M. Bannon	Traveling expenses	35.35
18	131	F. H. Newell	Field expenses	11.08
18	132	Robert Robertson	Traveling expenses	34.10
18	133	John C. Parker	Stationery	3.00
18	134	F. M. Smith	Field expenses	68.08
18	135	Robert Robertson	...do	142.55
19	136	T. M. Bannon	...do	119.53
19	137	W. A. Farish	...do	154.59
20	138	J. B. Williams	Traveling expenses	68.85
20	139	...do	Field expenses	55.30
21	140	G. F. Wakefield	...do	73.58
21	141	P. H. Christie	...do	5.00
21	142	Harold M. Dyar	Services, June 1 to 15, 1890	37.50

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 23	143	F. M. Smith	Traveling expenses	$16.50
24	144	Frank P. Thwaites	Field expenses	11.00
24	145	W. L. Wilson	Traveling expenses	16.95
24	146	J. B. Williams	...do	21.05
24	147	...do	Field expenses	46.10
25	148	Frank T. Thwaites	Traveling expenses	28.00
25	149	William Ham Hall	...do	43.25
30	150	Pay roll	Services, June, 1890	280.20
30	151	...do	...do	322.80
30	152	...do	...do	290.26
30	153	...do	...do	150.00
30	154	...do	...do	115.00
30	155	...do	...do	176.66
30	156	Sumner H. Bodfish	...do	197.80
30	157	W. W. Follett	...do	200.00
30	158	F. H. Newell	Field expenses	5.00
30	159	W. W. Follett	...do	19.25
30	160	P. H. Christie	...do	63.72
30	161	W. A. Farish	...do	75.09
30	162	Iona Coal and Iron Co	Forage of stock	128.70
30	163	Perkins Bros	...do	131.25
30	164	W. W. Butler	Services, May and June, 1890	12.00
30	165	Theodor Hall	Services, April, 1890	10.00
30	166	W. W. Follett	Traveling expenses	53.55
30	167	Pay roll	Services, May 1 to 24, 1890	89.02
39	168	E. C. Hawkins	Field expenses	18.93
30	169	Curt W. Miller	Services, June, 1890	20.00
30	170	Frank P. Thwaites	...do	75.00
30	171	Albert de Ruiz	Services, April 17 to 30, 1890	42.00
30	172	L. D. Hopson	Field expenses	65.83
30	173	William B. Lane	...do	67.06
30	174	...do	Services, June, 1890	60.00
30	175	Henry E. Kemp & Co	Field material	86.31
30	176	J. J. Lallie	Repair of instrument	60.65
30	177	...do	...do	12.30
30	178	Hendrie & Bolthoff Manufactur'g Co	Field material	63.57
30	179	Thomas Brinson	...do	30.00
36	180	George M. Scott & Co	...do	67.95
30	181	...do	...do	42.10
30	182	Dunham, Carrigan & Hayden Co	...do	21.39
30	183	James McHenry	Services and cartage, April 14 to 16, 1890.	12.50
30	184	W. J. Thomson	Services and material	15.35
30	185	Williams & Orton	...do	9.00
30	186	John A. Roebling's Son's Co	Field material	13.01
30	187	W. W. Briggs & Co.	...do	12.00
30	188	Electrical Supply Co	...do	63.45
30	189	Clot & Meese	...do	35.00
30	190	Cole & O'Hair	Hire of transportation	35.00
30	191	G. F. Wakefield	Field expenses	17.40
30	192	W. P. Merrill	Subsistence and forage	17.00
30	193	Barney Gilmore	Services, May 1 to June 30, 1890	20.00
30	194	R. W. Parry	Forage of stock	21.00
30	195	John Raycroft	Subsistence	3.58
30	196	John McMartin	Services, May 12 to June 10, 1890	6.00
30	197	J. & J. Raycraft	Forage	29.25
30	198	Boca Mill Co	Subsistence	4.25
30	199	J. M. Benton	Hire of transportation	11.00
30	200	Electrical Supply Co	Field expenses	4.00
30	201	James McHenry	do	5.00
30	202	George W. Rodenbach	Forage and subsistence	23.83
30	203	James Sherritt	Subsistence	31.75
30	204	William P. Trowbridge, jr	Field expenses	13.93
30	205	B. F. Groves	Traveling expenses	8.25
30	206	C. Lemery	Subsistence	49.87
30	207	F. M. Smith	Field expenses	21.00
30	208	M. H. Jones	Storage	5.80
30	209	J. B. Williams	Field expenses	42.00
30	210	L. F. Hopson	Transportation, etc	263.70
30	211	Anderson Bros	Field supplies	33.65
30	212	John A. Roebling's Son's Co	Field material	22.81
30	213	H. P. Croft	Services, June, 1890	60.00
30	214	Robert Robertson	Field material	160.71
30	215	T. M. Bannon	Field expenses	87.68
30	216	...do	...do	79.65
30	217	...do	Traveling expenses	7.50
30	218	...do	Services, June, 1890	75.00
30	219	J. B. Williams	...do	160.00
30	220	A. D. Foote	...do	247.25
		Total		6,853.32

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during June, 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 20	1	R. S. Woodward	Traveling expenses	$42.75
20	2	...do	...do	129.55
20	3	...do	Field expenses	183.17
20	4	H. S. Pritchett	Services, April 29 to June 17, 1890	250.00
21	5	A. Russell	Supplies	36.00
21	6	G. T. Nash	...do	23.36
24	7	Carver Mercantile Co	Storage	35.00
25	8	Arthur P. Davis	Traveling expenses	58.95
25	9	A. P. Davis	Field expenses	78.50
30	10	Employés	Pay roll, June, 1890	1,280.90
30	11	...do	...do	1,054.90
30	12	...do	...do	923.05
30	13	A. P. Davis	Services, 1890	164.80
30	14	C. H. Fitch	...do	148.30
30	15	H. C. Rizer	Traveling expenses	45.00
30	16	J. W. Dobbins	Services, June, 1890	50.00
30	17	William H. Otis	...do	25.00
30	18	S. S. Mitchell	...do	45.00
30	19	J. D. Reeves	Storage	38.50
30	20	John Sunderland	...do	9.00
30	21	C. L. Walker	...do	6.00
30	22	John Hartmann	...do	6.00
30	23	R. W. Parry	...do	6.00
30	24	J. W. Miller	Supplies	9.25
30	25	Amos Scott	Services, April 1 to June 30, 1890	130.00
30	26	H. C. Dangberg	Feed and care of stock	90.00
30	27	Charles W. Howell	Services, June, 1890	60.00
30	28	J. B. Block	Supplies	17.50
30	29	Hughes & Stoffel	Material	5.60
30	30	T. J. Shinick	Labor	14.25
30	31	R. W. Parry	Storage	23.75
30	32	J. Stewart Tod	...do	40.96
30	33	Frank Ervin	Pasturage	20.00
30	34	James Mayberry	...do	184.22
30	35	Conrad & Conrad	...do	24.00
30	36	Overland Freight Transfer Co	Storage	11.66
30	37	Pitts & Woolley	...do	56.00
30	38	John S. Halsey	...do	38.33
30	39	L. C. Goldsborough	Office rent	35.00
30	40	The Denver Transit Warehouse Co	Room rent	20.00
30	41	Charles Kreiling	Hire of team	20.00
30	42	C. W. Moore	Storage	35.00
		Total		5,525.25

Total amount expended, as per detailed statement herewith, to June 30, 1890		$235,657.63
Amount of bonded railroad accounts settled through Treasury Department, viz:		
Freight	$394.80	
Transportation of assistants	3,265.81	
		3,660.61
Total		239,318.24

IRRIGATION LITERATURE.

The following is a list of books, pamphlets, and articles on irrigation and allied subjects, mainly contained in the library of the U. S. Geological Survey. It is not a complete bibliography, but has been prepared by members of the U. S. Geological Survey for the convenience of students of irrigation. The principal titles of this list have been taken from a card catalogue prepared by Mr. Charles A. Burnett, to which numerous additions have been made by other persons, notably of references to subjects.

The following abbreviations or contractions are used in this list:

Am. Inst. Min. Eng.: For American Institute of Mining Engineers, New York.

Am. Met. Jour.: For American Meteorological Journal.

Am. Soc. C. E.: For American Society of Civil Engineers, New York.

Ann. des Ponts: For Annales des Ponts et Chaussées.

Chief Eng., U. S. A.: For Annual Report of the Chief of Engineers, United States Army, to the Secretary of War.

M. I. C. E.: For Minutes of Proceedings of the Institution of Civil Engineers, with other selected and abstracted papers, London (consists of 105 volumes to 1891).

Senate Report: For Report of the Special Committee of the United States Senate on the Irrigation and Reclamation of Arid Lands, Fifty-first Congress, first session, Report No. 928 (in 6 volumes).

U. S. Agr. Dep.: For United States Department of Agriculture.

U. S. G. S.: For United States Geological Survey.

U. S. Int. Dep.: For United States Department of Interior (including United States Geological Survey, Census Office, etc.).

ABBAY (R.). Periodicity of the fresh-water lakes of Australia. Nature, vol. 14, pp. 47-48, London, 1876; also, Zeitschr. Met., vol. 11, pp. 250-251, Wien, 1876.

Restoration of the ancient tank system of irrigation in Ceylon. Nature, vol. 16, pp. 509-512, London, 1877; also, Littell's Living Age, vol. 153, p. 489; Eclectic Engineering Magazine, vol. 18, p. 52.

ARBOTT (W.E.). Water supply in the interior of New South Wales. Trans. Royal Soc. N. S. W., vol. 18, pp. 85-111, Sidney, 1884.

ACADÉMIE DES SCIENCES. Comptes-Rendus, Paris. See in particular, Barral, J. A., Sur les irrigations, etc.

ACHESON (FREDERICK). The Victorian government prize essays, vol. 8, Melbourne, 1861, 8°. Contains essay on the collection and storage of water in Victoria, by Frederick Acheson, C. E., pp. 1-49.

AFRICA, Irrigation in:

Cape of Good Hope. Colonial botanist report, 1866.

Cape of Good Hope. Irrigation commission report, 1883.

Cape of Good Hope. Ministerial dept. report, 1883.

Collins, V. D., Agriculture in Morocco. U. S. Agr. Dept., 1862.

Gamble, J. G., Water supply, Cape Colony. M. I. C. E., 1887.

Gamble, J. G., Storage reservoir, Achterfeld. M. I. C. E., 1880.

Hallé, G., Public works of Orange Free State, 1884.

AGRA CANAL (India).

Anderson, C. E. Allahabad, 1878.

Forbes, J. C. Simla, 1885.

Public Works Department, Simla, 1885.

AGRICULTURAL DEPARTMENT, U. S.

See U. S. Agr. Dept.

ALEXANDER (B. S.) *and others.* Irrigation of the San Joaquin, Tulare, and Sacramento valleys, 1874. Report of the Board of Commissioners on Irrigation. House Doc. 290, 43d Congress, Washington, 1874.
Report upon the desert lands of Kern County. *See* Haggin, J. B., 1877, pp. 300-306.

ALGERIA, Irrigation in:
Blanc, E. Sahara Desert. M. I. C. E., vol. 102, p. 375, 1890.
Crugnola, C., Habra dam. M. I. C. E., vol. 70, p. 447.
Doumère. Revue scientifique, vol. 40, p. 235.
Grad, C., Habra dam. M. I. C. E., vol. 53, p. 325; also, La Nature, 1878, part i, pp. 249-299.
Ney, N. Scribner's, Nov., 1891.
Pochet, L., Plain of Habra. Ann. des Ponts. 1875, pp. 261-387, 3 pl.
Rolland, G., M. I. C. E., vol. 41, pp. 247-251, 1875.
Saint Pulgent, L. de., The Forez irrigation canal. 1872, 64 pp., 1 map.
Société agricole et industrielle de Batna et du sud algérien, 1889.
Torricelli, G., Laghi artificali dell' Algeria, etc. M. I. C. E., vol. 84, 1886. Abstract from Giornale del Genio Civile, p. 611, 1885.

ALKALI IN SOILS. (Composition, amount, and relation to irrigation.)
Donaldson, T., Public domain.
Hilgard, E. W., Senate report, 1890.
Hilgard, Jones and Furnas, 1882.
Powell, Arid region, 1879.

ALLARD (E.). Prevision of floods. Ann. des Ponts, etc., vol. 17, 1889; also, M. I. C. E., vol. 99, p. 432.

ALLARDT (G. F.). Culture of sugar cane. Report on water supply for irrigation, etc. *See* Schuyler, James D.

ALTENECK (VON HEFNER). Electrical apparatus for indicating the water level in reservoirs. M. I. C. E., vol. 69, p. 509.

AMERICAN CYCLOPÆDIA, 1883. Irrigation, vol. 9, pp. 414-416.

AMERICAN METEOROLOGICAL JOURNAL. Heavy rainfalls in Texas in May, p. 157, 1884-'85.

AMERICAN NATURALIST, 1872. Irrigation and the flora of the plains. E. L. Greene. Vol. 6, pp. 76-78.

AMERICAN SOCIETY OF CIVIL ENGINEERS. Transactions of. New York. *See* in particular:
Dorsey, E. B., Irrigation, vol. 16, p. 85.
Foote, A. D., Water meter, vol. 16, p. 134.
Foote, A. D., Waste weir, vol. 18, p. 59.
Schuyler, J. D., Sweetwater dam, vol. 19, p. 201.
Wilson, H. M., Irrigation in India, vol. 23, p. 217.
Wilson, H. M., American irrigation engineering, vol. 25, p. 161.

ANDERSON (C. E.). Damage to works of Agra Canal by floods of September, 1875, to February, 1877. Allahabad, India, 1878.

ANDERSON (GEO. G.). Large irrigation canals. Railroad and Engineering Journal, 1890.
Some aspects of Irrigation. Denver Society of Civil Engineers and Architects, 1890, vol. 1, pp. 52-62.
Construction, operation, and maintenance of large irrigating canals. Trans. Denver Society of Civil Engineers and Architects, vol. 1, p. 23-42, 1890.
Economical use of water. Irrigation Age, vol. 1, Denver, 1891.

ANDERSON (J. C.). Irrigation in Madras Presidency. Professional papers on Indian Engineering, No. 253, Roorkee.

ANDERSON (WILLIAM). Notes of a journey through the northeast portion of the Delta of the Nile, 1884. M. I. C. E., vol. 76, pp. 346-354. Discusses irrigation.

ANNALES DES PONTS ET CHAUSSÉES. Paris. Contain numerous references.

ANNICUT. *See* Weir.

ANNIS (FRANK J.). Colorado State board of agriculture. Agricultural statistics of the State of Colorado, 1886. Denver, 1888, 8°, 30 pp.

AQUEDUCTS.
On high embankments. Engineering News, New York, May 3, 1884.

ARID LANDS OF THE UNITED STATES:
Dodge, J. R., Amer. Assn. A. S., 1889-'90.
Hilgard, Jones, and Furnas, 1882.
Powell, Report arid region, 1879.
U. S. Congress, Senate Special Committee, 1890.

ARIZONA:
Bancroft, H. H., Agriculture and irrigation, 1889.
Black, J. A., Arizona, 1890.
Blake, W. P., 1889.
Gulley, F. A., Agr. Experiment Station, 1890.
Hamilton, P., Arizona resources, 1883.
Hancock, W. A., Agua Fria Storage Enterprise, 1891.
Hill, J. R., Arizona's Development, 1888.
Hinton, R. J., Handbook of Arizona, 1878.
King, C. H., Citrus fruit belt, 1887.
Maricopa County Immigration Union, 1887.
Mowry, S., Address. Amer. Geog. and Statis. Soc., 1859; new ed., 1863.
Newell, F. H., Census Bulletin, 1891.
O'Neill, Buckley, Arizona's Ancient Irrigators, 1891.
Pinal County, Resources, 1889.
Sorin, T. R., Handbook, Tucson, 1880.
U. S. War Dept., Report of Secretary, 1888-1889.
Widney, J. P., Colorado Desert. Overland Monthly, 1873.

ARNY (W. F. M.). New Mexico, Resources, 1873. Irrigation, pp. 11-12.

ARTESIAN WELLS, location, number, and value in irrigation.

Aughey, Samuel, and White. Wells on Great Plains, 1882.

Boring by water jet. M. I. C. E., vol. 45, p. 320.

Carpenter, L. G., Colo. Agr. College, Bull. 16, 1891.

Engineering News, New York, 1891.

Fischer, S., Destruction of pipes, M. I. C. E., vol. 100, p. 462, 1890.

Grunsky, C. E., Flow of wells, 1884.

Gill, J. C., Address. M. I. C. E., vol. 101, 1890.

Hall, C. W., Geological conditions of Minnesota.

Hay, R., Irrigation in western Kansas, 1889.

Mohs, Deepest bore hole. M. I. C. E., vol. 81, 1885.

Montana, Report 50th Congress, 1st session, House, doc. No. 1340, 1888.

Nettleton, E. S., Artesian Investigation, 1891.

Pilburn, J., Oölitic rocks of Bourne, Lincolnshire, 1856.

Temperature of water. M. I. C. E., 1884.

Thomas, H., Paris well. M. I. C. E., vol. 94.

Trevellini, L., First boring in Roman Campagna. M. I. C. E.

U. S. Agr. Dept., Location of wells, 1890.

U. S. Treas. Dept., Bureau of Statistics Report on Dakota, 1889.

West Shore, 1890.

White, C. A., Great Plains. White and Aughey, 1882.

ASHHURST (FRANCIS HENRY). Reconstruction of the Bhim Tal dam, Kumaon. Northwest provinces. M. I. C. E., vol. 75, 1884, pp. 202–210.

ASIA, natural and artificial irrigation, mainly in China and Japan.

Capron, H., U. S. Agr. Dept. Japan, 1873.

Dingelstedt, V., Irrigation of Samarkand and Bokhara, 1888.

Ki Tong, Tcheng, Irrigation in China, 1890.

Latham, H., Irrigation and farming in Japan, 1888.

Scottish Geog. Mag. 1888.

See, also, India.

ASIATIC SOCIETY OF BENGAL. Journal of; Calcutta: *See* in particular—Tolbort, J. W. H., Trans-Indus, 1871.

ASTA (D.). Prevention of floods in rivers. M. I. C. E., vol. 76, p. 395.

ATKINSON (W.). Failure of the Henares Irrigation Canal in Spain. M. I. C. E., vol. 49, pp. 187–188.

AUGHEY (SAMUEL). Artesian wells upon the Great Plains. U. S. Dept. Agr., 1882.

Physical geography and geology of Nebraska. Omaha, 1880, 326 pp.

AULL (CHARLES). Dam and canal of San Quetin, California; Eleventh Annual Report of State Board of Prison Directors, Sacramento, 1890.

AUSTRALIA, Irrigation in:

Abbott, W. E., Water supply New South Wales, 1884.

Acheson, F., Victorian water supply, 1860.

Brady, J., Sandhurst water supply. Victoria, M. I. C. E., vol, 56., p. 134, 1878–'79.

Brassey, Hon. T. A., Water in Australian Saharas, 1890.

Chaffey Bros., Irrig. colonies on River Murray, Australia, 1889.

Conservation of water. New South Wales Royal Commission, Final Report, 1887.

Cureton, S., Products of irrigated lands. Victoria Royal Commission, 1887.

Deakin, A., 1st report irrig. in Western America. Victoria Royal Commission, 1885.

4th report irrig. Egypt and Italy. Victoria Royal Commission, 1887.

Derry, J. D., Report American engineering. Victoria Royal Commission, 1885.

Dobson, Edw., Geelong and Sandhurst water supply. M. I. C. E., vol. 56, p. 94, 1879.

Griffin, G. W., New South Wales. Commerce and Resources, 1888.

Hayter, H. H., Victoria, Gov. Statistics. Year Book, 1883–1884.

Hérisson, A., Irrig. and navigation. Victoria Royal Com., 1887.

McKinney, H. G., Irrig. New South Wales, relation to pastoral industry. M. I. C. E., vol. 100, p. 775, 1890.

Ritso, G. F., Canterbury Plains water supply and irrig., 1883.

Water supply. Victoria Royal Com. Reports, 1885 and 1886.

AYMARD (MAURICE). The irrigation works of Alicante in Spain. M. I. C. E., 1876, vol. 45, pp. 309–311. Abstract from Annales du genie civil, vol. 4, p. 309.

Irrigation du midi de l'Espagne, 2 vols., text and atlas. Paris, 1864.

BABB (CYRUS C.). Water storage on the Sevier River, Utah. Irrigation Age, vol. 2, p. 260, 1891.

BAIRD (T. M.). Irrigation in New Mexico. U. S. Agr. Dept., 1851, pp. 483–484.

BAKER (BENJAMIN). The actual lateral pressure of earthwork. M. I. C. E., vol. 65, p. 140.

The river Nile. M. I. C. E., vol. 60, p. 367.

BAKER (F. P.). Forestry of Mississippi Valley and tree planting on the plains, 1883. U. S. Agr. Dept., 1883, 45 p.

BAKER (IRA O.). A treatise on masonry construction, New York, 1890, 552 pp., 6 pl.

BALFOUR (J.). Effect of irrigation upon the health of communities in the East Indies. London and Edinburgh Monthly Journal of Medical Science, vol. 2, pp. 30–34, 1842.

BANCROFT (HUBERT HOWE). Agriculture and irrigation in Arizona and New Mexico. 1889, vol. 17, pp. 275–276, 534–535, 594–595, 644–645, 766–768.

BARGNE (J. P.). Irrigations et prairies combinées à convertir les inondations en une riche conquête, Alais, 1861.

BARI DOAB. Benton, J., report on hydraulic experiments on the Bari Doab canal, 1879.

BAROIS (J.). Irrigation in Egypt. Paris, 1887. Translated by Maj. A. M. Miller, U. S. A. Washington, 1889. *Also, see* M. I. C. E., vol. 91, p. 510, 1888.

BARRAGE. *See* Moncrieff (C. C. Scott.)

BARRAL (J. A.). Drainage, 1856, 3 vols.

Drainage, irrigation, engrais liquides, 2d ed., Paris, 1860, 4 vols.

Les irrigations dans le département des Bouches-du-Rhône, Paris, 1876, 2 vols.

Les irrigations dans le département de Vaucluse, Paris, 1877, 2 vols.

Discours sur les irrigations (in the Pyrenees, Alps, etc.,) Paris, 1880.

L'agriculture, les prairies et les irrigations de la Haute-Vienne, Paris, 1884.

BARROWS (W.). "The Great American Desert —there is none." Magazine of Western History, 1885. Vol. 2. pp. 113–133.

BARSTOW (GEORGE). Irrigation canals in California. Annual report U. S. Agr. Dept., 1870–1871, p. 517.

BARWICK (J. A.). Rainfall and weather from Sept. 1, 1849, to Dec. 31, 1884. (California.) 8vo, 42 pp.

BAUM (A.). Current meter measurements in the Rhine. M. I. C. E., vol. 81, p. 456.

BAYLEY (G. W. R.). Levees as a system for reclaiming lowlands. M. I. C. E., vol. 45, p. 300.

BAZALGETTE (C. NORMAN). The sewage question. M. I. C. E., 1877, vol. 48, pp. 105–251. Discusses relative merits of sewage and fresh-water irrigation.

BAZIN (H.). New experiments on flow over weirs. M. I. C. E., vol. 96, p. 372. *Also see*, Engineers' Club, of Philadelphia. Proceedings, vol. 7, pp. 259–310, 1890.

Note on measurement of velocities by gauging tubes. M. I. C. E., vol. 91, p. 508.

Employment of double floats for measuring velocities in large streams. M. I. C. E., vol. 78, p. 473.

BEARDMORE (N.). Manual of hydrology, London, 1862.

BEAR RIVER, Utah. Irrigated lands of the Bear River valley near Corinne and Ogden, Utah, 16 pp.

Newell, F. H., Irrigation Age, 1891.

BEAR VALLEY DAM, California. *See* report Special Senate Committee on Irrigation, vol. II, p. 337.

Holt, L. M., Alessandro, Cal., Dec., 1890.

Schuyler, J. D. Trans. Am. Soc. Civil Engineers.

BEAUPRÉ (——). Avant projet pour la canalisation, etc. (Preliminary project for the canalization of the Loire, the preservation of its levees, the improvement of agriculture by water, and the irrigation of all the prairie lands in the valley on the right bank of that river.) 1858, pp. 262–273, 285–300, pl. 14.

BEHERA. Moncrieff, C. C. Scott, cost of pumping in Behera. Irrigation report, 1888. Behera Irrigation Society. Irrigation report, 1887.

BELGRAND (M.). Rainfall of basin of the Seine. M. I. C. E., vol. 39, p. 364.

Travaux souterrains de Paris. Vol. 1, La Seine, Paris, 1873, 622 pp., vol. 2, Aqueducs romains; vol. 3, Anciennes eaux.

BELL (J. H.). Report of committee on project of an annicut across Kistna River for irrigation of districts of Masulipatam and Guntoor. Professional papers, Corps of Engineers, Madras, India, 1856.

BELLASIS (E. S.). Gauges in shifting rivers. M. I. C. E., vol. 89, p. 510.

Inundation canals in the Punjab. M. I. C. E., vol. 89, p. 251 (from professional papers on Indian engineering, 1886, p. 109).

BELOE (C. H.). On the construction of catchwater reservoirs in mountain districts for the supply of towns or for other purposes, London, 1872.

BELPAIRE (T.). Advance of floods, and on influence of works of river improvement. M. I. C. E., vol. 66, p. 405.

BENGAL. Papers relating to the Orissa canals, 1869 to 1877 and 1881 to 1883. The Bengal Secretariat Press, Calcutta, 1884. *See also* India.

BENT (SILAS). Letter in regard to the precipitation of moisture throughout the great dry area of the interior. In U. S. Treas. Dept., Bureau of Statistics. Rep. on the internal commerce of the U. S. Washington, 1885, app. No. 8, p. 210.

BENTABÓL Y URETA (AURELIO) *and* PARDO. (Legislation of waters, 1846–1879.) Madrid, 1879. An authorized compilation comprising all laws, royal orders, etc., relative to waters and irrigation, promulgated from 1846 to 1879.

(Repertory of the latest legislation of waters) Madrid, 1884. A continuation of the work by this author and Pardo, but in a more systematized form.

BENTON (J.). Report on hydraulic experiments on the Bari Doab Canal to ascertain the most suitable form for notches of falls on the Sirhind Canal, Lahore, 1879, fol., 1 pl., 38 pp.

BENYAURD, (W. H. H.). Water gauges on the Mississippi River and on its principal tributaries. Rep. Chief of Eng., Washington, 1876 (pt. 1), pp. 600–618, 13 pl.

BÉRARD ( ). Motion of floats in currents. M. I. C. E., vol. 89, p. 510.

BERESFORD (J. S.). Memorandum on the irrigation duty of water, and the principles on which its increase depends. (Abstract.) M. I. C. E., vol 48, pp. 319-321. Also Professional papers Indian Engineers, No. 212, 1875, Roorkee, India.

Proposed standard designs for masonry outlets. Nanai Tal, India, June, 1882.

BERTIN (JEAN LOUIS HENRI). Code des irrigations. (Villeroy, F., and Muller.) Manuel de l'irrigation, 1850. Irrigation code, followed by reports of Dalbaz and Passy, and on foreign legislation. 1852.

BERTOZZI (GIULIO CESARE). Relazione dell' ingegnere, etc. (Report of Julius Cæsar Bertozzi to the commissary of the king, Commander Quintino Sella, on the design of forming with the waters of the rivers Tagliamento and Ledra a network of irrigation canals for the service of the vast unwatered plains of the province of Friuli. (Abstract). Giornale del genio civile, Florence, 1858, p. 234, 1867-68, pp. 234-235.

BETALOO DAM, South Australia. Railroad and Engineering Journal, New York, May 30, and July, 1891.

BETWA CANAL, INDIA. Public Works Department, Allahabad, 1874.

Records of Government, Calcutta, 1887.

BHIM TAL DAM, INDIA. Ashhurst, F. H. Kumaon, India, 1874.

BIBLIOTHÈQUE DE L'ENSEIGNEMENT Agricole publiée sous la direction de M. A. Mantz, professeur à l'Institut National agronomique, Paris, 1888, 8°. Contains Les irrigations, Les eaux d'irrigation et les machines, par A. Ronna, 1888, 730 pp.

BIBLIOTHÈQUE DU CULTIVATEUR, Paris, 1883, 12°, contains Pratique des irrigations en France et en Algérie, by F. Vidalin, 1883, 155 pp.

BIERDER (G. F.). Remarkable rain. Symons's Met. Mag., London, 19, 1884, p. 93.

BINNIE (A. R.). Lectures on water supply, rainfall, reservoirs, conduits, and distribution, delivered at the School of Military Engineering. Chatham, 1877, fol. privately printed, 1878.

Observations on rainfall, flow from the ground and evaporation at Nagpur; and on fluctuations of rainfall in India and other places. M. I. C. E., vol. 39.

BIRCH (B. W. PEREGRINE). Sewage irrigation by farmers: or, fifty instances of profitable sewage utilization, London, 1879, 2 pl., 60 pp.

BIRCHA (——). Distribution of water from irrigation canals. M. I. C. E., vol. 72, p. 445. London, 1882.

BIRKINBINE (H. P. M.). Rainfall in the basin of the Schuylkill River. Journal Franklin Institute, Philadelphia, vol. 71, pp. 185-191, 1876.

BLACK (JOHN A.). Arizona, 143 pp., 9 tables. Phœnix, 1890.

BLACKWOOD. Irrigation in Lombardy. In Blackwood's Magazine, Edinburgh, vol. 73, p. 447.

BLAKE (WILLIAM PHIPPS). Note upon some results of the storage of water in Arizona. (Walnut Grove dam.) Trans. Am. Inst. Min. Eng., 3 pp., 1889.

BLANC (ÉDOUARD). The Sahara desert and the future of the oases. M. I. C. E., vol. 102, p. 375, 1890. From Bulletin de l'Association française pour l' avancement des sciences, Paris, p. 866, 1889.

BLANFORD (H. F.). Influence of the Indian forests on the rainfall. Jour. Asia. Soc. Bengal, Calcutta, vol. 56 (part 2), 1887.

Meteorology of the Indian famine year. To the editor of the Times. Calcutta, 1877.

Diurnal variation of rainfall. Frequency at Calcutta. M. I. C. E., vol. 59, p. 355.

Description of rain gauge with evaporimeter for remote and secluded stations. M. I. C. E., vol. 66, p. 398.

BLISS (EDWARD). Colorado, soil, climate, etc. U. S. Agr. Dept., 1861, pp. 154-157; irrigation, p. 156.

BLUM (RICHARD). Current meter of Prof. A. R. Harlacher. M. I. C. E., vol. 67, p. 358; appendix, p. 366.

BOILEAU (P.). New process for gauging rivers. M. I. C. E., vol. 57, p. 351.

BOISSAY (C.). Results of irrigation, drainage, and replanting of desert land. M. I. C. E., vol. 56, p. 341.

BOMBAY (Water Supply). Tullock, H., Roorkee, India.

BOMBAY (presidency). Irrigation revenue report of the Bombay presidency, 1888, fol. 2, p. l., xxvi, i, 36 pp.

Administrative report of the public works department (irrigation), 1887-'88, 1 p. l., 27 pp., 3 maps, fol.

Same for 1889-'90, 1 p. l., 24 pp., 3 maps, fol.

BOOTHBY (H. E.). Climate, soil, and water and their relation to homes in Fresno County, the great raisin, wine and fruit center of California. Broadside (Fresno County board of trade).

BORING WELLS. Boring artesian wells by a water jet. M. I. C. E., vol. 45, p. 320.

BORNEMANN (K. R.). Discharge of water through sluices. M. I. C. E., vol. 63, p. 344.

BOSWELL (GEORGE). Treatise on watering meadows; also remarks on a late pamphlet on that subject. 134 pp. 5 fold. pl. 1792.

BOTELLA (F. de). Irrigation in the provinces of Murcia and Albacete, Spain. M. I. C. E., vol. 45, pp. 311–314, 1876.

BOURGEOIS (C.). Vallée water meter. M. I. C. E, vol. 64, p., 417.

BOUQUET (——). Mode of determining the turbidity of water. M. I. C. E., vol. 53, p. 318.

BOWIE (AUG. J.). The destruction of the English dam. Trans. Tech. Soc. Pacific Coast, No. 11, vol. 2, p. 3, San Francisco, 1885.

Measurement and flow of water in ditches. Trans. Tech. Soc. Pacific Coast, No. 2, vol. 1, p. 51, San Francisco, 1884. Also vol. 2, No. 20, 1885.

BOWMAN (JOHN B.). Development of the arid regions of the West. Argument before Senate Committee of Agriculture and Forestry in favor of the Jornada and El Paso Reservoir and Canal Company, 1888, 10 pp. U. S. Congress.

Development of the arid regions of the West by irrigation. 1 pl. 16 pp.

BOYD (*Captain*). Irrigation by flooding in Colorado. U. S. Depart. Agr., 1870, p. 579.

BRACKETT (D.). Rainfall on the watershed of Sudbury River, and of Cochituate and Mystic Lakes, U. S. Journal of the Association of Engineering Societies, 1886, p. 395. M. I. C. E., vol. 88, 1886–'87, p. 515.

BRADY (JOSEPH). The Sandhurst water supply, Victoria, Australia. *See* Dobson (Edward). The Geelong water supply.

BRANDENBURG (F. C.). The drought of 1886 in Dakota and Minnesota. U. S. Monthly Weather Rev., Washington, 1886, p. 326.

BRANT (B. K.). Practicability and profit of fruit and vine culture by irrigation on the staked plains of west Texas. In "Odessa Land and Townsite Company," Texas, 1888, p. 14–22.

BRASSEY (T. A.). Water in Australian Saharas. Nineteenth Century, September, 1890, p. 425.

BRÉBANT (——). Prétendus dangers de l'Irrigation pour l'hygiéne. (Pretended dangers of irrigation to hygiene). In Société médicale de Reims, Bulletins No. 14, pp. 94–96, 1876, 8 vol.

BREVOOBT (ELIAS). New Mexico, her natural resources and attractions. Santa Fé, 1874, pp. 3–176. 1 slip. Irrigation, pp. 134–137.

BBEWER (WM. H.). On the subsidence of particles in liquids. Mem. of Nat. Acad. Sci., vol. 2, 1883. *See also* Am. Jour. Sci., vol. 29, 3rd series, p. 1, Jan., 1885. On the suspension and sedimentation of clays.

BRICKA (M). Distribution of water from irrigation canals. Van Nostrand's Engineering Magazine, 1883, vol. 28, pp. 472–473.

Same, M. I. C. E., vol. 70, pp. 445–447.

BBIDGES (LYMAN). Overflow of the Mississippi. Am, Soc. C. E., vol. 11, p. 251, *also* M. I. C. E., vol. 72, p. 345.

BRODIE (F. J.). The recent drought. Nature, London, vol. 36, 1887, pp. 395–397.

BROWN (CALVIN). Irrigation. On the utilization of water, and its sources, in California. Annual Report of Surveyor-General of California, 1862–63.

BROWN (D. J.). Watering or irrigation. U. S. Agr. Depart., 1854–'55, pp. 322–333.

Gardening. U. S. Agr. Dept., 1854–'55, pp. 322–393.

Drainage, its history, principles, and advantages to the agriculturist. U. S. Agr. Dept., 1858–'59, pp. 273–280.

BROWN (JOHN C.). Reboisement in France.

Hydrology in South Africa, 1875, 7–260 pp.

Water supply in South Africa and facilities for the storage of it, 1877, 651 pp.

Irrigation and agriculture, in Report of Colonial Botanist, Cape of Good Hope, 1886.

BROWN (R. H.). Bahr Yussufi and Basin Irrigation of West Ibrahimieh Canals, 1886. *See* Moncrieff, C. C. S.

Canal regulators, emptying basins, Irrigation Report, 1887. *See* Moncrieff, C. C. S.

BROWNE (J. ROSS). Agricultural capacity of California. Overland Monthly, 1873, vol. 10, pp. 297–314.

Irrigation. Same, pp. 309–314.

BRUNN (C. G.). Tidal and stream observations on west coast of Schleswig. M. I. C. E., vol. 52, p. 372.

BBUSCHETTI (GIUSEPPE). Storia dei progetti, etc. (History of the project and of the works for irrigation of the Milanese). Lugano.

BUCKLE (*Capt.* **E.**). Report upon capabilities of that part of the Masulipatam and Rajahmundry districts lying towards the coast between the rivers Kistna and Godavery, with reference to irrigation. Corps of Engineers, Madras, India, 1851.

BUCKLEY (ROBEBT B.). Keeping irrigation canals clear of silt. M. I. C. E., vol. 58, pp. 278–280. London, 1879.

Statistical review irrigation works in India. Calcutta, India, 1889.

Statistical review irrigation works in India, 1887–'88. M. I. C. E., vol. 99, p. 442. 1890.

Movable dams in Indian weirs. M. I. C. E., vol. 60, p. 43. 1880.

Irrigation works of India and their financial results. London, 1880, 198 pp.

BURBANK (L. S.). On certain land-locked ponds as natural meterological registers. Proc. Nat. Hist. Soc., vol. 18, pp. 212–213, 1875–'76; Sci. Monthly, Toledo, vol. 1, pp. 438–439, 1876.

BUREAU OF STATISTICS. Artesian wells in Dakota. *See* Report U. S. Treas. Dept., Report on Internal Commerce of United States for 1889, part 2, pp. 139–140.

BURKE (C. T.). The Ashti tank, India. M. I. C. E., vol. 76, pp. 288–316. London, 1883.

BURKE (U. R.). Controversy on Irrigation in India. In Dublin University Magazine, vol. 91; new series, vol. 1, pp. 201-206. Dublin and London, 1878.

BURN (R. SCOTT). Outline of modern farming. New edition, Lockwood & Co., London. 1250 pp.

BURNELL (GEORGE R.). The rudiments of civil engineering and recent practice in civil engineering. *See* Law, Henry.

BYRNE (HENRY). Irrigation in Ceylon. M. I. C. E., vol. 57, pp. 231-238.
Same. Eclectic Engineering Magazine, vol. 23, p. 197.

CAINE (J. C.). Lake Oredon dam. M. I. C. E., vol. 66, p. 402.

CAINE (JOHN T.). Irrigation in Utah. *See* Dana, F. L. The Great West. Denver, 1889, pp. 131-134.

CALIFORNIA, Alessandro Water System. Holt, L. M. 1891.
Alexander, B. S., and others. Irrigation of San Joaquin, Tulare, and Sacramento valleys. 1874.
Barstow, George, Irrigation canals. U. S. Agr. Dept., 1870-'71.
Boothby, H. E., Fresno County.
Brown, Calvin, Surveyor-general's report 1862-'63.
Browne, J. Ross, Agricultural capacity. Overland Monthly, 1873.
Carpenter, F., Irrigation. Eclectic Magazine.
Davidson, Geo., Desert lands. Kern Co., 1877.
Davidson, Geo., Irrigation, San Joaquin, Tulare, and Sacramento valleys. 1874.
Dow, John L., Irrigation San Joaquin valley. 1884.
Finkle, F. C., San Bernardino County. 1891.
Fox, William, Irrigation in southern California. M. I. C. E., vol. 105, p. 238. 1891.
Friedlander, ——., Irrigation in California. Sacramento, 1873.
Gardner, Henri F., Water facilities for irrigation, Santa Ana valley. 1885.
Haggin, J. B., Kern County. 1877.
Hale, Edson D., Description San Bernardino County and city. 1888.
Hall, William Hammond, Report California State engineer. 1880, 1881, 1883, 1886.
Hartt, W. H. H., District Irrigation Laws. 1891.
Hawley, A. T., Los Angeles city and county. 1876.
Hendricks, W. C., Wright Irrigation bill. 1889.
Hilgard, E. W., Report agricultural experiment station, University of California. 1890.
Houghton, J. F., Surveyor-general's report. 1862.
Hulton, J. H., Irrigation Yolo Co. Cal. State Agr. Soc. 1864-'65-'66.

CALIFORNIA—Continued.
Jackson, Helen Hunt, Outdoor industries of southern California. Century, New York, 1883.
Lower California Co. New York, 1868.
McAfee brothers. Tehama Co.
Mendell, G. H., Practical irrigation. 1874.
Mendell, G. H., Report, desert lands, Kern Co., 1877.
Newell, F. H., Census bulletins.
Nordhoff, Charles, Farmers' information. Harper's Magazine, 1872.
Player-Froud, J. G., Six months in California. 1872.
San Francisco Call Co., Cal. Written by 70 authors and editors, 1882.
San Francisco Chronicle. California's irrigation system. San Francisco, June 7, 1891.
San Luis Rey Co., Irrigation, 1887.
Schuyler, J. D., Sweetwater dam. American Society of Civil Engineers, vol. 19, p. 201.
Specht, G. J., Earthworks, upper San Joaquin Canal. M. I. C. E., 1883.
Tucker & Hogue. Fresno and Fresno Co.
Tulare Valley. Kern Co. Irrig. Co., 1888.
Tulare irrig. district, Tulare Co., 1890.
U. S. Agricultural Department, Irrigation and cotton cultivation, 1873.
Van Dyke, T. S., 1890.
Van Nostrand's Magazine. Irrig. canal, 1885.
Widney, J. P., Colorado desert, Overland Monthly, 1873.
Wyckoff (V.), Irrig. Yolo Co. Cal. State Agr. Soc., 1864-'65.

CALIFORNIA STATE AGRICULTURAL SOCIETY, Transactions of, during 1864 and 1865. 1866, 413 pp. Contains: Irrigation, pp. 69-75, 211-212. The need of irrigation, by Dr. E. S. Holden, pp. 219, 220. Irrigation in Yolo County, pp. 301-302.

CALIFORNIA STATE BOARD OF FORESTRY. First biennial report for 1885-'86, 238 pp., 4 maps, 1 fold. tab. Necessity of and facilities for irrigation in the coast range, pp. 132-133.

CALIFORNIA STATE BOARD OF HEALTH. Reclamation of arid lands by irrigation, 1889, 52 pp.

CALIFORNIA, STATE ENGINEER. *See* Hall, Wm. H.

CALIFORNIA STATE GRANGE, journal of proceedings of the seventeenth annual session. Pacific Rural Press print, San Francisco, 1889, 188 pp. Contains Artesian Belt, by C. E. Grunsky, pp. 69-92.

CALIFORNIA STATE IRRIGATION CONVENTION. Proceedings. 1886, 205, 144 pp.

CALIGNY (A. DE), Experiments on waves and particularly on the diminution of lateral mean pressures of the water undulating in a canal. M. I. C. E., vol. 87, p. 483.
Experiments on a new hydraulic machine employed for irrigation (abstract). M. I. C. E., 1888, vol. 92, p. 452. (Comptes-rendus de l'Académie des sciences, 1887, vol. 105, p. 226.)

CALINELS (—.), On the cleaning of weir reservoirs in Algeria. *In* Annales industrielles, 1879, fasc. II, pp. 774–806, 1880; fasc. I, pp. 26–91; fasc. II, pp. 456–465.

CALLOWAY CANAL, Resources of California, San Francisco, Cal., Oct., 1888.

CAMPBELL (ALLEN), Cost of storage. Trans. Amer. Soc. Civil Eng., vol. 16, art. 354. Mar., 1887, p. 92.

CANADA. Dickey, Canadian northwest. Speeches in Dominion Senate, 1890.
MacInnes, D., Canadian northwest. Speeches in Dominion Senate. 1890.

CANAL: Construction, cost, methods, structures, etc.
Anderson, Geo. G., Large irrigation canals, Denver, 1890.
Atkinson, W., Failure of Henares canal in Spain. M. I. C. E. Vol. 49, p. 187.
Benton, J., Experiments on the Bari Doab canal, 1879.
Bricker, M., Distribution of water, 1883.
Dickens, C. H., Calcutta, India, 1861.
Fontaine, Cylindrical sluice gates. M. I. C. E., vol. 88, p. 504.
Garbe, Construction of canals in marsh districts of East Friesland. M. I. C. E.
Hall, Wm. H. *See* various reports.
Moncrieff, C. C. Scott. *See* various reports.
Scougall, H., Polytechnic Society of Utah, 1891.
Sospizio, C., Il canale Cavour, 1884.
Spons, J., Dictionary of engineering, p. 907.
Thiré, A., Canals for supplying water motors, M. I. C. E.
Thomason, Civil Engineering College Manuals, Roorkee, India.
Van Nostrand's Magazine, Irrigating Canals, 1885.

CAPE OF GOOD HOPE:
Irrigation commission. Preliminary report and proceedings, with appendices of the irrigation commission. Part 1. Cape Town, 1883, fol. 4, pl. xxii, 138, xiii pp.
Hydraulic engineer, report of the, for 1884, fol. 36 p. (Report of Irrigation Commission), Ministerial Dept.
Botanist, Colonial, report of, for 1886, (contains appendix, abstract of a memoir prepared on irrigation and its application to agricultural operations in South Africa, etc.)

CAPIT (M.). Underground water courses and means of utilizing them. M. I. C. E., vol. 81, p. 381.

CAPRON (HORACE). Agriculture in Japan. U. S. Dept. Agr. 1873, pp. 364–374.

CARPENTER (F.). Irrigation in California. Eclectic Engineering Mag., vol. 16, p. 79.

CARPENTER (L. G.). Reports of section of meteorology and irrigation engineering in the annual reports of the agricultural experiment station of the State Agricultural College of Colorado, 1888, 1889, 1890, Fort Collins, Colo.

CARPENTER (L. G.)—Continued.
Measurement and division of water, 45 pp., 7 illus., 4 tables. State Agr. College, Bull. 13, 2d ed., 1891. Fort Collins, Colo., 1891.
Artesian wells of Colorado, in bulletin No. 16, experiment station, State Agricultural College, July, 1891, 28 pp.

CARPENTER (S. W.). The law of water for irrigation in Colorado, 1886. 127 pp.

CARRO (T.). Canalization by means of self-acting weirs. M. I. C. E., vol. 94, p. 330.

CARTER (O. M.). Survey of Savannah River, Ga., discharge, river heights, etc., Washington, 1890; in annual reports of Chief of Engineers, U. S. Army, 1890, 1891.

CASTLEWOOD DAM (Colorado):
Engineering News, New York, May 2, 1891.
Furman, H. Van F., Denver, 1889.

CASTLEWOOD RESERVOIR:
Storage Reservoir, The Great Divide, Denver, Oct., 1890.
Denver Republican, Denver, Colo., May 16, 1891.

CAUTLEY (*Col. Sir* PROBY T.). Report on the Ganges Canal Works, 3 volumes and atlas, London, 1860.
A disquisition on the heads of the Ganges and Jumna Canals, London, 1864.

CAUVERY RIVER. Cotton, A. T. Reports and letters upon the rivers Cauvery and Coleroon, etc.

CAVOUR CANAL. Amministrazione speciale dei canali demaniali d' irrigazione. Canale Cavour ed Annessi. Tariffa, Capitolato par el Concessione d'acqua nel periodo 1877–1883, Ministero delle Finanze Roma, 1876.
Compagnia generale dei canali d' irrigazione italiani. Canale Cavour, Progetto d' irrigazione del agro Casalese. Torino, 1872.
Sospizio, C. Il Canale, Cavour. etc.

CENSUS. Bulletins on irrigation. *See* Newell, F. H.

CENTRAL IRRIGATION DISTRICT. Hall, Wm. Ham.

CERDAN Y PONTERO (A.). Sobre las aguas, etc. (On the waters that fertilize the valleys of Lima.) 1793.

CERINI (GIUSEPPE). Razioni teorotico-pratiche, etc. (Theoretico-practical notions on irrigation.) Milan, 1837.

CHAFFEY BROTHERS. The Australian irrigation colonies on the river Murray, in Victoria and South Australia, London, 1889, 16 pp.

CHAMBERS' ENCYCLOPEDIA. Philadelphia, 1879, vol. 5, Irrigation, pp. 641–642.

CHAMBRELENT. Les irrigations agricoles, etc. (Agricultural irrigation in France from 1866 to 1886.) Revue Scientifique, 1888, vol. 42, pp. 467–469.

CHENUT (L.). Apparatus for measuring velocity of a stream of water. M. I. C. E., vol. 77, p. 419.

CHEYAUR ANNICUT AND CHANNELS. Collyer, G. C.

CHEYENNE DAILY SUN, Cheyenne, Wyoming, March 28, 1889, fol. 24 pp. (contains Irrigation, p. 1, 8, 18, 23; Irrigation does it, p. 4; Irrigation a success, p. 13; Advantage of irrigation, p. 17).

CHRONICLE, The San Francisco.
Bear Valley irrigation system, June 7, 1891.
California's irrigation system, June 7, 1891.
How to make the desert bloom as a rose, Aug. 23, 1889.

CHURCH (ARTHUR HERBERT). Irrigation. Encyclopedia Britannica, 1881, vol. 13, pp. 362–370.

CIPOLLETTI (C.). Villoresi canal; experiments on flow of water over weirs. M. I. C. E., vol. 85, p. 450.

CIRCULARS FOR GUIDANCE OF OFFICERS. Irrigation branch, public works department, Calcutta, India.

CLARK (D. KINNEAR). Rudiments of civil engineering, with treatise of hydraulic engineering, and recent practice in civil engineering. *See* Law, Henry.

CLAYE (A. DURANT). Utilization of sewer water of Paris for agriculture. M. I. C. E., vol. 39, p. 380.

CLIFF-DWELLERS. Long-lost extensive canals and storage reservoirs that were utilized by a great population. Daily Sun, New York, April 12, 1891.

CLINE (J. M.). Rainfall in its source in the Southern slope. U. S. Monthly Weather Review, Washington, 1886, pp. 333, 334.

CLOUD-BURSTS. Nevada, cloud-bursts in 1877. Kansas City Review, 1877–'78, pp. 51, 52.

COGHLAN (T. A.). Discharge of streams in relation to rainfall, New South Wales. M. I. C. E., vol. 75, p. 176.

COLE (ASAHEL N.). The new agriculture, or the waters led captive. New York, 1885. 3-223 pp., inc. 9. pl.

COLE (A. P.). Cole's combined system of drainage and irrigation. 1889. 103 pp., 1 part.

COLEROON RIVER.
Cotton, A. T. Reports and letters upon the Cauvery and Coleroon rivers.
Sim, D. Report on Annicut, Coleroon.

COLLINS (V. D.). The agriculture of Morocco. U. S. Dept. Agr., 1862, pp. 499–508.

COLLYER (G. C.). Cheyaur Annicut and channels. Professional papers. Corps of Engineers, Madras, India, 1856.

COLMATAGE. *See* Meadows.

COLORADO:
Agriculture by irrigation in Colorado; information for those contemplating settling in Colorado, etc. Colorado Loan and Trust Co., Denver, 1883.
Agricultural experiment station, Report of. Carpenter, L. G. Fort Collins, Colo., 1890.
Annis, Frank J. Agricultural statistics, 1886.
Bliss, Edward. Soil, climate, U. S. Dept. Agr., 1861–'62.
Boyd, *Capt.* Irrigation by flooding, U. S. Dept Agr., 1870–'71.
Carpenter, L. G. Agricultural college.
Carpenter, S. W. Law of water for irrigation, 1886.
Graves, W. H. Engineer reports.
Greene, J. S. State engineer report, 1887–'88.
Latey, J. H. Proper employment irrigation, U. S. Dept. Agr., 1870.
Mead. Elwood. Report, 1887.
Nettleton, E. S. Reports of State engineer, 1883–'86.
O'Meara, Patrick. M. I. C. E., 1882–'83.
Osborne, *Judge.* Irrigation, U. S. Dept. Agr., 1870–'71.
Pabor, Wm. E. Colorado as an agricultural State, 1883.
Perrin, S. K. Two methods of irrigating near Denver, U. S. Dept. Agr., 1870–'71. Irrigation in Jefferson County, Colo., U. S. Dept. Agr., 1870–'71.
Powell, J. W. Effect of irrigation upon certain rivers, U. S. Int. Dept., 1889.
Richards & Co. Summering in Colorado, 1874.
Sanger, J. S. Agriculture and irrigation, 1881–'82.
San Luis Park, U. S. Dept. Agr., 1869.
Stranger, J. S. Report upon agriculture, 1882.
State Engineer, Report of, 1883–'84–'85–'86–'87.
Stinson, Eugene K. Engineer report, 1881–'82.
Stockslager, S. M. Effect upon rivers by diversion of water, U. S. Dept. Int., 1889.
Titcomb, John S. Some aspects of irrigation. Denver, 1890.

COLORADO RIVER DAM (Texas). Engineering News, New York, July 11, 1891.

COMPETITION OF IRRIGATION MACHINERY. Engineering and Mining Jour., 1885, p. 386.

CONSERVATION OF WATER. New South Wales Royal Commission. Third and final report of commissioners. Diagrams and plans, 1887; 29 maps, plans, and diagrams on 28 sheets.

CONSULAR REPORTS. *See* U. S. State Department.

CONYBEARE (H.). Tanks in Rajputana. M. I. C. E., vol. 17, p. 569, London.

COOPER, ELWOOD. Heavy rains before Jan. 1st, followed by light after, in California. U. S. Month. Weather Rev., Washington, 1884, p. 102; 1885, p. 317.

CORTESE (E.). (Irrigation of Apulia.) Report on the study of the reservoir on the Ofanto, fol., 56, pp.

CORTHELL (E. L.). South Pass jetties, Mississippi River. Trans. Am. Soc. Civil Eng., vol. 13, 1884, p. 313. M. I. C. E., vol. 80, p. 393. History of Mississippi jetties, 1881, p. 11.

CORVEE. Egypt, Note on Corvee in. Moncrieff, C. C. Scott. Corvee ransom, irrigation report, 1887.

COSSIGNY (J. CHARPENTIER DE). Notions elementaires. etc. (Elementary, theoretical, and practical notions on irrigation applied to lands under culture, to gardens and fields, and considered more especially in relation to the different climates of France), XI, 637 pp., Paris, 1874, 8vo. (Société des agriculteurs de France.)

Ideas, theoretical and practical, on irrigation, in Victoria Royal Commission on Water Supply. Fourth progress report. Melbourne, 1887, fol. Appendix I, pp. 47–53.

COTTON (A. R.) and ROSS (A.). Reports and letters upon the rivers Cauvery and Coleroon in connection with the construction of the Upper and Lower Annicuts. Report on same by Maj. A. Ross. Professional papers. Corps of Engineers, Madras, India, 1851.

COTTON (A.). Irrigation from Godavery. *See* Madras Engineers.

COVENTRY (WALTER BULKELEY). The design and stability of masonry dams. M. I. C. E., vol. 85. 1886.

CRAIG (JAMES). Maximum flood discharges from catchment areas. M. I. C. E., vol. 80, p. 201, London, 1885.

CRAWFORD (J. J.). Report of commissioners, Sacramento, 1890. *See* Reid, C. F.

CROCKER (H. S.). The Merced fruit district. Crocker-Huffman Land and Water Company, 40 pp., 2 maps, H. S. Crocker Co., San Francisco.

CROES (J. J. R.). Flow of west branch of Croton River. M. I. C. E., vol. 39, p. 367.

CROFTON (J.). Report on the Ganges Canal, 3 vols. Public works department, Calcutta, India, 1865.

CULCHETH (W. W.). Quantity of water consumed in irrigation. M. I. C. E., 1882, vol. 69, pp. 440, 441. (Proc. Royal Soc. Victoria, 1882.)

CUNNINGHAM (ALLAN). Recent hydraulic experiments. M. I. C. E., vol. 81, p. 33.

Discharge of canals. M. I. C. E., vol. 51, p. 357.

CUPPARI (P.). Manual of agriculture. Florence, 1870.

CURETON (STEPHEN). Tillage and products of the soil on irrigated lands. Victoria royal commissioner on water supply, 1887, fol. appendix 2, pp. 54–58.

CURRENT METER (and floats). General description, rating, etc.

Basin, H., Double floats, measuring large velocities. M. I. C. E., 1884.

CURRENT METER (and floats)—Continued.

Baum, A., Meter measurements in the Rhine. M. I. C. E., 1882.

Bérard, Motion of floats in currents. M. I. C. E., 1887.

Blum, Richard, Meter of Prof. A. R. Harlacher. M. I. C. E., 1881.

Bourgeois, C., Vallée water meter. M. I. C. E., 1880.

Chenut, L., Measuring velocity of stream. M. I. C. E., 1884.

Cunningham, A., Hydraulic experiments. M. I. C. E., 1882.

Current meter. M. I. C. E., 1876.

Girardon, Forez water canal, apparatus for gauging water supply. M. I. C. E., 1881.

Gordon, R., Report Irrawaddy River, 1879.

Goulier, *Col.* Fragus water meter. M. I. C. E., 1886.

Harlacher A. R. M. I. C. E., vol. 45, p. 220, 1876.

Henry, Ellis, or Price meter. Jour. Franklin Inst., vol. 62. Also Report chief engineer, U. S. Army, 1867.

Johnson's surveying, method of rating, 1889.

Mackenzie, A., Meter observations, Mississippi River, 1879.

Marr, G. A., Method of using Buff & Berger meters; method of determining meter coefficient, 1881.

Mead, Elwood, Colorado meter, 1885–'86.

Moore, B. T., Current meter. M. I. C. E., 1876.

Nettleton, E. S., Report State engineer Colorado, 1883–'84.

Ritter, C., Improvements in current meters. M. I. C. E., 1885.

Stearns, F. P., Current meter. M. I. C. E., 1883.

Thames River. M. I. C. E., 1876.

Turner, Henry T., Gauging flowing waters. M. I. C. E., vol. 80, p. 318, 1885.

Urwin, W. C., Current meter, Thames. M. I. C. E., 1882.

Von Wagner, New current meter. M. I. C. E., 1880.

CURTIS (GEORGE E.). Irrigation for western Kansas. Kansas State board of agriculture, 1889, pp. 29–30.

DACOSTA (J.). Irrigation works in India. Contemporary Review, vol. 27, pp. 549–558, 1876.

DAKOTA:

Grand Forks, Report Chamber of Commerce, 1881.

United States Treasury Department, Report of Bureau of Statistics, 1889.

DAMS:

Ashhurst, F. H., Reconstruction Bhim Tal dam. M. I. C. E., vol. 75.

Baker, Benj., Pressure of earthwork. M. I. C. E., vol. 65.

Baker, Ira O., Masonry construction, 1890.

Bear Valley dam, Report of Senate committee.

Bowie, A. J., The destruction of the English dam.

Coventry, W. B., Stability of dams. M. I. C. E., 1885.

DAMS—Continued.
Deacon, Geo. F., Liverpool water supply, 1885.
Doherty, W. J., M. I. C. E., vol. 41.
Engineering News, New York, Sept., 1891.
Follett, W. W., Denver Soc. C. E. and A., 1890.
Francis, J. B., Trans. Am. Soc. C. E., vol. 19.
Grad, C., Dam in Algeria. M. I. C. E., vol. 53.
Gruber, P., Osselitz dam. M. I. C. E., vol. 96.
Haupt, L. M., Movable dams for Ohio River.
Herschell, C., Preservation of dams at Holyoke, Mass., 1886.
Kresnik, P., Safety and service of dams. M. I. C. E., vol. 99.
Leffel, J., Milldams, 1881.
McMaster, J. B., High masonry dams.
Schuyler, J. D., Sweetwater dam, 1888.
Spon's Dictionary of Engineering.
Wagoner, Luther, and Vischer, H., Strains in curved masonry dams, 1890.
Wegmann, E., Quaker Bridge dam, 1890.
See also index of transactions of American Society of Civil Engineers, under title *Dams*.

DANA (F. L.). The Great West. A vast empire. 1889, 160 pp., 32 pp.

DANVERS (F. C.). Theory of irrigation. Eclectic Magazine, vol. 12, p. 435.

D'ARCY. Hydraulic tables based on the formulæ of D'Arcy and Kutter. *See* Flynn, P. J.

DAVIDSON (GEORGE). Irrigation and reclamation of land for agricultural purposes as now practiced in India, Egypt, Italy, etc. Senate Exec. Doc. No. 94, U. S. Senate, 44th Congress, Washington, D. C., 73 pp., 23 pl., 1875.
Report Board of Commissioners, Washington, 1874.
Report upon desert lands of Kern County. 1877. *See* Alexander, B. S., and others.
Report on irrigation of the San Joaquin, Tulare, and Sacramento valleys, 1874. *See* Alexander, B. S., and others.

DAVIEL (ALFRED). Commentaire de la loi du 29 avril, 1845, sur les irrigations: suivi des rapports faits aux deux chambres par MM. Dalloz et Passy, 1845.

DAVIS (W. M.). Short period oscillations in lakes. Seiches. Am. Met. Jour., Ann Arbor, Mich., vol. 3, 1886–'87.
Mountain meteorology, Appalachia vol. 4, No. 4, 1886, pp. 225–244 and 327–350. Also as separate.

DAVY (JOHN). A discourse on draining and irrigation, delivered before the General Agricultural Society of Barbadoes at its fourth half-yearly meeting on the 22d of December, 1847. In Edinburgh New Philosophical Journal, vol. 44, pp. 335–348.

DAWSON (WM. B.). The Paroy reservoir. M. I. C. E., vol. 65, p. 259.

DEACON (GEO. F.). Additional water supply (of Liverpool); report as to the Vrynwy masonry dam. 1885. 36 pp., 10 pl., Liverpool.

DEAKIN (ALFRED). Royal Commission on Water Supply. First progress report: Irrigation in Western America, so far as it has relation to circumstances of Victoria. 175 pp., numerous tables. Melbourne, 1885.
Fourth progress report: Irrigation in Egypt and Italy, 1887, 64 pp. Victoria Royal Commission on Water Supply. Melbourne.
First Irrigation conference. Victoria water supply. Melbourne, 1890.

DEBAUVE (ALPHONSE). Manuel de l'ingénieur des ponts et chaussées, Paris, 1871–'84. Fascicule 18; des eaux en agriculture, 1884. 222 pp.

DEBEIL (M.). New system of movable weirs. (Annales des Travaux Publics de Belgique, vol. 38, 1881, p. 521.) M. I. C. E., vol. 68, p. 402.

DEBY (J.). (Practical manual of irrigation.) Brussells, 1850.

DECOUDUN'S HYDROMETER. M. I. C. E., vol. 61, p. 328.

DELAFIELD (C.). The Vicksburg settling basin. Trans. Am. Civil Engineers, p. 88, 1889.

DELAIRE (M. A.). Hydrology of basin of Seine. M. I. C. E., vol. 39, p. 365.

DELPRAT (J. P.). Relation between water levels of main rivers in Holland. M. I. C. E., vol. 39, p. 368.

DENISON (WILLIAM). On the construction of dams, with a view to irrigation. In Royal Society of Van Dieman's Land. Hobart Town, vol. 1, pp. 257–264.

DENTON (J. BAILEY). An argument in favor of collecting and storing waste surface waters of large areas in reservoirs and tanks constructed of concrete or cement. New York, 1874, 18 pp.
On water supply to villages and farms. London, 1865.
The storage of water. London, 1874, 18 pp.
Agricultural drainage: a retrospect of forty year's experience, 1883, vol. 8, 94 pp., 1 map.

DERRY (J. D.). Victoria Royal Commission on Water Supply. Fourth Progress Report: Being a report on some of the engineering features of American irrigation. Melbourne, 1885. 46 pp., 21 pl.

DICKENS (C. H.). Projects of canals of irrigation from the River Soane. Government Printing Office, Calcutta, India, 1861.

DICKEY. The Canadian Northwest. *See* MacInnes, D., and Dickey.

DICKINSON (A. B.). Irrigation Prize Essay, New York State Agricultural Society. Report, 1860. Albany, 1861, pp. 197–207.

DIEBITSCH (EMIL). Irrigation in the United States. Goldthwaite's Magazine, vol. 1, No. 4, New York, 1891.

DINGELSTEDT (VICTOR). Irrigation, natural and artificial, in Samarkand and Bokhara. Scottish Geographic Magazine, vol. 4, pp. 642–654, 1888.

DISCHARGE (of rivers and streams):

- Methods of measuring discharge of streams. *See, also,* Current meter.
- Bazin, H., Gauging tube for velocities. M. I. C. E.
- Boileau, P., New process for gauging rivers. M. I. C. E.
- Bornemann, K. R., Water through sluices. M. I. C. E.
- Cautley, Sir Proby T., The Ganges canal.
- Cipolletti, C., Gauging for irrigation. M. I. C. E.
- Cunningham, Allan, Canals. M. I. C. E.
- Durance, Gauging and silt of the. M. I. C. E.
- Flynn, P. J., Flow of water in open channels, 1890.
- Fteley, A., and Stearns, F. P., Sudbury River. M. I. C. E., 1883.
- Gramatzey, E., Constant mean velocity. M. I. C. E.
- Greene, J. S., Flow of water in ditches. 1890.
- Harlacher, A: R., and Richter, H. M. I. C. E.
- Harman, H. J., In large rivers in upper Assam. M. I. C. E.
- Henry, D. F., Flow of water in rivers and canals.
- Herschel, C., Venturi water meter. M. I. C.E.
- Journal Franklin Institute, short article, 1871.
- Longridge, Jas. A., Flow of water through level canals. M. I. C. E.
- Mair, J. G., experiments. M. I. C. E.
- Makaroff, *Capt.*, Interchange of water, Black Sea and Mediterranean. M. I. C. E.
- Mocquercy, C., Investigations in upper basin of Saône. M. I. C. E.
- Montanari, T., Discharge and regulation of Tiber. M. I. C. E.
- Nazzani, J., Velocity of Tiber. M. I. C. E.
- Nettleton, E. S., Report Colorado State engineer, 1883-'84.
- Parkin, J. H., River gauging. M. I. C. E.
- Perrodil, M. de. Instrument for gauging flow of streams. M. I. C. E.
- Ringel, A., Flow of Elbe in Saxony. M. I. C. E., 1886-'87.
- Ritter, C., Rapid gauging of floods. M. I. C. E.
- Sadler, R. Flow in earthen channels. M. I. C. E., vol. 103, p. 273, 1891.
- Sebert, M. Registering variations. M. I. C. E., vol. 64.
- Shelford, Wm., Flow of mill stream. M. I. C. E.
- Smith, Baird, Italian irrigation.
- Thames, Flow of river. M. I. C. E., 1876.
- Turner, Henry T., Gauging flowing water. M. I. C. E.
- Van Nostrand's Magazine, Kutter's formula, 1886.
- Warren, G. K., Connecticut River, 1878.
- Wilson, H. M., Montana streams, 1890.

DISTRIBUTION OF WATER. Bircha, London, 1882.

DISTRICT LAW (Irrigation districts).

- Hartt, W. H. H., 1891.
- Van Dyck, T. S., Denver, 1891.
- Wright, C. C., San Francisco Chronicle, June 7, 1891.

DIXON (C. G.). Works of irrigation in Ajmeer and Mairwara, Govt. report, India.

DOBSON (EDWARD). Geelong water supply, Victoria, Australia. M. I. C. E., vol. 54, pp. 94-152.

DODGE (J. R.). Our arid regions and the rainfall. Paper read at meeting A. A. A. S., 1889-'90. (Referred to in Popular Science Monthly, vol. 36, 1890.)

DOHERTY (W. J.). Description of cofferdams used at Dublin, Birkenhead, and Hull. M. I. C. E., vol. 51, p. 137.

DONALD (JAMES). Land irrigation, etc. In his land drainage, etc., London, 1853.

DONALDSON (THOMAS). "The public domain," p. 411, classification of lands, Washington, 1880.

DONKIN (B.) *and* SALTER (F.). Experiments on the measurement of water over weirs. M. I. C.E., vol. 83, p. 377.

DORNÈS (A.). Note sur le colmatage de la plaine de "la Cran" et le desséchement des marais de Fos, en vue de leur mise en culture. Extrait des Mémoires de la Société des Ingénieurs civils, mai 1889, 39 pp., 4 tables; 7 pl. and maps.

DORSEY (EDWARD BATES). Excavations and embankments by water power. Trans. Am. Soc. Civil Engineers, p. 348, 1886, vol. 15.

Irrigation, with discussion. Am. Soc. Civil Engineers, 1887, vol. 16, pp. 85-133.

DOUMERC (J.). Les barrages réservoirs de l'Algérie. Revue scientifique, vol. 40, p. 235, Paris, 1887.

DOW (JOHN L.). Irrigation in California. Six companies furnishing water from Kings River to reclaim parched lands in the San Joaquin Valley, estimated capacity to water 650 sq. miles. Scientific American supplement, 1884, vol. 17, pp. 6676-6677.

DOWNING (SAMUEL). Elements of practical hydraulics, part 1, 3d edition, 1875, 232 pp.

DRAINAGE. (In connection with irrigation.)

- Brown, D. J., History of drainage. U. S. Dept. Agr., 1858-'59.
- Cautley, Proby T., Ganges canal, 1860.
- Cole, A. P., System of drainage and irrigation, 1889.
- Denton, J. Bailey, Agricultural drainage, 1883.
- Forrest, R. E., Dehra Dun, Roorkee, India.
- France, Marsh lands in north of. M. I. C. E., vol. 64, p. 364.
- Garay, F. de, Valley of Mexico, 1883.
- Hilgard, E. W., Sacramento, 1886.
- Lawes, J. B., and others, Waters collected at Rothamsted, 1882.
- Scarapri, G., Low-lying lands. M. I. C. E.
- Streeruwitz, W. von., and Dumble, E. T., Bulletin Texas Geological and Scientific Assoc., 1888.
- Willcocks, W., Egyptian irrigation, 1889.
- Ysabeau, Alexandre, Clearings, irrigation, etc., 1861.

DRAINAGE—Continued.

Drainage of St. Jurgensfeld. (Zeitschrift Vereines deutscher Ingenieure, 1886, p. 688.) M. I. C. E., vol. 87, p. 506.

DRAPER (LYMAN C.) *and* **CROFFUT (W. A.).** A helping hand for town and country. Intro. by Horace Greeley, 1869, 821 pp.

DRUMMOND (WILLIS, Jr.). Land grants in aid of internal improvements. U. S. Dept. Int., 1879, Washington, pp. 165–182.

DUBOIS (F. T.). Admission of Territories. Argument of the delegate from Idaho in United States Congress. Hearings before the Committee on Territories in regard to reclamation of arid lands by irrigation. Washington, 1889, pp. 42–45.

DU BOYS (P.). The Rhone and rivers with beds liable to scour. M. I. C. E., vol. 59, p. 379.

DUMBLE (E. T.). Irrigation in Texas. In bulletin of Texas State Geological and Scientific Assoc. Houston, Texas, 1889, vol. 1, No. 9.

DUMONT (ADRIAN) *and* **DUMONT (ARISTIDE).** De l'organization légale des cours d'eau, sous le triple point de vue de l'endiguement. de l'irrigation et du desséchement, Paris, 1845, 534 pp.

DUMONT (ARISTIDE). [Memoir on subject of southern irrigation canal for irrigating plains of Provence and Languedoc, and supplying potable water to cities of Nîmes, etc.] 2d ed. Lyon, 1857.

Des travaux publics dans leurs rapports avec l'agriculture, Paris, 1848.

DUMONT (G.). Irrigation in south of France. Abst. M. I. C. E., vol. 58, pp. 387–388, London, 1879.

[Hydraulics. The distribution of waters and irrigation canals at the Universal Exposition of 1878.] Extrait des Etudes sur l'Exposition Universelle de 1878.

DUNHAM (D. M.). Irrigation in Maine. Abst. U. S. Dept. Agr. Report, 1876, Washington, 1877, pp. 380–381.

DUNWOODY (H. H. C.). Charts and tables showing geographical distribution of rainfall in the U. S. Signal Service, Washington, 1883, 51 pp., 13 chts. Also, Zeitsch. Met., Wien, vol. 19, 1884.

DUPONCHEL (A.). [Preliminary project for the creation of a fertile soil.] Montpellier, 1864.

Treatise on agricultural hydraulics and geology. Paris, 1868.

Théories des alluvions artificielles, fertilisation des landes et réservoirs d'aménagement des eaux de crue dans la région des Pyrénées, 1882.

DUPUIT (A. J. E.). [Theoretical and practical treatise on the conduction and distribution of waters.] 2d ed., Paris, 1865.

DURANCE:

Gauging the waters and silt of the. M. I. C. E., vol. 89, p. 509.

DURNERIN (PAUL). (On non-navigable and non-floatable water courses, especially from the irrigation point of view.) 1879.

DUTTON (CLARENCE E.). Irrigable lands in the valley of the Sevier river, in Lands of the Arid Region, Powell, J. W. U. S. Dept. Int., Washington, 1879, pp. 128–149.

On the cause of the arid climate in the western portion of the United States. Am. Jour. Sci., New Haven, vol. 22, 1881, pp. 247–250; Kansas City Review, vol. 5. 1881–'82, pp. 432–434; Sci. Am. Suppl., New York, vol. 13, 1882, p. 5094.

DUTY OF WATER:

Alexander, B. S. and others, Report. Am. Soc. C. E., 1887.

Beresford, J. S., Roorkee, India, 1887.

Culcheth, W. W., Water consumed in irrigating. M. I. C. E., 1882.

Dorsey, E. B. Am. Soc. C. E., vol. 16, New York, 1887.

Hall, W. H., Report State Engineer of California, 1880.

Nettleton, E. S., Report State Engineer of Colorado.

Powell, J. W., Arid lands, 1879.

New South Wales Royal Commission, report of, 1886.

Smith R. B., Irrigation in Italy, 1855.

DYRENFORTH (R. G.) and Newcomb (Simon). Rainmaking. North American Review, October, 1891.

EARLE (E. L.). Note on Mr. Benton's experiments on discharging capacity of notches. In Punjab Public Works Dept., 1879, pp. 31–38.

EARTHWORK:

Flynn, P. J. Shrinkage of earthwork.

Moncrieff, C. C. S. Irrigation report, 1888.

Raymond, N. G. Graphic method for estimating earthwork.

ECLECTIC REVIEW:

Theory and practice of irrigation. London, vol. 106, p. 409.

EGLESTON (N. H.). The value of our forests. Popular Science Monthly, New York, vol. 19, 1881, 176–186.

EGYPT:

American Jour. Sci., Notices of Egypt, 1835.

Anderson, William, Notes on journey through delta of the Nile, 1884.

Baker, Benj., River Nile. M. I. C. E.

Barois, J., Irrigation, translated by A. M. Miller, 1889.

Davidson, Geo. Washington, 1875.

Deakin, A., 1887.

Jones, Helsham, Outline irrigation canals, 1884.

Lienur, G. A., Wady Rayan.

Moncrieff, C. C. S., Irrigation reports, 1883.

Nubar Bey (Boghos), Irrigation. M. I. C. E.

Rousseau Pasha, Irrigation report, M. I. C. E., 1884.

EGYPT—Continued.
Whitehouse, Cope, Wady Rayan project, 1890.
Willcocks, W., Irrigation. M. I. C. E., 1876–'77.
Same, irrigation, London, 1889.
Woods, Edward, Address. M. I.C. E., 1886.

ELLIS (F. W.). Report on river and flood warnings. Report U. S. Signal Service. Washington, 1887, pp. 121–127.
Floods of Missouri River, Ann. Rep. Chief of Eng. U. S. A., 1888, p. 2324.

ENCYCLOPEDIA BRITANNICA:
Irrigation, pp. 362–370, New York, 1881.

ENGINEERING:
Carpenter, L. G., Irrigation engineering, Fort Collins, Colo.
Fanning, J. T., A practical treatise on hydraulic and water-supply engineering, etc.
Graves, Walter H., Irrigation and agricultural engineering, 1886.
Law, Henry, Rudiments of civil engineering, hydraulic engineering and recent practice in civil engineering.
Medley, J. G., India and Indian engineering, three lectures.
Spon's Dictionary of Engineering, Irrigation, p. 2139.
Wilson, Herbert M., Irrigation engineering, New York, 1889.

EUROPE, (Irrigation in):
Alps, Irrigation in. M. I. C. E., 1884.
England, Irrigation in. U. S. Dept. Agri., 1872.
Europe, Irrigation in. U. S. Dept. Agri., 1870.
Hawksley, Thomas, Address. M. I. C. E., 1872.
Jenkinson, Henry T. J., Irrigation in Switzerland. R. A. S. E., 1850.
Moncrieff, C. C. S., Irrigation in Southern Europe, 1868.
Russia, Irrigation in. Scientific American, 1889.

EVANS (JOHN). Rainfall and evaporation; on the percolation of rainfall on absorbent soils. M. I. C. E., vol. 45, session 1875–'76, part 3; London, 1876.

EVAPORATION:
Beardmore, N. Manual of Hydrology.
Blanford, H. F., Description. M. I. C. E.
Cunningham, Allan, Hydraulic experiments. M. I. C. E.
Desmond, Fitzgerald. Am. Soc. C. E.
Fanning's water supply, engineering, 1877.
Fitzgerald, D. Am. Soc. C. E., 1886.
Gilbert, G. K. Lake Bonneville, 1891.
Greaves, Evaporation and percolation. M. I. C. E., 1876.
Graves, Walter H., Colorado. Am. Soc. C. E., 1887.
Powell, J. W., Report arid lands, 1879.
New York, State Engineer of, report of, 1890.
New South Wales, table of evaporation for 1859 to 1875. Van Nostrand's Magazine, 1870. Sydney.
Scientific American Supplement, Evaporation experiments, New York, vol. 21, 1886, pp. 8693–8694.

EVAPORATION—Continued.
Symons, G. J. Rainfall and evaporation; on the floods in England and Wales during 1875.
Wilde, H. Stelling, 1883.

EWBANK (THOMAS). History of hydraulic and other machines for raising water, with observation on various subjects connected with mechanic arts, etc., 15th ed. New York, 1870.

EXPOSITION UNIVERSELLE EN 1867 (Paris). [Notices of the models, maps, and designs relative to the public works collected under the auspices of the minister of agriculture, commerce, and public works.] Paris, 1867.
Improvement and irrigation of the plain of Forez. M. I. C. E. vol. 54, p. 304.
See Universelle Exposition en 1867.

FABIAN (BENTHAM). The resources of Utah, with statistics of progress for year 1872. Salt Lake City, 1873, 46 pp.

FAHEY (CHARLES SWAINE). The River Indus as a source of supply for irrigation canals in Sind. M. I. C. E., London, 1883, vol. 71, pp. 279–297.

FAMINE: Irrigation a prevention.
Thornton, W. T. London, 1878.

FAMINE COMMISSION REPORT:
Appendix 1. Condition of country and people of India, 1881. Part 2. Measures of protection and prevention, London, 1886.
Appendix, vol. 3. Report of country and people of India. London.
Appendix 5. Irrigation as a protection against famine in India. London, 1881.

FANNING (J. T.). A practical treatise on hydraulic and water-supply engineering relating to the hydrology, hydrodynamics, and practical construction of water works in North America, with numerous tables and illustrations. 8th ed. revised, D. Van Nostrand Co., New York, 1890, pp. 644.

FARGUE. Regulation of river channels, deduced from the widths of the bed of the Garonne. M. I. C. E., vol. 72, p. 340.

FARMERS' CANAL. Resources of California. San Francisco, Oct., 1888.

FAYOUM: in Egypt.
Ross, J. C. Improvements in the Fayoum. Irrigation report, 1887. *See* Moncrieff, C. C. Scott.

FIELD, ROGERS, AND SYMONS (G. J.). Van Nostrand's Eng. Mag., Feb., 1870. On determination of real amount of evaporation from surface of water.

FINETI (B.). Water supply of Venice. M. I. C. E., vol. 81, p. 380.

FINKLE (F. C.). Irrigation and irrigation systems of San Bernardino County, California. Engineering News, July 4, 25, Aug. 15, 22, 1891.

FISCHER (STEFAN). The destruction of artesian well pipes. M. I. C. E., vol. 100, p. 462, 1890. From Wochenschrift des österreichischen Ingenieur- und Architecten-Vereins, p. 355, 1889.

FISHER (*Rev.* OSMOND). The physics of the earth's crust. London, 1881, 300 pp.
2nd edition, London and New York, 1889, 391 pp.

FITZGERALD (DESMOND). Analysis of the rainfall at Lake Cochituate, Mass., 1852–'83. Am. Soc. Civil Eng., vol. 13, 1884, pp. 359 to 375.
Does wind cause the diminished amount collected in elevated gauges? Jour. Asso. Eng. Soc. New York, vol. 3, pp. 233–242, 1884.
Spontaneous evaporation. Am. Soc. Civ. Eng., 1886, pp. 581–645. M. I. C. E., vol. 88, 1886–87, pp. 516, 517.
Maximum rates of rainfall. Am. Soc. Civ. Eng., p. 93, 1889.

FLOATS. *See* Current meters.
Bérard, Motion of. M. I. C. E., vol. 89.
Bazin, H., double floats. M. I. C. E., vol. 78, p. 473.

FLOOD:
Allard, E., Prevision of floods. M. I. C. E., vol. 99, p. 432, 1890.
Apparatus for automatically registering river floods. M. I. C. E., vol. 51, p. 327.
Asta, D., Provision of floods in rivers. M. I. C. E.
Belgrand, E., and Lemoine, G. Seine flood, 1876.
Belpaire, T., Advance and influence. M. I. C. E.
Craig, James, India. M. I. C. E. 1885.
Francis, J. B., effect of rapid increase. Am. Soc. C. E., vol. 21. 1889.
Gallizia, Chev. P., Po floods, 19th century. M. I. C. E.
Gigault d' Olincourt, F., Inundations, 1861.
Gremand, A., Training a mountain torrent.
Moncrieff, C. C. S., Note on the Nile flood of 1887.
Rainfall in the basins of the Witham, Welland, Nen, and Ouse, and at Boston, and its effects in causing floods.
O'Connell, P. P. G., Flood discharges. India, 1890.
Santeires, M., Cofferdams. M. I. C. E.
Remise, Saône floods. M. I. C. E., 1882.
Ritter, C., Gauging. M. I. C. E.
Symons, George J., England and Wales, 1875.
Willcocks, W., Egyptian irrigation. 1889.

FLOW (of water). *See* Discharge.

FLUME. Laybourn iron, Engineering News, New York, Oct. 17, 1891.

FLUVIOGRAPH. *See, also,* Nilometer. M. I. C. E., vol. 57, p. 351.

FLYNN (P. J.). Shrinkage of earthwork. Trans. Tech. Soc. Pacific Coast, No. 21, vol. 2, Geo. Spaulding & Co., San Francisco, 1885.

FLYNN (P. J.)—Continued.
Hydraulic tables based on the formulæ of D'Arcy and Kutter. Trans. Tech. Soc. Pacific Coast, No. 15, vol 2, p. 37. Geo. Spaulding & Co., San Francisco, 1885.
Tulare irrigation district, Reports on the projected works of the. 47 pp., 2 illustrations, Daily Evening Register, Tulare, Cal., 1890.
Kutter's formula. 10 pp., 1 table, Trans. Tech. Soc. Pacific Coast, vol. 3, No. 30, San Francisco, 1886.
Flow of water in open channels, with tables, based on Kutter's formula. San Francisco, 1890.
Irrigation canals and other irrigation works, 600 pp. Denver, 1891.

FOLLETT (W. W.). Forms and construction of dams and reservoirs, 4 pp. Trans. Denver Soc. Civil Engineers and Architects, vol. 1, p. 67. Denver, 1890.

FOLSOM DAM AND CANAL:
Report Directors State Prison, Sacramento, 1890.
Engineering News, New York, Oct. 17. 1891.

FONTAINE. Cylindrical sluice gates on locks of Canal du Centre. M. I. C. E., vol. 88, p. 504.

FOOTE (A. D.). A water meter for irrigation. 3 pp., 1 pl., Trans. Am. Soc. Civil Engineers, vol. 16, No. 355, p. 134.
An automatic waste weir. 3 pp., 1 pl., Trans. Am. Soc. Civil Engineers, vol 18, No. 378, New York, 1888.
Idaho, Agriculture in. Irrigation Age, vol. 1, Denver, 1891.
Idaho, Report on the irrigation and reclaiming of certain desert lands in, and other projects connected therewith. New York, 1887, 54 pp., including 2 pls., 1 map.
Our forest and grazing lands, Irrigation Age, vol. 2, p. 240, 1891.

FORBES (*Col.* J. G.). Agra Canal, revised estimates of. Simla, India, 1885.

FOREST DEVASTATION. [Effects of, on erosion.] Vienna, 1884.

FORESTRY:
Baker, F. P., Mississippi forestry, 1883.
Boissay, C., Irrigation, etc., on arid lands. M. I. C. E.
Brown, John C., Reboisement in France.
Donaldson, Thomas. Public domain,
Erosion and deforesting. *See* Report Adirondack survey, 1886.
Forests and irrigation, Garden and Forest, New York, 1890.
Hilgard, Jones, and Furnas, Pacific Slope, 1882.
Powell, J. W., Report arid lands.
New York Forest Commission, report of, 1888.
Roberts, T. P., Forests concern floods. M. I. C. E.
Schlich, Wm., Manual, 1889.
U. S. Dept. Agr., Div. of Forestry, reports of.

FOREZ:
Improvement and irrigation of the plain of. Exposition Universelle, Paris, 1878. M. I. C. E., vol. 54, p. 304, London, 1878.
Irrigation canal, upper Loire. M. I. C. E., vol. 89, p. 514, London, 1887.

FORREST (R. E.). Irrigation and drainage in the Dehra Dun. Professional Papers, No. 5, Roorkee, India.

FOSCHINI (A.). Hydrographic changes in Italy: the estuary of the Po. M. I. C. E., vol. 57, p. 357.

FOSSETT (FRANK). Colorado: a historical description and statistical work on the Rocky Mountain gold and silver mining region. Denver, 1876.
Colorado: its gold and silver mines, farms and stock ranges, and health and pleasure resorts. Tourist's Guide to Rocky Mountains, New York, 1879.

FOWLER (JOHN). River Tees improvements. M. I. C. E., vol. 90, p. 344.

FOX (WILLIAM). Irrigation in Southern California with special reference to the artesian wells in San Barnardino County. M. I. C. E., vol. 105, p. 238, 1891.

FRANCE. Ministère de l'agriculture et du commerce. [Irrigation in department of Bouches-du-Rhône. Report on the meeting of 1875 (1876) for better use of waters of irrigation, by J. A. Barral.] Paris, 1876; fol. 2 v.
[Irrigation in the department of Vaucluse. Report on the meeting of 1876 (1877) for the better use of waters for irrigation, by J. A. Barral.] Paris, 1877; fol. 2 v.
Annales de l'Institut national agronomique. No. 6, 5e année, 1880–'81. Paris, 1883. Contains: Hérisson, A., Rapport sur les irrigations de la vallée du Pô, pp. v–viii, 219.
Bulletin, cinquième année, 1886. Paris, 1886. Contains: Italy, Décret royal du 28 février sur les syndicats d'irrigation.
Bulletin, Direction de l'hydraulique agricole. Documents officiels, Statistique, Rapports, Fascicule A. (G. H. I. J.) Paris, 1885–'88.
Direction de l'agriculture, L'agriculture, les prairies et les irrigations de la Haute-Vienne, par J. A. Barral, Paris, 1884, ix, 771 pp.

FRANCE, GERMANY, AND HOLLAND (Irrigation in):
Barral, J. A., Drainage arable lands, 1856.
Barral, J. A. Irrigation in department of Vaucluse, 1877.
Barral, J. A., Irrigation eastern Pyrenees. 1880.
Barral, J. A., Irrigation Bouches-du-Rhône, M. I. C. E.
Blackwood's Magazine, Irrigation in Lombardy.
Beaupré, L., Canalization of the Loire, 1858.
Belgrand, M., Basin of the Seine. M. I. C. E.
Boissay, C., Plain of Toulouse. M. I. C. E., 1879.
Cossigny, J. Charpentier de, Irrigation, 1874.

FRANCE, GERMANY, AND HOLLAND—Cont'd.
Chambrelent, Agricultural irrigation, 1866 to 1886.
Delaire, N. A., Basin of Seine. M. I. C. E.
Delprat, J. P., Holland water levels. M. I. C. E., vol. 39, p. 368.
Dumont, Aristide., Irrigation canals, 1857.
Dumont, G., Irrigation. M. I. C. E., 1879.
Exposition Universelle, Notices, Paris, 1867.
Forez Irrigation canal, Loire. M. I. C. E., 1887.
Garnier, François Xavier Paul, Comment on law, 1845–'47.
Irrigation in the Carnague, Rhone. M. I. C. E., 1887.
Maitrot, de Varenne F., Irrigation and drainage, 1857.
Mangon, Hervé, Irrigation of Campine, etc., 1850.
Mylne, R. W., Irrigation. M. I. C. E.
Purvis, Marc Antoine, Advantages of irrigation, 1884.
Raillard, Chas. Louis Emmanuel, Irrigation, 1865.
Rennie, G., Irrigation. M. I. C. E.
Vidalin, F., Irrigation, France and Algeria, 1874.
Vidalin, F., Rhone irrigation canal. M. I. C. E., 1877.
Villeroy, Felix, Irrigation. Annual, 1850.
Vitard, A., Treatise, 1851.
Von Winter, H., System of drainage, M. I. C. E.
Wilson, Geo., Irrigation in department of Bouches-du-Rhône. M. I. C. E., 1878.

FRANCIS (J. B.). Cause of maximum velocity of water flowing in open channels being below the surface. Trans. Am. Soc. C. E., vol. 7, p. 109; *also* M. I. C. E., vol. 55, p. 357.
Experiments on flow of water over submerged weirs. Trans. Am. Soc. C. E., vol. 13, p. 303; *also* M. I. C. E., 1884, vol. 13, p. 303.
High walls or dams to resist the pressure of water. Trans. American Society of Civil Engineers, vol. 19. p. 149, 1888; *also* in M. I. C. E., vol. 96, p. 389.
Effect of a rapidly increasing supply of water to a stream on the flow below the point of supply. Trans. Am. Society of Civil Engineers, vol. 21, 1889.

FRANK (A.). Self-registering rain gauge. M. I. C. E., vol. 77, p. 414.

FRANKLIN INSTITUTE (*Journal of*). Short articles, 1871 and 1877.

FRIEDLANDER. Irrigation in California. The San Joaquin and Tulare Plains. A review of the whole field. Record Steam Printing Co., Sacramento, Cal., 1873, 22 pp.

FRISI (PAUL). A treatise on rivers and torrents; with the method of regulating their course and channels. Weale, 1861 (translation of an old Italian work printed in 1770).

FRIZELL (J. P.). Power of running water to hold matter in suspension. M. I. C. E., vol. 55, p. 356.

FROST (MAX). New Mexico. New Mexican Printing Co., Santa Fé, 1890. 216 pp., a map, 19 tables.

FROWD (J. G. PLAYER). *See* Player-Frowd, J. G.

FTELEY (ALPHONSE). Flow of Sudbury River, Mass., for years 1875–79. Trans. Am. Soc. C. E., vol. 10, p. 225; *also* M. I. C. E., vol. 67, p. 448.

FUCHS (E.). Der Peterscnsche Wiesenbau, Unter Mitbenutzung des Petersenchen Nachlasses, Berlin, 1885, 234 pp.

FULTON (J.). Western Jumna Canal, revised estimates, 1876, for remodeling and completing western Jumna Canal. Lahore, 1876. Punjab Public Works Department.

FURMAN,(H. Van F.). Castlewood dam and reservoir. The Mining Industry and Tradesman, Denver, 1889, pp. 111.

FURNAS (R. W.). Report on the climatic and agricultural features and the agricultural practice and needs of the arid regions of the Pacific slope, with notes on Arizona and New Mexico. *See* Hilgard, E. W., and others.

GAGE (R. D.). Texas. Pecos River Valley, west Texas. Facts about irrigation. Dallas, Tex., 1888.

GAGE, KNIGHT AND WALTHALL. Alfalfa, its culture, worth, and profits, etc. Pecos City, New Mexico, 1889.

GALLIZIA (CHEV. P.). Floods of the Po in the 19th century. M. I. C. E., vol. 54, p. 300.

GALTON (DOUGLAS). On sanitary progress in India. In Journal of the Society for the Encouragement of Arts, Manufactures, and Commerce. No. 1223, p. 519, London, 1876.

GAMBLE (JOHN G.). Water supply in the Cape Colony. M. I. C. E., vol. 90, p. 255.

Storage Reservoir in the Achterfeld. M. I. C. E., vol. 62, p. 380.

GANGES. Lower Ganges Canal Project. Public Works Dept., Allahabad, India, 1874–'76.

Cautley, Col., Sir Proby T., Ganges Canal, London, 1860. Same, 1864.

Crofton, Capt. J., Ganges Canal. Calcutta, India, 1865.

GANNETT (HENRY). Arable and pasture lands of Colorado, in U. S. Geol. and Geog. Surv., 1876, pp. 311–357.

GARAY FRANCISCO DE. Drainage of the valley of Mexico. Trans. Am. Soc. C. E., 1883, vol. 12, p. 153; *also* M. I. C. E., vol. 73, p. 424.

GARBE. On construction of canals in the marsh districts of east Friesland. M. I. C. E., vol. 75, p. 339.

GARDNER (HENRI F.). Water facilities for irrigation in Santa Ana valley. Santa Ana Valley Immigration Asso., Los Angeles, 1885.

GARAX (F. DE). Drainage of valloy of Mexico. M. I. C. E., vol. 12, 1883.

GARDEN AND FOREST. Forests and irrigation, vol. 3, No. 121, p. 293. New York, 1890. fol.

GARNIER (FRANÇOIS XAVIER PAUL). [Comment on the law of July 11, 1847, on irrigation, and new observations on the law of April 29, 1845, relative to same subject, 1855.]

GARSTIN (W. E.). Drainage bordering Lake Menzaleh. *See* Moncrieff, C. C. S.

GATTON (*Capt.* DOUGLASS). Sanitary progress in India. Jour. Soc. Arts. No. 1223, London, 1876.

GAUGING OF RIVERS. Haywood, Capt., Roorkee, India, 1870. *See also* current-meters, discharge, floats.

GEELONG AND SANDHURST. Notes on the Geelong and Sandhurst water supply. M. I. C. E., vol. 57, p. 195.

GEIKIE (ARCHIBALD). Text-book of geology, London, 1882, 971 pp.

Table of proportion of earthy matter by weight in various rivers, p. 370.

GÉNIEYS (R.). Essay on the means of conducting, raising, and distributing water. Paris, 1829.

GEOGRAPHICAL MAGAZINE. London. Contains, Irrigation in southern India, by C. R. Markham, vol. 1, pp. 329–332, 364–367.

Storage of water in Peru. Note, vol. 2, p. 377.

The irrigation of Firozpier by David Ker, vol. 3, pp. 58–63.

Irrigation in southern India, by C. R. Markham, vol. 4, pp. 279–288, 307–311; 2 maps.

Indian irrigation, by H. P. Malet, vol. 5, p. 232. Irrigation in Monghyr. Note, vol. 5, p. 232.

GEOLOGICAL SURVEY. Report of the, on the subject of irrigation. *See* U. S. Interior Department, U. S. Geological Survey.

GEPPERT (A.). New and simple method of training rivers. M. I. C. E., vol. 54, p. 298.

GERSTEL (GUSTAVE) Drainage of clay mountains. M. I. C. E., vol. 39, p. 309.

GIGAULT d'OLINCOURT (F.) [Transformation of inundations into rich irrigation, or agriculture made flourishing by the use of rain water by means of an improved system of horizontal tillage, of a system of irrigated plantations and of irrigation basins.] Paris, 1861.

GILA BEND RESERVOIR AND IRRIGATION CO. Horton, E. J. 40 pp., 3 ills., Tucson, Arizona, 1890.

GILBERT (G. K.). Water supply, also irrigable lands of the Salt Lake drainage system, in U. S. Dept. Interior, Geog. and Geol. survey of Rocky Mountains. Lands of the arid region, 1879, pp. 57–80, 2 pl., pp. 113–127.

GILL (JOHN CHARLES). Artesian wells in south Lincolnshire. M. I. C. E., vol. 101, p. 218.

GIRARDON (——). Forez irrigation canal. Apparatus for gauging water supply. M. I. C. E., 1881, vol. 65, pp. 397, 398.

GLASSFORD (W. A.) *See* U. S. War Department, Signal Service.

GODAVERY. Irrigation from the Godavery. *See* Madras Engineers.

Irrigation from the Kistna and Godavery Rivers. *See* Buckle, E.

GOOD (W.). The construction of the new Nadrai (Kali Nadi) acqueduct, Lower Ganges Canal. M. I. C. E., vol. 105, p. 147, 1891.

Failure of the Kali Nadi Acqueduct, Lower Ganges Canal. Public Works Dept., records of the govt. of India, No. 240, Calcutta, 1888.

GORDON (GEO.). On the value of water and its storage and distribution in southern India. M. I. C. E., 1872, vol. 33, pp. 376–428.

Same, vol. 76, 1883.

GORDON (R.). Report on the Irrawaddy River, 1879.

GORDON (W. B.). Notes on well sinking at Nadrai, aqueduct. Allahabad, India, 1883.

GOSLIN (S. B.). How to avert or mitigate famine and droughts. London, 1878.

GOULD (E. SHERMAN) AND JACOB (ARTHUR). Designing and construction of storage reservoirs. D. Van Nostrand & Co., New York, 1888, 137 pp.

GOULIER (*Col.*). Frager's water meter. M. I. C. E., vol. 86, p. 444.

GRAD (C.). Habra irrigation dam in Algeria. M. I. C. E., vol. 53, p. 325.

GRAEVE (P.). Observations on movement of water in streams. M. I. C. E., vol. 57, p. 352.

GRAFFENRIED (C. de). Regulation of the waters of the Jura. M. I. C. E., vol. 60, p. 363.

GRAMATZEY (E.). Channel of constant mean velocity. Professional papers, Indian engineering, Roorkee, 2d series, vol. 4, p. 405. M. I. C. E., vol. 60, p. 432.

GRAND FORKS, City of. Chamber of commerce, annual report of the, 1881, Grand Forks, N. Dak. 40 pp., inc., 7 pl.

GRANTHAM (B. B.). Hydraulic works of northern Italy. M. I. C. E., vol. 19, p. 82.

Adaptation of large rivers for purposes of irrigation. Tanks in Madras Presidency. M. I. C. E., vol. 19, pp. 80–81.

GRAVES (WALTER H.). Engineer's report on the irrigation canals of Colorado. Denver 1886, 12 pp.

Irrigation and agricultural engineering. A paper read before Denver Soc. Civil Engineers and Architects, 1886. Republican Pub. Co., Denver, Colo., 1886, 16 pp.

GRAY (P.). The influence of trees on climate and rainfall. Trans. and Proc. Dumfriesshire and Galloway Nat. Hist. Soc. Dumfries, vol. 4, 1887.

GREAT DIVIDE storage reservoir. Castlewood reservoir. Great Divide. Vol. 4, No. 2, 1890, Denver.

GREATHED (*Col.* W. H.). On the practice and results of irrigation in northern India. M. I. C. E., 1873, vol. 35, pp. 139–186.

Same. Vol. 45, London, 1873.

GREAVES (CHARLES). Rainfall and evaporation; evaporation and percolation. Discussion on same. M. I. C. E., vol. 45, 1875–'76.

GREELY (*Gen.* A. W.). Irrigation and water storage in the arid regions. 51st Congress, 2d sess., House Ex. Doc. 287.

National Geographic Magazine. Vol. 2, p. 55.

See also U. S. War Dept., U. S. Signal Service.

GREELEY (HORACE). Irrigation, U. S. Dept. Agri., 1869–'70, pp. 510–511.

GREENE (E. L). Irrigation and the flora of the plains. Am. Naturalist, Salem, Mass. Peabody Academy of Science, 1872, vol. 6.

GREENE (*Lieut.* FRANK). Report on the interior wheat lands of Oregon and Washington. Washington, 1888, U. S. War Dept. Signal Service.

GREENE (J. S.). Fourth biennial report of the State engineer of Colorado for years 1887–'88. State Printers, Denver, 1889, 1 vol. 424 pp., vol. 2, plates, numerous tables, 2 vols.

Flow of water in ditches. Trans. Denver Soc. Civil Engineers and Architects, vol. 1, p. 71. C. J. Kelly, 1890, 12 pp., 3 ills.

GREGORY (J. W.). Irrigation statement on, before the Select Committee on Irrigation of the House of Representatives, 1890. 24 pp. U. S. Congress.

GREMAND (A.) Training a mountain torrent. M. I. C. E., vol. 76, p. 398.

GRIERSON (B. H.). Irrigation in New Mexico and Arizona. U. S. War Dept. Report of the Secretary of War, 1888–'89. Washington, 1890, vol. 1, pp. 180–188.

GRIFFIN (G. W.). New South Wales, her commerce and her resources. Sydney, 1888.

GROS (M.). Insufficiency of reservoirs for diminishing the danger of floods. M. I. C. E., vol. 66, p. 408.

GROVER (JOHN W.). Chalk water springs in the London basin; illustrated by the Newbury, Workingham, Leatherhead, and Kirkmansworth Waterworks. M. I. C. E., vol. 90, part 1.

GRUBER (P.). Osselitz Dam. M. I. C. E., vol. 96, p. 390.

GRUNSKY (C. E.). Report of commissioner, San Francisco, 1890. *See* Reed, C. F.

The flow of artesian wells. Trans. Tech. Soc. Pacific Coast, vol. 1, No. 4. Geo. Spaulding & Co., San Francisco, 1884, 7 pp. 1 ill.

Artesian Wells in California, in Journal of Proceedings of the Seventeenth Annual Session of the California State Grange, San Francisco, 1889.

GUÉRARD (ADOLPHE). Mouth of the River Rhone (from the French). M. I. C. E., vol. 82, p. 305.

GUÉSOULT (P.). Waterworks at St. Denis. M. I. C. E., vol. 83, p. 483.

GULLEY (F. A.). Arizona Agricultural Experiment Station. Bulletin No. 1, 1890. Tucson, Ariz., 4 pp.

GULLIVER (*Maj. Gen.* H. W.). Report on the revised estimates for the Sirhind Canal. Punjab Public Works, Dept. Lahore, 1881,

HAGEN (G.). On position which a movable plane takes in floating waters. M. I. C. E., vol. 56, p. 328.

HAGGIN (J. B.). The desert lands of Kern County, Cal. Report of Gen. B. S. Alexander and others. San Francisco, Cal., 1877, 306 pp., 1 map,

HAIG (F. T.). Note on irrigation and communication in Bengal. Calcutta, 1878.

HALE (EDSON D.). The county of San Bernardino, Cal., and its principal city. Board of Trade, San Bernardino, Cal., 1888, 72 pp.

HALL (C. W.). Geological conditions which control artesian well borings in Minnesota. Minn. Bulletin Acad. Nat. Sci., vol. 3, part 1.

HALL (WM. HAM). Report of the State Engineer to the legislature of California, session of 1880, part 4, irrigation of the plains, Sacramento, 1880.

Report of the State engineer to the legislature of California, 1881, part 4, the irrigation question.

Third progress report of the State engineer to the legislature of California, 1883, 15 pp.

Outline of matter and advanced sheets of report on the legislative, administrative, technical, and practical problems of irrigation, 1884, 304 pp.

Physical data and statistics of California. Tables and memoranda of data, collected and compiled by the State engineering department of California. Sacramento, 1886, 547 pp.

The irrigation question. Memorandum transmitted to the legislature of California. Sacramento, 1886, 18 pp.

Report of State engineer for 1886. Part 1, Irrigation development. Sacramento, Cal., 1886, 1 pl., 38 pp.; same for 1888, 12 pp.

Irrigation development: History, customs, laws, and administrative systems relating to irrigation, water courses, and waters in France, Italy, and Spain. Introductory to report of State engineer of California, 1886, Sacramento, 1886, 622 pp.

Irrigation in California (Southern). The field, water supply, and works, organization and operation in San Diego, San Bernardino, and Los Angeles counties. The second part of the report of the State Engineer of California on irrigation and the irrigation question. Sacramento, 1888, 672 pp.

Irrigation in California. National Geographic Magazine, 1889, vol. 1, No. 4, pp. 277-290.

HALL (WM. HAM)—Continued.

Central irrigation district: Its physical, engineering, and business problems and conditions. 60 pp., 15 tables, 1 map, 1 ill.

Perris irrigation district: Its physical engineering and business problems and conditions. Bacon & Co., San Francisco, 1891, 73 pp., 2 ills., 9 tables, 2 maps.

Cost of canal works and storing water. In Nevada State Board of Trade. Address on water supply and irrigation, by F. G. Newlands, Reno, 1890, appendix A., pp. 16-17.

HALL (W. L.). Unique water wheels; Irrigation Age, vol. 1, p. 186, 1891.

HALLÉ (GUSTAVE). The public works of the Orange Free State, South Africa. M. I. C. E., vol. 81, pp. 272-278, 1884.

HAMILTON (PATRICK). The resources of Arizona. 2d ed., 275 pp., 1883; same 1884, 414 pp.

Arizona. For homes, for health, for investments. Phœnix, 1886, 126 pp.

HANCOCK (WM. A.) *and* LEONARD (H. R. Sr.). The Agua Fria water storage and irrigation enterprise. Phœnix, Ariz., 1891, 12 pp.

HARCOURT (L. F. VERNON). Fixed and movable weirs. M. I. C. E., vol. 60, p. 24.

HARLACHER (*Prof.* A. R.). Current meter. M. I. C. E., vol. 67. London, 1876.

Simple method of ascertaining the discharge of rivers. M. I. C. E., vol. 91, p. 397.

Prediction of the height of the Elbe in Bohemia and Saxony. M. I. C. E., vol. 91, p. 400.

HARMAN (H. J.). Operations for obtaining the discharges of the large rivers in Upper Assam. M. I. C. E., vol. 59, p. 367.

HARPER'S NEW MONTHLY MAGAZINE. New York. Contains: Passages of eastern travel by an American, vol. 12, pp. 482-490, vol. 13, pp. 323-335.

California. Its products and productiveness. Information for farmers, Charles Nordhoff, vol. 45, pp. 255-267.

HART (J. E. H.). Mutha Canals. Bombay, India, 1879.

HARTT (WILLIAM H. H.). District irrigation laws of California. Decisions thereon by the Supreme Court. Notes and index compiled and prepared by Attorney-General. Sacramento, 1891, 75 pp.

HASKOLL (W. DAVIS). The practice of engineering field work applied to land and hydraulic, hydrographic, and submarine surveying and leveling for railways, canals, irrigations, etc.

Second edition, revised with considerable additions, and a supplementary volume on waterworks, or the distribution of water in towns under the constant and intermittent systems; gauging streams; sewers, sewage, and irrigation. London, 1878. 2 vols. in 1.

Engineering field work, embracing water work, seswage, and irrigation. London, 1871. 2 vols. in 1.

HAUPT (LEWIS M.). Movable Dams. Proc. Engineers Club of Philadelphia, Pa., Dec. 6, 1884.

HAUSER (I. L.). Wheat culture in India. U. S. Dept. Agri., 1885, pp. 569–582.

HAWKSLEY (THOMAS). The collection and application of water other than sewage water for the farmers' use in irrigation in England. M. I. C. E., vol. 33, p. 349, 1872.

HAWLEY (A. T.). The present condition, growth, progress, and advantages of Los Angeles City and County, Southern California. 1876, 144 pp. By authority of the Los Angeles Chamber of Commerce.

HAWN (F.). Source of rain in Kansas. Quart. Rept. Kansas Board of Agriculture. Topeka, Kans., 1881.

HAY (ROBT.). Artesian wells in relation to irrigation in Western Kansas. 11 pp. 1889.

HAYDEN (F. V.). Annual reports of the U. S. Geological and Geographical Survey of the Territories, containing numerous articles; *also see* Gannett, H.

HAYTER (HENRY HEYBYN). Victorian Yearbook for 1883–'84. Melbourne, 1884. (Irrigation, pp. 436–438.)

HAYWOOD (*Capt.*). Practical gauging of rivers: Professional papers, vol. 7, Roorkee, India, 1870.

HAZEN (H. A.). Danger lines and river floods of 1882. U. S. Signal Service notes, No. 15, Washington, 1884, 30 pp.

Droughts in Kansas and Texas, and secular variation in rainfall. U. S. Monthly Weather Review, Washington, 1887, 119.

HAZEN (WM. B.). Our barren lands. The interior of the United States west of the 100th meridian and east of the Sierra Nevadas. Cincinnati, 1875. 53 pp.

HEMET VALLEY DAM (California). Engineering News, New York, January 24, 1891.

HENCH (G.). Water supply of Weissenfels. M. I. C. E., vol. 75, p. 361.

HENDRICKS (W. C.). Secretary of State of California. Wright irrigation bill and amendments. State Printer, Sacramento, Cal., 1889. 31 pp.

HENNY (D. C.). Wooden pipes; how they can be used to advantage in irrigation. Irrigation Age, vol. 1, Denver, 1891.

HENBY (D. FARRAND). Flow of water in rivers and canals.

HENRY (JOSEPH). Rainfall in Kansas, 1836–1874. Kansas Agri. Rept., Topeka, 1874, pp. 95-100.

HENRY (STUART O.). Rainfall on the plains. Pop. Sci. Monthly, Feb., 1890.

HÉRISSON (ALBERT). Irrigation in the valley of the Po. Journal d'hygiène, Paris, 1883, vol. 8, pp. 237–251.

Irrigation and navigation. In Victoria Royal Commission on water supply, 1887. Appendix 6, pp. 63–64.

HERRISH (C.). Regulation of River Theiss and Catastrophe at Szegedin. M. I. C. E., vol. 59, p. 381.

HERSCHEL (C.). Problem of submerged weirs. Trans. Am. Soc. C. E., vol. 14, p. 189; *also* M. I. C. E., vol. 14, 1885, p. 189.

Note on recent experiments on flow of water in rivers and canals. Van Nostrand's Engineering Magazine, 1887, p. 138.

Work done for preservation of dam, Holyoke, Mass. M. I. C. E., vol. 88, p. 510.

Venturi water meter; instrument making use of a new method of gauging water. Trans. Am. Soc. C. E., vol. 17, p. 228; *also* M. I. C. E., vol. 93, p. 515.

HEUER (*Capt.* **W. H.**). Annual report of improvements of South Pass, Mississippi River. M. I. C. E., vol. 88, p. 421.

HIGGIN (G.). The old water supply of Seville. M. I. C. E., vol. 88, p. 334.

Irrigation in Spain; chiefly in reference to the construction of the Henares and the Esla canals in that country. M. I. C. E., vol. 27, p. 483, 1869.

HILGARD (E. W. JONES AND FURNAS). Report on the climatic and agricultural practice and needs of arid regions of the Pacific slope, U. S. Agri. Dept., 1882, 182 pp.

HILGARD (E. W.). Alkali lands, irrigation and drainage in their mutual relations. Abstract of Government report on alkali lands of India. University of California. Supt. State Printing, Sacramento, Cal., 1886, 45 pp., 4 tables, appendix No. 7 to report for 1886.

Irrigation of the arid region. In Martindale (M. A.) Prospectus of the American irrigation system. Elkhart, Ind., 1883, pp. 10–14.

Report on Agricultural Experiment Station of University of California, with descriptions of the regions represented. Sacramento, 1890. 204 pp., pl., and tables.

HILL (J. ROWLAND). Arizona's development. The Golden Era, vol. 37, No. 12, San Diego, Cal., 1888, 5 pp.

HILL (R. T.). Fort Worth Artesian Area. American Journal of Science, April, 1887.

Water conditions of Cretaceous Rocks of Texas, in first annual report of the Geological Survey of Texas, pp. 110 and 138, 1889.

HILTON (H. R.). Effects of civilization on the climate and rain supply of Kansas. Daily Capitol, Topeka, Kans., Apr. 8, 9, 1890.

HINTON (RICHARD J.). The handbook to Arizona. San Francisco, 1878, 431 pp.

Irrigation in the arid west. In Harper's Weekly, 1888. Sept. 22, pp. 721–724.

Irrigation in the United States. Government Printing Office, Washington, 1890, 386 pp.

Progress report on irrigation in the United States. Government Printing Office, Washington, 1891.

Making the desert bloom. Our Government's irrigation problem. Frank Leslie's Popular Monthly, New York, Sept., 1889.

HINTON (RICHARD J.)—Continued.
Proper location of artesian wells. U. S. Agri. Dept., 1890.

HOLDEN (E. S.). The need of irrigation. In California State Agri. Soc., 1864–'65, 1866, pp. 219–220.

HOLLISTER (O. J.). The resources and attractions of Utah, Salt Lake City, 1882, 93 pp., 1 map.

HOLT (L. M.). State board of irrigation. Legislation asked by the irrigation districts of the State. Holt's Orange Belt, vol. 1, No. 5, Alessandro, Cal., 1891.
Alessandro water system, The. (Two articles.) Holt's Orange Belt, vol. 1, No. 5, Alessandro, Cal., 1891.
Arrowhead reservoir system. The Orange Belt, Alessandro, Cal., vol. 1, June, 1890.
The Bear Valley Irrigation Co. (two articles), 3 maps. The Orange Belt, Alessandro, Cal., vol. 1, June, 1890.
Irrigation district notes. The Orange Belt, Alessandro, Cal., vol. 1, June, 1891.

HOME (*Lieut.* F.). Tank irrigation in Ajmere and Mairwara. Professional papers, on Indian irrigation, No. 229, Roorkee, India.

HOME (F. J.). Sidhnai Canal project, including the Koranga, Fazal Shah and Abdul Hakim Canals, 1888. Public Works Dept., Punjab, India. Lahore, 1888, 56 pp.

HOME (*Col.* R.). Note on Mr. Benton's report on notches. Public Works Dept., Punjab, India. Lahore, 1879, 39 pp.
Notes to hydraulic experiments on the Bari Doab canal, etc. Public Works Dept., Punjab, India. Lahore, 1888.
Report and revised estimate for the Sirhind canal, 1880. Public Works Dept., Punjab, India.
Report on the Sidhnai Canal project, 1883. Public Works Dept., Punjab, India. Lahore, 1883, 4 pp.

HORSLEY (STEPHEN). Restoration and enlargement of ancient irrigation works in Travancore. M. I. C. E., 1886, vol. 84, pp. 485–487.

HORTON (E. J.). Gila Bend Reservoir and Irrigation Co., Tucson, Ariz., 1891.

HOSIE (ALEXANDER). Droughts in China, A. D. 620–1643. Jour. North. China Branch Asiatic Soc., Shanghai, 1878.

HOUGH (F. B.). Letter in regard to the effect of forests in increasing rainfall. In U. S. Bureau of Statistics, Report on the internal commerce of the United States. Washington, 1885.

HOUGHTON (J. F.). Annual report of the surveyor-general of the State of California, 1862, 148 pp., 1 map.

HUGHES (SAMUEL). A treatise on water works for the supply of cities and towns. Crosby, Lockwood & Co., London, 1882, 412 pp., 17 ills.

HUGUES (CARLO). [Mountain irrigation.] Milan 1888, 129 pp.

HULTON (J. H.). Irrigation in Yalo county. In California State Agri. Soc., 1864–'65, 1866, pp. 301–302.

HUNT (*Governor*), of Colorado. The New Mexico *method of irrigation. In U. S. Dept. Agri.*, Report 1870, Washington, 1871, pp. 581–582.

HYDRAULIC (MANUALS AND TABLES):
Armstrong, W. G., History of water-pressure machinery. M. I. C. E.
Benton, J., Report of experiments, 1879.
Burnell, George R., Rudiments, 1858.
Caligny, A. de. Experiments. M. I. C. E.
Cunningham, Allan, Experiments. M. I. C. E.
Delaire, Alphonse, Engineer's manual.
Dorsey, Edward, Water power. A. S. C. E., 1886.
Downing, Samuel, Elements, 1875.
Dumont, George, Distribution of waters, 1878.
Duponchel, A., Agri. treatise, 1868.
Dupuit, A. J. E., Theoretical and practical treatise on waters. Paris, 1865.
Durnerin, Paul, Non-navigable and non-floatable waters, 1879.
Earle, E. L., Notes on Benton's experiments, 1879.
Ewbank, Thomas, Descriptive account, 1870.
Fanning, J. T., Practical treaties, 1890.
Flynn, P. J., Tables, 1885.
Francis, J. B., Cause of velocity of water.
Fteley, A., and Stearns, P., Experiments.
Hagen, G., Movable plane. M. I. C. E.
Haskoll, W. D., Field work.
Jackson, Lewis, D'A., Manual, 1875.
Merriman, M., Hydraulics, 1889.

HYDROGRAPHY:
Baker, Benjamin, River Nile. M. I. C. E.
Beardmore, N., Hydrology, 1862.
Bridges, Lyman, Mississippi overflow. Trans. Am. Soc. C. E., vol. 11, p. 251.
Carter, O. M., Report on Savannah River, 1890.
Delaire, M. A., Basin of Seine. M. I. C. E.
Foschini, A., Venetian lagoons. M. I. C. E.
Gaeay, Francisco de Valley of Mexico. M. I. C. E.
Gordon, R., Irrawaddy River, 1879.
Grover, John W., London Basin. M. I. C. E.
Harlacher, A. R., and Richter H., Elbe. M. I. C. E.
Hilgard, Jones, and Furnas, Pacific Slope arid regions, 1882.
Humphreys and Abbot's report, Mississippi.
Johnson, J. B., Theory and practice of surveying.
Lemoine, G., Seine observations. M. I. C. E.
Lombardini, E., Italy, 1844.
Lucas, Joseph, Surrey and Hampshire. M. I. C. E.
Rolland, G., Algeria, 1866.
Rittor, C., Method of gauging. M. I. C. E.

HYDROGRAPHY—Continued.

Roelants, T. J., Rivers Rhine and Meuse. M. I. C. E.

Schmidt, M. W., Elbe observations. M. I. C. E.

Schermerhorn, L. V., North American lakes. M. I. C. E.

Seine Basin. M. I. C. E., vol. 84, p. 211.

Suter, C. R., Description, 1881.

Van Nostrand's Note, 1877.

Von Wagner's Hydrometry. M. I. C. E.

Warren, G. K., Connecticut River, 1877.

HYGIENE. (In relation to irrigation.)

Balfour, J., Effect of irrigation upon health in East Indies.

Brebant, Pretended dangers of irrigation, 1876.

Cautley, Proby T., Ganges canal.

Deakin, Alfred, Irrigation in western America, 1885.

Galton, Douglas, Sanitary progress in India, 1876.

Hilgard, E. W., Alkali lands, 1886.

Marsh, G. P., Evils, irrigation report, U. S. Dept. Agri., 1874-'75.

Orme, H. S., Irrigation, influence on health, 1885.

IBRAHIMIEH CANAL.

Moncrieff, C. C. S., Basin irrigation of west Ibrahimieh canal.

Moncrieff, C. C. S., Rapport sur le canal Ibrahimieh, 1884.

IDAHO:

Foote, A. D., Agriculture in. Denver, 1891.

Newell, F. H., Census bulletin. 1891.

Shoup, George L., Report of governor, 1889.

Stevenson, Edward A., Report of governor, 1888.

Straughn, Jos. C., Statement before Senate Committee, 1889.

Union Pacific Railroad Co., Resources and attractions of. Omaha, 1888.

INDIA. (*See* also Revenue reports.)

Abbay, R., Irrigation, 1877.

Agra Canal, Roorkee, 1884.

Bell, J. H., Report of committee on project of an anicut across the Kistna River, etc.

Bellasis, E. S., Inundations. M. I. C. E., 1886.

Bengal, Public Works Department, Irrigation Reports.

Beresford, J. S., On Water duty.

Binnie, A. R., Observations, M. I. C. E.

Bombay Presidency, Public Works Department, Irrigation report. 1888.

Buckle, E., Irrigation from Kistna and Godavery rivers.

Buckley, Robert B., Irrigation works, M. I. C. E., 1880.
  Statistical review, M. I. C. E, 1887-'88.

Burke, Charles T., Ashti tank, M. I. C. E., 1884.

Burke, V. A., Controversy on irrigation, 1878.

Byrne, Henry, Irrigation in Ceylon.

Collyer, G. C., Cheyaur anicut and channels.

Conybeare, H., Tanks in Rajputana, M. I. C. E.

INDIA—Continued.

Cotton, A. T., Reports and letters upon the rivers Cauvery and Coleroon.

Dacosta, J., Irrigation works, 1876.

Davidson, G., Report, 1875.

Fahey, Charles Swaine, Indus, M. I. C. E., 1883.

Famine Commission, Reports of, London, 1880-'85, 8 vols.

Forrest, R. E., Irrigation of Deyrah Dhoon.

Gordon, George, Value of water, M. I. C. E., 1872.
  Irrawady River, 1879.

Grantham, R. B., Large rivers for irrigation, M. I. C. E.

Greathed, W. H., Results of irrigation, M. I. C. E., 1873.

Gulliver, H. W., Sirhind canal, 1880-'81.

Haig, F. T., Bengal irrigation, 1878.

Hauser, I. L., Wheat culture, 1885.

Home, F., Tank irrigation.

Home, R., Note on notches, 1879.
  Sirhind canal, 1880, 1883, 1888.

Horsley, Stephen, Travancore, M. I. C. E., 1886.

Irrigation and cotton culture, Eclectic Review, London.

Irrigation, Eclectic Magazine, New York.

James, A. G. F., Indian industries.

Jones, H. H., Marora Works, Ganges canal, M. I. C. E.

Lake, A., Anicut across the Kistna, 1856.

Lambert, George, Irrigation report, 1887-'88.

Latham, John Herbert, Soonesala canal, M. I. C. E., 1872.

Login, Thomas, Irrigation. 1869.
  Benefits of irrigation, M. I. C. E.

Maclean, L. F., Report Sidhnai canal, 1883.

Madras agricultural exhibition essays, 1883.

—— Presidency, Public Works Department, Progress report, 1877-'78.

Markham, Clements R., Southern India Geographical Magazine, 1874.

Malet, H. P., irrigation, 1880.

Medley, Julius G., Lectures on engineering, 1872-'73.

Nelson, Wind power, M. I. C. E., 1879.

Nicolls, J. R. C., Agricultural engineering.

Norton, C. E., Irrigation, North American Review.

Northwest Provinces, Public Works Department.

Palmer, E. C., Irrigation Experiments.

Phillpotts, W., Irrigation in Ceylon.

Playfair, J. W., Deccan.

Punjab, Reports Public Works Department.
  Sidhnai canal atlas, 1889.

Revenue irrigation report, 1877-'78.

Rundall, F. H., Irrigation works lectures, 1876.

Sim, D., Coleroon anicut.

Sind (Province of) report, Public Works Department, 1888-'89.

Thornton, W. T., Irrigation works.

Tickell, R. P., Ganges canal, M. I. C. E.

Tolbort, T. W. H., District Dera Ismail Khan, 1871.

Water supply, M. I. C. E.

INDIA—Continued.

Whitney, J. E., Mura canal, M. I. C. E., 1884.

Wilson, Allan, Irrigation, M. I. C. E.

Wilson, H. M., Irrigation in India, 1890.

Wingate, Andrew, Ahmednager irrigation, 1881.

INSTITUTION OF CIVIL ENGINEERS. (Minutes of proceedings of, London.)

On the value of water, and its storage and distribution in Southern India, by Geo. Gordon, vol. 33, pp. 376–428, pl. 7.

Address of the President, Thomas Hawksley. The collection and application of water, other than sewage water, for the farmers' use in irrigation in India, vol. 33, p. 349.

On the Soonkesala canal of the Madras Irrigation and Canal Company, with discussion by Geo. Herbert Latham, vol. 34, pp. 67–110, pl. 14–16.

On the practice and results of irrigation in Northern India, with discussion by W. H. Greathed, vol. 35, pp. 139–185, pl. 6.

The improvement of the Sologne, by M. Sainjon. Abst., vol. 40, pp. 306–307.

Irrigation of the Plain of l'Habra, by Leon Pochet. Abst., vol. 41, pp. 247–251.

Irrigation works in the Haute-Garonne, by M. Tranie. Abst., vol. 42, pp. 276–278.

On irrigation in the department of Bouches-du-Rhône, by J. A. Barral. Abst. vol. 45, pp. 308–309.

The irrigation works of Alicante, in Spain, by M. Aymard, vol. 45, pp. 309–311.

Irrigation in the Provinces of Mercia and Albacete, Spain, by F. de Botella. Abst., vol. 45, pp. 311–314.

The Sewage System, with discussion by C. Norman Bazelgette, vol. 48, pp. 311–314.

Rhone irrigation canal, by F. Vidalin. Abst., vol. 48, pp. 315–318,

Memorandum on the irrigation duty of water, and the principles on which its increase depends, by J. S. Beresford. Abst., vol. 48, pp. 319–321.

Failure of the Henares irrigation canal in Spain, by W. Atkinson, vol. 49, pp. 187, 188.

Irrigation of the Marchfeld, by E. von Podhagsky. Abst., vol. 50, pp. 233, 234.

Irrigation in the south of France, department of the Bouches-du-Rhône, by George Wilson. Vol. 51, pp. 213–236.

The drainage, irrigation, and cultivation of the Albufera of Alcudia, Majorca, etc., by Henry Robert Waring. Vol. 51, pp. 243–249.

The Habra irrigation reservoir dam in Algeria, by C. Grad. Abst., vol. 53, pp. 325, 326.

Exposition Universelle à Paris, 1878, Improvement and irrigation of the plain of Forez. Abst., vol. 54, p. 304.

Results of irrigation, drainage, and replanting of desert lands, by C. Boissay. Abst., vol. 56, pp. 341–342.

Irrigation in Ceylon, by Henry Byrne. Vol. 57, pp. 231–238.

On keeping irrigation canals clear of silt, by R. B. Buckley. Vol. 58, pp. 278–280.

INSTITUTION OF CIVIL ENGINEERS—Cont'd.

Irrigation in south of France, by G. Dumont. Abst., vol. 58, pp. 387, 388.

Inquiry into the possibility of the use of wind power for irrigation in India, by Mr. Nelson. Abst., vol. 59, pp. 409, 410.

A storage reservoir in the Achterfeld, by John G. Gamble. Abst., vol. 62, pp. 380, 381.

On the Cigliano elevator, and on irrigation in Piedmont, by E. Paladini. Abst., vol. 64, pp. 361–363.

Experiments on a new form of module for irrigation purposes, by John Lewis Felix Target. Vol. 65, pp. 313–322.

Quantity of water consumed in irrigation, by W. W. Culcheth. Abst., vol. 69, pp. 440, 441.

Distribution of water from irrigation canals, by M. Bricka. Abst., vol. 70, pp. 445–447.

The river Indus as a source of supply for irrigation canals in Sind, by Charles Swaine Fahey. Vol. 71, pp. 279–297.

The introduction of irrigation into new countries, as illustrated in northeastern Colorado, with discussion and correspondence, by Patrick O'Meara. Vol. 73, pp. 178–272.

Water supply and irrigation of the Canterbury plains, New Zealand, by George Frederick Ritto. Vol. 74, pp. 238–245.

Description of earthwork on the upper San Joaquin irrigation canal, California, by G. J. Specht. Abst., vol. 74, pp. 317–319.

Reconstruction of the Bhim Tal dam, Kumaon, N. W. P., India, by Francis Henry Ashhurst. Vol, 75. pp. 202–210, pl. 8.

The Ashti tank, by Charles Tolar Burke. Vol. 76, pp. 288–316.

Notes of a journey through the northeast portion of the delta of the Nile in April, 1884, by William Anderson. Vol. 76, pp. 346–354.

Water supply in some parts of Peru, and Probyn's distilling apparatus at Iquique, by C. M. Johnson. Vol. 77, pp. 342–346.

The Nira irrigation canal, by J. E. Whiting. Abst., vol. 77, pp. 422, 423.

Irrigation in the Alps. Abst., vol. 77, pp. 423–425.

Report of the ministry of public works on the irrigation of Egypt, and an examination of a proposal relating to it, by Rousseau Pasha. Abst., vol. 77, pp. 425–428.

The public works of the Orange Free State, South Africa, by Gustave Hallé. Vol. 81, pp. 272–278.

Sluices, scour culverts, and waste weirs for irrigation storage reservoirs, by G. Torricelli. Abst., vol. 83, pp. 473–476.

Notes upon the more important features of large reservoirs for irrigation, by G. Torricelli. Abst., vol. 84, pp. 483–485.

Restoration and enlargement of ancient irrigation works in Travancore, by S. Horsley, Abst., vol. 84, pp. 485–487.

Weir with free overfall and constant coefficient of contraction for gauging water supplied for irrigation, by C. Cipollette. Abst., vol. 85, pp. 454–457.

INSTITUTION OF CIVIL ENGINEERS—Cont'd.
Address by Edward Woods. Vol. 87, pp. 1-59 (Nile irrigation works, pp. 53-55).
Irrigation in Lower Egypt, with discussion and correspondence, by William Willcocks. Vol. 88, pp. 300-358, inc. 3 pl.
Irrigation in the Camargue, near the mouth of the Rhone. Abst., vol. 89, p. 513.
Forez irrigation canal, upper Loire. Abst., vol. 89, p. 514.
Irrigation in Egypt, by Boghos Nubar Bey. Abst., vol. 89, pp. 515-521.
Irrigation in Lower Egypt. Reply of William Willcocks to discussion and correspondence. Vol. 90, pp. 240-247.
Inundation canals in the Punjab, by E. S. Bellasis. Abst., vol. 89, p. 521.
Water supply in the Cape Colony, by John G. Gamble. Vol. 90, pp. 255-294.
Irrigation in Egypt, by J. Barois. Abst., vol. 91, pp. 510-515.
Experiments on a new hydraulic machine employed for irrigation, by Marquis de Caligny. Abst., vol. 92, p. 452.
The failure of the Kali Nadi acqueduct on the Lower Ganges canal, W. H. Thelwall, vol. 95, p. 283.
The Sidhnai Canal System, L. H. Mac Lean, vol. 103, p. 264.
The construction of the New Nadrai (Kali Nadi) aqueduct, Lower Ganges canal, W. Good, vol. 105, p. 147, 1891.
Irrigation in Southern California, with special reference to the artesian wells in San Bernardino County, William Fox, vol. 105, p. 238, 1891.

INTERIOR (Department of). *See* United States, Department of Interior, Secretary, report of the, concerning irrigation of certain lands, 1888.

INTERNATIONAL CONGRESS on the utilization of the waters of rivers. Rapport de M. André de Llaurado, Paris, 1889. 12 pp.

INTZE (O.) The rational employment of the water ways of Germany. M. I. C. E., vol. 72, p. 348.

INUNDATION CANALS. Bellasis, E. S., Punjab, India, 1887.

IRRIGATION:
Irrigation and reclamation of arid lands. *See* report Bureau Statistics, 1889, part ii, pp. 606-616.
Irrigation as a renovator of pasture land. U. S. Dept. Agr., Washington, 1870, p. 526.
Irrigation systems of different countries. U. S. Dept. Agr., Washington, 1872, pp. 275-287.
Irrigation as a remedy for chinch bug. U. S. Dept. Agr., report of, 1881-'82. Washington, 1882, pp. 88, 89.
Irrigation and cotton culture in India. Eclectic Review, London, vol. 106. p. 104.

IRRIGATION (general discussion of):
American Cyclopedia, Irrigation, 1883.
American Naturalist, Irrigation, 1872.

IRRIGATION—Continued.
Anderson, Geo. G. Aspects of Irrigation. Denver Soc. C. E., 1890.
Balfour, J. London and Edinburg Journal, vol. 2.
Barois, J., Egyptian irrigation, 1887.
Barral, J. A., Irrigation drainage, 1860.
Beresford, J. S., Irrigation. M. I. C. E.
Bertin, J. L. H., Irrigation Code, 1850.
Brassey, T. A., Australian Saharas, 1890.
Brown, D. J., Gardening, 1854-'55.
Bruschetti, Giuseppe, Milanese Irrigation.
Buckley. Irrigation works in India, 1887-'88.
Cautley, P. T., Ganges canal works, 1860.
Church, A. H., Irrigation, Ency. Brit., 1881.
Cole, A. N., New Agriculture, 1885.
Davidson, Geo., India, 1875.
Deakin, A., Irrigation in North America, 1885.
Dorsey, E. B., Irrigation. Am. Soc. C. E., 1887.
Encyclopædia Britannica.
Green, J. S., State engineer, Colorado.
Hall, Wm. Ham., State engineer, California.
Hérisson, A., Valley of Po. M. I. C. E., 1883.
Hilgard, Jones and Furnas, Pacific slope report, 1882.
Hilgard, E. W., Report, 1890.
Hinton, Richard J., Report, 1887.
Marsh, G. P., Man and nature, 1887.
Mead, Elwood, State Eng., Wyoming.
Moncrieff, C. S. S., Irrigation in southern Europe, 1868.
Mullins, Gen. J., Irrigation manual, 1890.
Nettleton, E. S., State Eng. Colo., 1882-83.
Newell, F. H., Census bulletins, 1891.
O'Meara, Patrick. M. I. C. E., 1883.
Poston, Chas. D., Irrigation.
Powell, J. W., Reports, 1878-'91.
Rawlinson, R., Drainage of uplands. M.I.C.E.
Scott, John, Irrigation and water supply, 1883.
Smith, E. Goodrich, Report, 1860-'61.
Smith, R. Baird., Italian irrigation, 1868.
Spain, Irrigation in. Am. Soc. C. E., 1887.
Spon's Dictionary of Engineering.
Victor, H., Professional papers.
Willcocks, W., Egyptian irrigation.
Wilson, H. M., in Montana and in India.
Wilson, G., South of France. M. I. C. E.
Wilson and Logan, in Spain.

IRRIGATION EXPERIMENTS:
Palmer, E. C., Roorkee, India.

IRRIGATION IN—
Madras. Smith, Capt. R. Baird, London, 1856.
Mysore. Sanky, Maj. R. H., Roorkee, India.
Northern India. Greathed, Col. W. H., London, 1873.

IRRIGATION MANUAL. Mullins, Lt. Gen. J., New York and London, 1890. (*See also* Manuals.)

IRRIGATION WORKS. Thompson Civil Engineering College, Roorkee, India, 1873.

ISMAILIEH CANAL. Rapports, etc., Moncrieff C. C. S., 1883.

ITALY.

Bertozzi, Giulio Cesare, Report, 1867-'68.
Cavour, Il Canale, etc.
Cortese, E., Irrigation of Apulia.
Davidson, George. Washington, 1875.
Deakin, Albert, Report, 1887.
Fineti, B., Water supply of Venice. M. I. C. E. Vol. 81.
Grantham, R. B., Hydraulic works. M. I. C. E.
Hérrisson, Albert, Po irrigation, 1883.
Lazzaro, Nicola, Naples waterworks. M. I. C. E.
Lombardina, Elia, Lombardy, 1844.
Lombardy and its irrigation. Blackwood's Magazine, 1853.
Mauny (de Mornay) Practice and legislation of irrigation in Italy and parts of Germany. 1844.
Ministero di agricoltura, industria e commercio (titles translated).
  Irrigation and artificial lakes of Spain, 1888.
  Irrigation by means of reservoirs in Sicily, 163 pp. (Manuscript lithographed.)
  Irrigation of the Puglie, etc., 107 pp. (Manuscript lithographed.)
  Preliminary project of damming the Tidone, 29 pp. (Manuscript lithographed.)
  Irrigation of the plain of Cagliari, Sardinia, 54 pp. (Manuscript lithographed.)
  Project for diverting the Tirsi, etc., 57 pp.
  Hydrographic map of Italy. Report of the ministerial commission on the irrigation existing in Emilia. Rome, 1888, 70 pp.
  Rules for engineers, etc. Rome, 1886, 38 pp.
  Irrigation in the following provinces of Italy, etc. Rome, 1888, 279 pp.
  Preliminary project of damming the torrent Baganza. 29 pp. (Manuscript lithographed.)
  Artificial lakes of Algeria, France, and Belgium, etc. Rome, 1886.
  Royal decree of the 28th of February, 1886, on irrigation syndicates.
Nadault de Buffon, Benj., Irrigation canals, 1843-'44.
  Agri. hydraulics, 1861-'62.
Naples waterworks. M. I. C. E.
Paladine, E. M. I. C. E., 1881.
Piedmont, Cigliano, Elevator and Irrigation. M. I. C. E. Vol. 64.
Smith, R. Baird, Irrigation report, 1852.
Sospizio, C., Reports, 1884.
Trevellini, L., Venice waterworks. M. I. C. E.
Van Nostrand's Magazine., Irrigation works, 1884.
Vignotti, A., Irrigation, Piedmont and Lombardy, 1863.

JACKSON (HELEN HUNT). Outdoor industries in southern California. Century, New York, 1883, vol. 4, pp. 803-820.

JACKSON (LOWIS D'A.):
  Hydraulic manual. London, 1875, 2 vols. in 1.
  Same, statistics of hydraulic works and hydrology in England, Canada, Egypt, and India. London, 1885.

JACOB (ARTHUR). Conservancy of rivers in the valley of the Irwell. M. I. C. E., vol. 101, p. 233.
  Design and construction of storage reservoirs. D. Van Nostrand & Co., New York. 1888. (*See also* Gould, E. S.)

JAMES (A. G. F. ELIOT). Indian industries (contains chapter on irrigation).

JANICEL (M.). Regulation and canalization of rivers. M. I. C. E., vol. 64, p. 368.

JAUBERT de PASSA (*Baron* **FRANÇOIS JACQUES**). [Researches on the subject of irrigation among ancient peoples.] Paris, 1846.

JENKINSON (HENRY T. J.). On irrigation as practised in Switzerland. Jour. Royal. Agri. Soc. of England. London, 1850, vol. 2, pp. 607-611.

JOHNSON (A. J. and SON). Johnson's Universal Cyclopædia, New York, 1877. (Irrigation, 1311-1313; Practical irrigation, pp. 1313-1316.)

JOHNSON (CHARLES MALCOLM). Water supply in some parts of Peru; and Probyn's distilling apparatus at Iquique. M. I. C. E., vol. 77, p. 342.

JOHNSON (J. B.). Three problems in river physics. Van Nostrand's Mag., p. 227, 1885; also, Proc. A. A. A. S.
  Theory and practice of surveying. New York, 1890, 703 pp.

JONES (*Lieut. Col.* **HELSHAM**). Royal Engineers' Institute, occasional papers, 1884.

JONES (*Maj.* **H. H.**). Constitution of Narora Works, head of Lower Ganges Canal. M. I. C. E., vol. 55, p. 371.

JONES (J. E.). Report of the surveyor-general and State land register of Nevada for 1887-1888, 154 pp.

JUMNA CANAL. Cautley, *Col. Sir* Proby T., London, 1864.

KALI NADI AQUEDUCT, LOWER GANGES CANAL. Records Government of India. Calcutta, 1888.

KALM (PETER). Travels into North America, Warrington, 1770, 3 vols., pp. 308-310 of vol. 1. Irrigation practiced in Pennsylvania.

KANSAS:
  Curtis, Geo. E., Irrigation report, 1889.
  Gregory, J. W., Irrigation statement, 1890.
  Hay, Robert, Artesian wells, 1889.
  Tweeddale, William, Report, 1890.

KEELHOFF (J.). Practical treatise on irrigation of meadows. Brussels, 1856.

KELLER. Formation of sand banks and sandhills and construction of harbors on sandy coasts. M. I. C. E., vol. 72, p. 455.

KENNISON (ROBERT L.). Irrigation in Utah. U. S. Dept. Agr., Washington, 1871, pp. 577–578.

KER (DAVID). The irrigation of Firzopier. Geographical magazine. London, 1876, vol. 3, pp. 58–63.

KERN COUNTY CANALS, CALIFORNIA. Description of, on p. 300. Report of special committee U. S. Senate, vol. 2, 1890.

KERN ISLAND CANAL. Resources of California. San Francisco, Cal., Oct., 1888.

KINDERMANN (F.). The connection between the heading-up due to weirs and the surface-fall according to measurements of the Nile. M. I. C. E., vol. 91, p. 518.

KING (CAMERON H.). The citrus fruit belt of southern Arizona. Crocker & Co.'s Print, San Francisco, 1887, 26 pp.

KING (G.). Irrigation with town sewage. Trans. Society of Engineers, London, 1866, pp. 84.

KINNEY (ARROTT). Forests and floods in western California. Am. Met. Jour., Ann Arbor, vol. 3, 1886–'87.

KISTNA RIVER:

Irrigation from Kistna and Godavery rivers. Buckle, E.

Project for constructing an annicut across the river Kistna, etc. Lake, A.

Report of committee on project of an annicut across Kistna River, etc. Bell, J. H.

KI TONG (TCHENG). *See* Tong (Tcheng Ki).

KLEITZ (M.). Theoretical investigation of variable motion of floods and its application to the propagation of floods of rivers. M. I. C. E., vol. 51, p. 356.

KOM OMBO PLATEAU. On the. J. C. Ross, Irrigation report 1887. *See* Moncrieff, C. C. S.

KRAFT (MAX). Reservoir construction. M. I. C. E., vol. 69, p. 437.

KRAJINRRINCK (J. A.). [On irrigation, its influence on agriculture, and the means of supplying it; with description of method of damming running waters, and raising the level, applicable where every other method is impossible.] Batavia, 1851.

KRANTZ (J. R.). Study on reservoir walls. Translated by F. A. Mahan. New York, 1883, 54 pp.

KRESNIK (*Dr.* P.). Measures adopted for the safety and service of reservoir dams. M. I. C. E., vol. 99, p. 439.

KUHL (CHARLES H.). The Salina mouth of the Danube. M. I. C. E., vol. 91, p. 329.

KUICHLING (E.). Relation between rainfall and discharge of sewers in populous districts. M. I. C. E., vol. 97, p. 465.

KUTTER. Hydraulic tables based upon the formulæ of D'Arcy and Kutter. *See* Flynn, P. J. San Francisco, 1886. Translation by L. D'A. Jackson. New formula for the mean velocity of discharge of rivers and canals, by W. R. Kutter.

LA JUNTA AND ITS DITCHES. Irrigation Age, vol. 1, Denver, 1891.

LAKE (*Capt.* ATWELL). Project for constructing an annicut across the river Kistna to irrigate portions of the Masulipatam and Guntoor districts. Professional papers. Madras, India, 1856.

LAMAIRESSE (M.). Damming of the Cheliff. M. I. C. E., vol. 39, p. 390.

LAMBERT (GEORGE). Annual irrigation revenue report, Sind, 1887–'88, fol. India.

LANTEIRES (M.). Cofferdams in flooded rivers. M. I. C. E., vol. 60, p. 442.

LATEY (J. H.). Proper employment of irrigation in Colorado. U. S. Dept. Agri. Report, 1870, Washington, p. 578.

LATHAM (H.). Irrigation and farming in Japan. U. S. Dept. State, Reports from the Consuls, No. 93, Washington, 1888, pp. 379–380.

LATHAM (JOHN H.). On the Soonkesala canal of the Madras Irrigation and Canal Company (with discussion). M. I. C. E., London, 1872, pp. 67–110.

LAWS (on irrigation). *See* Legislation.

LAW (HENRY), BURNELL (GEORGE R.), *and* **CLARK (D. KINNEAR).** The rudiments of civil engineering, including a treatise on hydraulic engineering. 7th ed. Crosby, Lockwood & Co., London, 1882, 638 pp.

LAWES (J.B.) *and others.* On the amount and composition of the rain and drainage-waters collected at Rothamsted; with appendix tables. London, 1882, Jour. Roy. Agri. Soc. England, vols. 17, 18.

LAZZARO. The Naples waterworks. M. I. C. E., vol. 81, p. 377.

LE CONTE (L. J.). Contamination of waters in storage reservoirs on the Pacific coast. M. I. C. E., vol. 102, p. 370, 1890.

LEFFEL (JAMES). Construction of mill dams and Bookwalter's Millwright and Mechanic. James Leffel & Co., Springfield, O., 1881, 83 ills., 283 pp.

Weir dam and measurement of waters, construction of mill dams. James Leffel & Co., 304 pp.

LEGISLATION.

Anderson, G. G. Some aspects of irrigation. Denver, 1890.

Bentabol y Ureta, Aurelio, and Pardo, Legislation of waters, 1846, '79. Same, 1884.

Drummond, Willis, Land grants, 1879.

Hall, W. H., Outline matter, 1884.

Nadault de Buffon, Benjamin, Agricultural hydraulics, 1861.

Pistoye, Alphonse de, Irrigation law, 1807–1844.

Rogers, Platt, Control of water, 1889.

Vignerte, Benj. C., Legal manual of irrigation, 1846.

LE MESURIER (J.). Slips in earthern embankments of tank in Bombay presidency, Bombay, India, fol., 6 pp.

LEMOINE (G.). Hydrometric observations in the basin of the Seine. M. I. C. E., vol. 59. p. 365.

LIERNUR (G. A.). Notes on the Wady Rayan, Wady Rayan survey. Public Works Ministry, National Printing Office, Cairo, 1888, 6 pp.

LINCOLN (JOHN W.) *Irrigation in Massachusetts.* U. S. Dept. Agr. Rept. Com. of Patents, 1851, part 2, agriculture. Washington, 1852, pp. 162-164.

LINDLEY (W. H.). Utilization of river water for water supplies. M. I. C. E., vol. 101, p. 349.

LLAURADO (ANDRÉS). [Treatise on waters and irrigation in Spain.] Madrid, 1878.

LOGIN (THOMAS) Wilson A., and others. *Irrigation in India and in Spain.* London, 1869, pp. 19-30.

Benefits of irrigation in India and on the proper construction of irrigation canals, with discussion. M. I. C. E., London, pp. 471, vol. 27.

LOISNE (M. de). Water supply in manufacturing towns of Lille. M. I. C. E., vol. 53, p. 321.

LOMBARDINA (ELIA). [On the hydrographic, natural and artificial state of Lombardy.] In Cattaneo, Carlo, Notizie naturale e civili sulla Lombardia, Milano, 1844.

Irrigation, in his Essai sur l'hydrologie du Nil, 1865.

LOMBARDY. [Irrigation of Upper Lombardy. Report of commissioners charged by the provincial deputation of Milan with the examination of a project for the irrigation of Upper Lombardy with water derivable from Lake Lugano and Lake Maggior.] In Giornale del genio civile, Parte non-ufficiale, Anno, vol. 1867, Firenze, 1868, pp. 124-129.

Lombardy and its irrigation, in Blackwood's Magazine, 1853, pp. 447-459.

See also Italy.

LONGRIDGE (JAS. A.). Flow of water through level canals. M. I. C. E., vol. 53, pp. 216.

LOOMIS (E.). Contributions to meteorology. Eighteenth paper. Mean annual rainfall for different countries. Am. Jour. Science, New Haven, vol. 25, 1883, etc.; also New Haven, 1883, 18 pp., map.

Letter addressed to the Chief of Bureau of Statistics in regard to principal sources of rainfall in different sections of the United States. U. S. Bureau Statistics, report on international commerce of the United States, Washington, 1885, pp. 6, p. 208.

LOWER CALIFORNIA COMPANY. Lower California: Its geography and characteristics, with a sketch of the grant and purposes of the Lower California Company. New York, 1865, pp. 18, 44.

LUCAS (JOSEPH). Hydrogeology of Lower Greensands of Surrey and Hampshire. M. I. C. E., vol. 61, p. 200.

LUCKNOW RESERVOIR, Mullins, Capt., Roorkee, India, 1869.

McAFEE BROTHERS. Tehama County, California, geography, topography, soil, climate, productions, etc. San Francisco, 32 pp.

McCAFFREY CANAL. Resources of California. San Francisco, Cal., 1888.

McCLELLAN (E. C.). Reservoir sites in Elko County, Nevada, 1890. Nevada State Board of Trade. Reno, 1890.

McCONOUGHY (O. H.). The San Diego Flume. The Golden Era, vol. 37, No. 12. San Diego, Cal., 1888, 10 pp., 4 illus.

McCORD CANAL. Resources of California. San Francisco, Cal., 1888.

McELROY (S.). *Irrigation of valley of Chimbote,* Philadelphia, Pa., Jour. Franklin Inst., vol. 18, p. 145.

McGEACHY (EDWARD). Irrigation in the West Indies; being a simple plan by which they may be perpetuated as valuable and productive sugar colonies. Kingston, Jamaica, 1846, 78 pp.

MacINNES (D.) *and* **DICKEY.** The Canadian Northwest. Speeches delivered in the Senate of Dominion of Ottawa. 1890. The Senate Debates.

MACHINERY. Irrigation and water supply. A practical treatise on raising water by machinery. *See* Scott, J.

Caligny, Marquis de. Experiments on hydraulic machine. M. I. C. E., 1888.

MACKENZIE (ALEXANDER). Report on current meter observations in the Mississippi River *near Burlington, Iowa, during the month of* October, 1871. Engineer Department, U. S. Army, Washington, 1884. 38 pp., 41 pls.

McKINNEY (H. G.). Irrigation in its relation to the pastoral industry in New South Wales. M. I. C. E., vol. 100, p. 445, 1890. From journal and proceedings of the Royal Society of New South Wales, p. 75, 1890, 2 maps.

MACLEAN (LOUDON F.). The Sidhnai canal system. M. I. C. E., vol. 103, p. 267, 1891.

Report on the Sidhnai canal project, 1883. Punjab Public Works Department.

McMASTER (JOHN B.). High masonry dams. D. Van Nostrand & Co., New York, 1876, 132 pp.

McMATH (ROBERT E.). Mean velocity of streams flowing in natural channels. Am. Soc. Civ. Eng., vol. 11, p. 186, 1882. 24 pp.

Silt movement by the Mississippi. Jour. Asso. Eng. Soc., vol. 1, p. 266.

MADRAS. Madras agricultural exhibition, 1883. Essays on the management of soils under coffee, etc.; on the utilization of irrigation water; on best method of planting fuel plantations in India. 1885. 157 pp.

MADRAS—Continued.
Annual progress report of the irrigation branch in the Madras Presidency, 1877–'78.
Madras Engineers. Professional papers. 4 vols. Madras, India, 1856–'59,
Anderson, J. C., Roorkee, India.

MAHANUDDY ANNICUT. Walker, J. P. H., Roorkee, India, 1870.

MAIR (J. G.). Experiments on discharge of water of different temperatures. M. I. C. E., vol. 84, p. 424.

MAITROT (DE VARENNE F.). [On irrigation and drainage in the department of Haute-Garonne.] 1857.

MAKAROFF (*Capt.*). Interchange of water between Black Sea and Mediterranean. M. I. C. E., vol. 87, p. 489.

MALET (H. P.). Indian irrigation, Geographic Magazine, vol. 5, p. 232, London.

MANBY (EDWARD J. T.). Villar reservoir on the river Lozoya. M. I. C. E., vol. 71, 1883,

MANCINI (FOSSA). On the yield of wells sunk in permeable sails. M. I. C. E., vol. 103, p. 436, 1891.

MANGON (HERVÉ). [Studies on the irrigation of the Campine and analogous works in Sologne and other points of France.] 1850.
[Experiments on the use of water in different climates, and on the proportion of earth transported by the water.] 1869, 198 pp.

MANUALS. Medley, J. G. Thomason Civil Engineering College, No. 10, Irrigation works. Roorkee, 1873.
Mullins, J., manual, 1890.

MARICOPA COUNTY, ARIZONA TERRITORY, Resources of. Report of Phœnix (Arizona) Chamber of Commerce, 1889, 9 pp.
What the Salt River Valley offers to the immigrant, capitalist, and invalid. A land for homes, for health, for investments. Phœnix, Ariz., 1887. 48 pp.

MARIENFIELD FRUIT-GROWING, GARDENING, AND IRRIGATION COMPANY. Charter and by-laws, Dallas, Tex., 1888.

MARKHAM (C. R.). Irrigation in Southern India. Geographic Magazine, vol. 1, p. 329, London; *also*, Eclectic Engineering Magazine, vol. 18, p. 158, New York.
On Spanish irrigation, London, 1867.

MARR (G. A.). Method of using Buff and Berger meters; method of determining meter coefficients. Report of Chief of Engineers, U. S. Army, 1881, p. 1710.

MARSH (G. P.). The earth as modified by human action. A new edition of man and nature. New York, 1877. 672 pp.
Irrigation; its evils, the remedies, and the compensations. U. S. Dept. Agr., 1874, 1875, pp. 362–381.

MARTINDALE (MOSES A.). Prospectus of the American irrigation system upon the great arid lands of the Rocky Mountains region of the United States, 1883, 20 pp.

MASONRY:
Baker, I. O. A treatise on masonry construction. 1890.
Beresford, J. S., Nanai Tal, India, 1882. Masonry outlets.
Krantz, J. B., reservoir walls, 1883.
McMaster, J. B., High masonry dams.
Mullins, Capt. Roorkee, India, 1869.
Vischer, H., On the strains in curved masonry dams.
Wegmann, Edward, jr., Design and construction of masonry dams. New York, 1889.

MAUNY (DE MORNAY). [Practice and legislation of irrigation in Upper Italy, and in certain States of Germany.] 1844.

MAZZOCCHI (L.). River Olona Conservancy. M. I. C. E., vol. 67, p. 447.

MEAD (ELWOOD). The ownership of water. The law on which title to water is based. The danger from monopolies. Address to farmers at Fort Collins, Colo. Times Printing Co., Denver, Colo., 1887, 8 pp.
Irrigation in northern Colorado. Engineering News, New York, May 3, 1884.
Report State Engineer of Colorado, 1885–'86, p. 18. Testimonial to efficiency of Colorado meter after extensive use.
Report of experiments in irrigation and meteorology, Colo. State Board of Agriculture, Bull. No. 1, 1887, pp. 3–12.
Advantages of irrigation. Resources of Wyoming, 1889. Cheyenne, 1889, pp. 9–14.
Second annual report of the Territorial Engineer to governor of Wyoming, 1889–'90. Cheyenne, 1890, 100 pp.
Law of water rights. Irrigation Age, vol. 1, Denver, 1891.

MEADOWS (Irrigated):
Boswell, Geo., Treatise on watering, 1792.
Keelhoff, J., Treatise on irrigation, 1856.
Scott, J.. Irrigation and water supply. A practical, treatise on water meadows, etc.
Sers, S. A., Irrigation in mountains, 1861.
Smith, John, Essay, 1792.
Smith, William, Improvement boggy land, 1806.
Tatham, William, Irrigation political economy, 1799. National irrigation, 1801.
Turner, Nicholas, Drainage essay, 1784.

MEASUREMENT: (of water).
Bowie, A. J., jr., Measurement and flow of water in ditches.
Carpenter, L. G., Measurement and division of water. Fort Collins, Colo., 1889.
See also current meters, discharge.

MEDLEY (JULIUS G.). India and Indian engineering: Three lectures delivered at Royal Engineer Institute, Chatham, 1872. E. & F. N. Spon., London and New York, 1873, 119 pp.
Manual of irrigation. Thomason Civil Engineering College, Roorkee, India, 1873.

MENDELL (GEO. H.):
San Joaquin, Tulare, and Sacramento Valleys. *See* Alexander, B. S. Report Board of Commissioners, Washington, 1874.
Practical irrigation. Johnson's cyclopedia, 1877, vol. 2, pp. 1313-1316.

MENZALEH, LAKE. Moncrieff, C. C. S., Drainage bordering Lake Menzaleh.

MERCED FRUIT DISTRICT, THE. Crocker, H. S., San Francisco, California.

MERRILL (W. E.). The difficulty of preventing the Ohio floods. In Science, vol. 3, pp. 385, 386, Cambridge, *1884*.

MERRIMAN (M.). A treatise on hydraulics. New York, 1889, 381 pp.

MERRY (THOMAS B.). Report on irrigation. U. S. Dept. State, U. S. Comm. to the Centennial International Exhibition at Melbourne, 1888. Washington, 1890, pp. 291-294.

MICHELIER. The Oredon Reservoir. M. I. C. E., vol. 91, p. 519.

MILL DAMS. Construction of. *See* Leffel, James.

MILLS (ANSON). Letter to Secretary of State on the general outline of a proposed scheme for an international dam and water storage in the Rio Grande River, near El Paso, Texas, for the control of the annual floods and the preservation of the national boundary to the Gulf, and for other purposes, 1888. U. S. Dept. State; *also* in report of special committee of U. S. Senate, 1890.

MILLWRIGHT AND MECHANIC. Construction of mill dams and Bookwalter's Millwright and Mechanic. *See* Leffel, J.

MINES AND WATER SUPPLY. Victoria, Dept. of Mines and Water Supply, first annual general report, etc., Melbourne, 1887.

MOCQUEREY (C.). Questions relating to the flow of streams in the upper part of the basin of Saône. M. I. C. E., vol. 61, p. 330.

MODES AND RESULTS OF IRRIGATION. U. S. Dept. Agri. Report, 1870, 1871, pp. 576-584.

MODULE. Various forms proposed for irrigation purposes.
Bricka, Distribution of water. M. I. C. E., vol. 70.
Foote, A. D., Water meter for irrigation. Am. Soc. C. E., 1887.
Smith, Baird, Italian irrigation.
Target, John Lewis Felix, Module experiments. M. I. C. E., 1881.

MOHR (E.). Weir and lock on Spree at Charlottenburg. M. I. C. E., vol. 88, p. 483.

MOHS (——). The deepest bore hole in the world. M. I. C. E., vol. 81, p. 403.

MOLESWORTH (GUILFORD). Village tanks, Ceylon. Professional papers, vol. 6, Roorkee, India, 1889.

MONCRIEFF (COLIN C. SCOTT). Irrigation in southern Europe, E. & F. N. Spon, London, 1868, 371 pp.

MONCRIEFF (COLIN C. SCOTT)—Continued.
Rapport sur le système d'irrigation dans la Basse-Égypte et sur le canal Ismaïlieh. Imprimerie nouvelle du Moniteur Égyptien, Jules et Cie, le Caire, 1883, 24 pp., 3 ills.
Report on irrigation in lower Egypt. pp. 3-7. Report of consular officers to Secretary of State for Foreign Affairs, No. 4 (1883), part 8, 1883.
Rapport sur le canal Ibrahimieh. Imprimerie Française F. Mourès et Cie, le Caire, 1884, 13 pp., 3 ills.
Irrigation report for 1884. Same.
Irrigation report for 1885. Public Works Ministry, National Printing Office, Cairo, 1886, 29 pp., 1 ill.
Report for year 1886. Public Works Ministry, National Printing Office, Cairo, 1887, 90 pp., 11 ills.
Note on the Corvee in Egypt. National Printing Office, Cairo, 1886, 13 pp.
Reid, A. G., Ross, J. C., and Brown, R. H. Irrigation report for 1887. National Printing Office, Cairo, 1888, 76 pp., 5 ills.
Note on the Nile flood of 1887. Public Works Ministry, National Printing Office, Cairo, 1888, 36 pp., 6 ills.
Same for 1888, 60 pp., 1 map, etc.
Notes on Wady Rayan. Public Works Ministry, National Printing Office, Cairo, 1888, 5 pp., 3 tables, 1 map.
Note on the Wady Rayan project. National Printing Office, Cairo, 1889, 10 pp.
Note on the prevention of Sharaki land in Egypt. National Printing Office, Cairo, 1889, 27 pp., 1 ill.

MONTANA:
Newell, F. H., Census bulletin, 1891.
Wilson, H. M., Irrigation problem, 1889.

MONTANARI (T.). Discharge and regulation of the Tiber. M. I. C. E., vol. 73, p. 410.

MONTPELLIER (ALBERT). Rainfall, California, 1876 to June, 1884. San Francisco, 1884.

MOORE (B. T.). Current meter. M. I. C. E., vol. 45, p. 220.

MORRIS (D.). Lecture on the occurrence of droughts, their causes and the means whereby their effects might be mitigated, modified, or relieved. Symon's Met. Mag., London, 1886.

MORRIS (WM.). Covered service reservoirs. M. I. C. E., vol. 73, p. 1.

MOVABLE DAMS:
Buckley, Robert B., Indian weirs. M. I. C. E., vol. 54, p. 300. London, 1880.

MOWRY, SYLVESTER). The geography and resources of Arizona and Sonora. 1859, new ed. 1863, Am. Geog. and Statistical Soc.

MUETTRICH (ANTON). Historical review of the arrangements in connection with forest meteorological stations in Prussia. Nature, London, vol. 31, 1884-85, pp. 331-332.

MÜLLER (*Prof.* **A.**). Effluent from Berlin Sewage Irrigation Works and its effect upon water into which it is conveyed. M. I. C. E., vol. 91, p. 525.

MULLER (ADAM). *See* Villeroy, Felix.

MULLINS (*Capt.*). Lucknow and Mason Reservoirs. Professional Papers, vol. 6, Roorkee, India, 1869.

MULLINS (*Lieut. Gen.* **J.**). Irrigation manual. Madras Public Works Department. E. & F. N. Spon, New York and London, 1890, 223 pp.

MUTHA CANALS. Hart, J. E. H., Bombay, India, 1879.

MYLNE (R. W.). Irrigation in the south of France. M. I. C. E., vol. 14, p. 214.

NADAULT DE BUFFON (BENJAMIN). [Irrigation canals of Northern Italy in the relation with those of the south of France, etc.] 1843–'44, 3 vols., atlas. [Course of agriculture and of agricultural hydraulics, etc.] Paris, 1853–'58, 4 vols.

[Agricultural hydraulics, etc.], 2d ed. Paris 1861–'62.

Same, 1867.

NADRAI AQUEDUCT. Gordon, W. B., Allahabad, India, 1883.

NAGPUR WATER WORKS. Binnie, A. R., M. I C. E., London, 1875.

NAPLES WATER WORKS. M. I. C. E., vol. 84, p. 468.

NATIONAL GEOGRAPHIC SOCIETY. Hall, Wm. Ham, Irrigation in California. Washington, 1889.

Wilson, H. M., Irrigation Problem in Montana. Washington, 1889.

NAVY, DEPARTMENT OF. *See* United States, Navy Department.

NAZZANI (J.). Measurements of the velocity of the Tiber. M. I. C. E., vol. 83, p. 406.

NEBRASKA:

Aughey, Samuel, Physical geography and geology of Nebraska, 1880.

Smythe, William E., Irrigation in. Omaha, Neb., 1891.

NELSON. Inquiry into possibility of use of wind power for irrigation in India. M. I. C. E., vol. 59, pp. 409–410.

NETTLETON (EDWIN S.). Proper location of artesian wells. Progress report of artesian and underflow investigation between 97th degree west longitude and foothills of the Rocky Mountains. Part 2. Government Printing Office, Washington, 1891, 14 pp., 9 maps,

Report State engineer of Colorado, 112 pp., 29 tables, Collier & Cleveland Lith. Co., Denver, Colo., 1885.

Third biennial report of the State engineer of Colorado, 1885–'86. Collier & Cleveland Lith. Co., Denver, 1887, 252 pp. and numerous tables, 1 map.

NEVADA:

Jones, J. E., Report, 1887–'88.

McClellan, E. C., Elko County, reservoir sites, 1890.

Newell, F. H., Census bulletin, 1891.

Newlands, Francis G., address, 1890.

Surveyor-general, Reports of, for 1865 to 1889, Carson City.

Widney, J. P., Colorado Desert, 1873.

NEWLANDS (FRANCIS G.). An address to the people of Nevada on water storage and irrigation, Reno, Nev., 19 pp. and numerous maps.

NEW MEXICO (Irrigation in):

Arny, W. F. M., resources, 1873.

Baird, T. M., irrigation, 1851.

Bowman, John B., development of arid regions, 1888.

Brevoort, Elias, resources, 1874.

Frost, Max, Santa Fé, and Chicago, 1890.

Gage, Knight and Walthall, Alfalfa, 1889.

Grierson, B. H., irrigation, 1888–'89.

Hunt (*Gov.*), of Colorado, irrigation, 1870.

Mills, Anson, letter, 1888.

Newell, F. H., Census bulletin, 1891.

Ritch, W. G., Illustrated, 1883.

Ross, Edmund G., report, 1885–'88.

U. S. Congress, arid lands of New Mexico, Washington, 1889, 50th Congress, 2d session.

NEWELL (F. H.). Irrigation in Arizona, Eleventh Census, Bulletin No. 35.

Irrigation in Idaho, Eleventh Census, Bulletin No. —.

Irrigation in Montana, Eleventh Census, Bulletin No. 153.

Irrigation in Nevada, Eleventh Census, Bulletin No. —.

Irrigation in New Mexico, Eleventh Census, Bulletin No. 65.

Irrigation in Utah, Eleventh Census, Bulletin No. 85.

Irrigation in Wyoming, Eleventh Census, Bulletin No. 107.

Irrigation work of the United States Geological Survey, Irrigation Age, vol. 1, p. 10.

Stream measurements of the United States Geological Survey. Trans. Am. Institute of Mining Engineers, 1891.

Utah Lake Reservoir, Utah. Irrigation Age, vol. 1., pp. 42, 69, 153, 1891.

Bear River, Utah. Irrigation Age, vol. 2, p. 289, 1891.

NEY (NAPOLEON). The Trans-Sahara Railway. Scribner, November, 1891.

NICOLLS (J. R. C.). Agricultural engineering in India. Reprinted from "Engineering," London, 92 pp.

NILE:

Ross, James C. Report on the low Nile of 1888, etc.

Moncrieff, C. C. Scott. Note of the Nile flood of 1887.

NILOMETERS. (Instruments for measuring heights of water, including rods, self-registering devices, etc.)

NILOMETERS—Continued.
Alteneck, H. von, Electrical apparatus. M. I. C. E., vol. 69, p. 509.
Apparatus for registering floods. M. I. C. E.
Bellasis, E. S., Ganges. M. I. C. E.
Fluviograph. M. I. C. E. Vol. 57.
Self-registering tide gauge. M. I. C. E.
Sibert, M., registering variations of river levels. M. I. C. E.
Voisin, Hydrometic service. M. I. C. E.

NIMMO, (JOSEPH, JR). Uncle Sam's farm. Frank Leslie's Illustrated Newspaper, three articles. New York, Nov. 16, 23, 30, 1890.
The conditions which appear to determine the limited amount of precipitation of moisture throughout the so-called dry area of the United States, etc. U. S. Bureau Statistics, Washington, 1885, pp. 101-106.
The arid region as a market for eastern products of agriculture. Washington, 1891. 7 pp., 1 map.

NIPHER (F. E.). On the relation between the violence and duration of maximum rains. Am. Met. Jour., Detroit, 1884-'85, pp. 241-242.

NIRA CANAL. Whiting, J. E., Public Works Department, Bombay, India, 1877-'81.

NORDHOFF (CHAS.). California, its products and productiveness; information for farmers. Harper's Mag., 1872, vol. 45, pp. 255-267.

NORTHWEST PROVINCES. *See* India.
Revenue Reports, Irrigation Branch, Allahabad, India.

NORTON (C. E.). Irrigation in India. North American Review, vol. 77, p. 439, New York; *also* Blackwood's Magazine, vol. 73., p. 207.

NURAR BEY (BOGHOS). Irrigation in Egypt. M. I. C. E., vol. 89, p. 515.

NURARIEH CANAL. Moncrieff, C. C. S., Irrigation report for 1887; same, 1888.

OCKERSON (J. A.). On the earlier floods of the lower Mississippi. Jour. Asso. Eng. Soc., Jan., 1885; *also* Science, p. 391, Cambridge, 1885.

O'CONNELL (P. P. G.). Flood discharges of rivers. Professional papers, vol. 7, Roorkee, 1870.

O'MEARA (PATRICK). Irrigation in northeast Colorado, 96 pp., 12 pl., 5 tables, 8 ills; M. I. C. E., vol. 73, sess. 1882-'83, part 3, London, 1883.

ONCIA. The unit of measurement commonly adopted in Italy is the "oncia," equal to 4·224 gallons per day, and water either sold in perpetuity or leased for years. M. I. C. E., vol. 99, p. 273.

O'NEILL (BUCKLEY). Arizona's ancient irrigators. Irrigation Age, vol. 1, Denver, 1891.

OREGON AND WASHINGTON:
Greene, Frank. Report on wheat lands, 1888.
Squire, Watson C., Report, 1884.

ORISSA CANALS. Papers relating to. The Bengal Secretariat Press, Calcutta, 1884.

ORME (H. S.). Irrigation; its Influence on health. Appendix to Report of State Board of Health of California. In Victoria Royal Comm. on Water Supply, 1885.

ORR (CHAS. J.). Annicut across Kistna River, Bell, J. H.

OSBORNE (*Judge*). Irrigation in Colorado. U. S. Agr. Dept. Rept., 1870-'71, pp. 579-581.

OSCILLATION. Annual limits of oscillation of the water levels in rivers and lakes of European Russia. M. I. C. E., vol. 77, p. 418.

PABOR (WM. E.). Colorado as an agricultural State, its farms, fields, and garden lands. New York, 1883, 213 pp., 3 pl.

PALADINI (E.). On the Cigliano elevator, and on irrigation in Piedmont. M. I. C. E., vol. 64, pp. 361-363, 1881.

PALMER (E. C.) Irrigation experiments. Professional papers, 2d series, No. 35, Roorkee, India.

PARETO (RAPHAEL). [Irrigation and purification of lands. Treatise on the use of water in agriculture.] Paris, 1851, 3 vols, atlas.

PARKIN (J. H.) River gauging at Vyrnwy Reservoir. M. I. C. E., vol. 92, p. 353.

PASSY (L. G. de). Étude sur le service hydraulic et sur les mesures administratives concernant les cours d'eau non navigables ni flottables. Paris, 1868; same, Paris, 1876, 533 pp.

PASTURE LANDS, Relation of Irrigation to:
Gannott, H., Colorado, 1876.
M'Kinney, H. G., Irrigation. M. I. C. E., 1890.
Nineteenth Century, 1890.
Proportion of irrigated lands to pasture. *See* Nineteenth Century, Sept., 1890, p. 426.

PEARSON (A. N.). A heavy Indian rainfall. Symon's Met. Mag., vol. 19, London, 1884.

PECOS VALLEY:
The Pecos Irrigation and Improvement Co., Eddy, New Mexico. Poole Bros., Chicago.
Wilson, H. M., New York, 1891.

PENNY MAGAZINE. Irrigation in the east. London, vol. 10, p. 180.

PERCOLATION:
Evans, J. Rainfall and evaporation: On the percolation of the rainfall on absorbent soils.
Greaves, C. Rainfall and evaporation: On evaporation and percolation.

PERIODICITY. In droughts. Am. Met. Jour., Ann Arbor, vol. 3, 1886-'87, 294.

PERRIN (L. K.). Two methods of irrigation in the vicinity of Denver, Colo., U. S. Dept. Agri., report for 1869. 1871, pp. 578-579.

PERRIS IRRIGATION DISTRICT. Hall, Wm. Ham., San Francisco, Cal., 1891.

PERRODIL (M. de). Instrument for gauging flow of streams. M. I. C. E., vol. 60, p. 430.
Relating to new type of gyrometer hitherto called hydrodynamometer; measures forces of gyration or eddies. M. I. C. E., vol. 86, p. 445.

PERU. *See* South America.

PESTALOZZA (A.) and ROSSI (L.). River embankments. M. I. C. E., vol. 75 p. 335.

PHILLPOTS (W.). Irrigation in Ceylon. Eclectic Eng. Mag., vol. 11, p. 303. New York.

PIEDMONT. The Cigliano Elevator and irrigation in Piedmont. M. I. C. E., vol. 64, p. 361.

PILBROW (J.). Some particulars of an artesian well bored through Oolitic rocks at Bourne Lincolnshire in 1856. M. I. C. E., vol. 75, p. 245.

PINAL COUNTY, ARIZONA. Resources of the county prepared for the Special Senate Committee on Arid Lands. By authority of the Board of Supervisors, Florence, Ariz., 1889, 23 pp.

PIONEER CANAL. Resources of California, San Francisco, Cal., 1888.

PIPES, Woodon, Henny, D. C., Denver, 1891.

PISTOYE (ALPHONSE de). Irrigation according to the law of Sept. 16, 1807, 1844.

PLAYER-FROWD (J. G.). Six months in California, 1872, 164 pp.

PLAYFAIR (J. W.). Irrigation in Deccan. Professional papers, No. 217, Roorkee, India.

PODHAGSKY (E. von). Irrigation of the Marchfeld. M. I. C. E., vol. 50, p. 233.

POSES WEIR. M. I. C. E., vol. 75, p. 338.

POSTON (CHARLES D.). Irrigation. U. S. Agri. report, 1867, 1868, pp. 193-200.
Irrigation, Chicago, 1887, 30 pp., inc. 6 pl.

POWELL (J. W.). Report on the lands of the arid region of the United States, with a more detailed account of the lands of Utah, with maps, first edition 1878, second edition 1879, 195 pp.
The effect upon certain rivers in Colorado of diversion of water for irrigation. Senate executive document 120, 50th Cong., 2d session, 1889.
The irrigable lands of the arid region, in Century illustrated monthly magazine, vol. 39, p. 766, New York, 1890.
The nonirrigable lands of the arid region, in Century, vol. 39, p. 915, New York, 1890.
Institutions for the arid-lands, in Century, vol. 40, p. 111.
Statement of J. W. Powell, Director of the U. S. Geological Survey. In report of the special committee of the United States Senate on the irrigation and reclamation of arid land, vol. 4, pp. 5-95, Washington, 1890.
Report on irrigation. Tenth annual report U. S. Geological Survey, part 2, Government Printing Office, Washington, 1890.
Report on irrigation engineering and hydrography. Eleventh annual of U. S. Geological Survey, part 2, Government Printing Office, Washington, 1891.

PRINCE (C. L.). Heat and drought of the past summer (1884). Am. Met. Jour., Detroit, 1884-'85, pp. 292, 293.

PROFESSIONAL PAPERS. Reports, correspondence, and original papers on various professional subjects connected with the duties of the corps of engineers. Madras presidency. Arranged and printed for private circulation. Madras, India, 1851-'56, 4 vols.

PUBLIC LANDS (as related to irrigation, homestead, timber culture, desert claims, etc.):
Donaldson, Thomas, Public domain, 1880.
Report, Governor of Dakota to Secretary of Interior, 1888.

PUBLIC WORKS DEPARTMENT: India.
Annual irrigation revenue report, Sind, India, 1888-'89.
Northwest Provinces, Revised estimates of Agra Canal, Sind, India, 1877.
Northwest Provinces, Annual irrigation revenue report, Roorkee, India, 1889.
Lower Ganges Canal project, Allahabad, India, 4 vols., 1874-'76.
Annual irrigation revenue report, Bombay, 1889.
Correspondence relating to Nira Canal, Bombay, India, 1877-'81.
Betwa Canal in Bundelhand, Allahabad, India, 1874.

PUMPING, Cost of, in Behera. Irrigation report of 1888. Moncrieff, C. C. S.

PUNJAB, Public Works Department. Irrigation branch, annual reports, Lahore, India.
Punjab Sidhnai Canal atlas. Plans, 1889, 2 pl. 7 fold. pl.

PURVIS (MARC ANTOINE). [On the advantages of irrigation, on the extent to which it can be used in France, and on the legal measures necessary to facilitate it.] 1844.

RAILLARD (CHARLES LOUIS EMMANUAL). [Irrigation in France, from the latest official statistics.] 1865.

RAILROAD AND ENGINEERING JOURNAL, New York. Anderson, G. G., large irrigation canals, pp. 307-309.
Betaloo Dam, South Australia, 1890.
Irrigation pp. 244-245.

RAIN-MAKING. General Dyrenforth and his rainmakers. Daily Sun, New York, Sept. 6, 1891.

RAINFALL (Report on) in Washington, Oregon, California, Idaho, Nevada, Utah, Arizona, Colorado, Wyoming, New Mexico, Indian Territory, and Texas, for from two to forty years. Prepared by Chief Signal Officer in accordance with instructions from U. S. Senate, Jan. 4, 1888. Washington, 1889, 100 pp., 15 pls.

RAINFALL. (As related to river flow.)
Beardmore, Manual of Hydrology.
Belgrand, M., Basin of Seine, 1873.
Binnie, A. R., Observations. M. I. C. E.
Blanford, H. F., Variation at Calcutta. M. I. C. E.
Brackett, D., On water sheds. M. I. C. E.
Brown, Reboisement in France.

RAINFALL—Continued.
Buckley, Irrigation works in India.
Davis, W. M., Mountain meteorology, 1886.
Evans, J., Percolation. M. I. C. E., vol. 45.
Fanning, Water supply, 1887.
Fitzgerald, Desmond, Maximum rates. Trans. Am. Soc. C. E., 1889.
Frank, A., Rain gauge. M. I. C. E.
Greaves, C., Rainfall and evaporation, 1876.
Henry, Stuart O., On the plains, 1890.
Hilgard, Jones and Furnas, Arid regions of Pacific slope, 1882.
Powell, J. W., Report of arid lands, 1879.
Smith, Baird, Italian irrigation, 1855.
Snow, F. H., Is the rainfall increasing on the Plains? 1868-'87.
Symons, Geo. J., Floods. M. I. C. E., 1875.
U. S. War Department. Reports of Chief Signal Officer.

RAJBUHA ESTIMATES. Western, J. H., Punjab, India.

RATIO OF IRRIGABLE LAND TO PASTURAGE, (*see also* Pasturage). Smith, Irrigation in Italy, 1855.
Gannett, H., Colorado, 1876.

RAWLINSON (R.). Irrigation of lowlands by the drainage of uplands. M. I. C. E., vol. 21, p. 99.

RAYMOND (WM. G.). A graphic method for estimating earthwork. Trans. Tech. Soc. Pacific Coast, No. 3, vol. 6, p. 67. Geo. Spaulding & Co., San Francisco, 1890.

REAGAN (JOHN H.). Irrigation of arid lands. Speech of Hon. J. H. Reagan, of Texas, in the U. S. Senate, July 17 and 18, 1890. 12 pp.

RECORDS, GOVERNMENT OF INDIA:
Buckingham Canal. Madras, No. 217, Calcutta, India.
Orissa Coast Canal, No. 204, Calcutta, India.
Palar Annicut System, No. 219, Calcutta, India.
Periyar project. Madras, No. 215, Calcutta, India.
Zhara Karez Irrigation Scheme, Belouchistan, No. 231. Calcutta, India, 1887.
Sidhnai Canal Project in the Punjab, No. 248. Calcutta, India, 1888.
Failure of the Kali Nadi Aqueduct, Lower Ganges Canal, No. 240. Calcutta. 1888.
Betwa Canal Project in Northwest Provinces, No. 232. Calcutta, India.

REIBER (JOSEPH). [On artificial prairies and irrigation, etc.], Strasbourg, 1849.

REID (A. G.). Barrage Report, 1888. *See* Moncrieff, C. C. S.
Report on Barrage Repairs, Irrigation report, 1887. *See* Moncrieff, C. C. S.

REED (C. F.), GRUNSKY (C. E.), *and* **CRAWFORD (J. J.).** Commissioners' report of the Examining Commission of Rivers and Harbors. State Office. J. D. Young, Supt. State Printing, Sacramento, 1890. 148 pp., 29 tables, 2 ills.

RENNIE (G.). Irrigation in the south of France M. I. C. E., vol. 14, p. 190.
Nottinghampshire irrigation. M. I. C. E., vol. 19, p. 99.

REMISE. Floods of the Saône and its chief tributaries in 1882. M. I. C. E., vol. 77, p. 419.

REPUBLICAN RIVER. Aughey, Samuel, Physical geography and geology of Nebraska, pp. 59 and 61.

RESERVOIRS (for Irrigation and water supply).
Beloe, C. H., Catch-water reservoirs for mountain districts, 1872.
Calinels, cleaning reservoirs in Algeria, 1870.
Campbell, Allen, Cost of reservoirs. Am. Soc. C. E., 1887.
Dawson, Wm. B., Paroy reservoir. M. I. C. E.
Delafield, C., Vicksburg Settling Basin. Am. Soc. C. E., 1889.
Denton, J. Bailey. M. I. C. E., 1874.
Fanning, J. F., Embankments and chambers.
Gamble, J. G., Storage reservoir. M. I. C. E.
Gould, E. S., Designing and construction, 1888.
Great Divide, The, storage reservoir, 1890.
Jacobs, A., Designing and construction, 1888.
Kraft, Max, Construction. M. I. C. E.
Krantz, J. B., Construction, 1883.
Manby, E. J. T., Reservoir on river Lozoya. M. I. C. E., 1882-'83.
Michelier, Oredon reservoir. M. I. C. E.
Morris, William, Covered service reservoirs. M. I. C. E.
Nettleton, E. S., Report State engineer of Colorado, 1885-'86; same, 1883-'84.
Powell, J. W., Report arid lands, 1879.
Report governor of Idaho to Secretary of Interior, 1888.
Report governor of New Mexico to Secretary of Interior, 1888.
Reservoir storage; M. I. C. E.
Scott, John, Catch water, 1883.
Sedgwick, Thos. S. Denver, 1891.
Torricelli, G., Discharge of water. M. I. C. E., 1885.
Van Nostrand's Magazine, 1886.
Willcocks, W., Egyptian irrigation.
Wilson, H. M., Irrigation in India. American irrigation engineering, 1891.
White and Aughey, Artesian wells on Great Plains, 1882.
Wood, C. J., Tunnel outlets. M. I. C. E.

RESOURCES OF CALIFORNIA, the, issued monthly. San Francisco, Cal., Oct., 1888.

REVENUE REPORTS (INDIA):
Revenue report of the irrigation department. Bengal, 1875-'90.
Revenue report of the irrigation department. Punjab, 1877-'78.
Revenue report, public works department. Sind, India, 1888-'89.
Revenue report, public works department. Roorkee, India, 1889.
Revenue report, public works department. Bombay, India, 1889.

REVUE SCIENTIFIQUE. Chambrelent, M., Les irrigations agricoles faites en France, pp. 467-469.

RÉVY (J. J.). Hydraulics of great rivers, observations and surveys on the largest rivers of the world. 4° plates and charts.

RHIND (R. H.). Coefficients of discharge applicable to certain submerged weirs of large dimensions. M. I. C. E., vol. 85, p. 307.

RIBERIO (C.). Exploring for water in neighborhood of Lisbon. M. I. C. E., vol. 63, p. 370.

RICHARDS & CO., Summering in Colorado. Denver, Colo., 1874, 158 pp; Irrigation, pp. 146, 147.

RICHOU (G.). Drainage of Lake Copais. M. I. C. E., vol. 88, p. 506.

RINGEL (A.). Measurements of flow of Elbe in Saxony, 1886–'87. M. I. C. E., vol. 95, p. 444.

RIPPI (W.). Capacity of storage reservoirs for water supply. M. I. C. E., vol. 71, p. 270.

RITCH (W. G.). Illustrated New Mexico, 4th ed. Published by Bureau of Immigration, Santa Fé, 1883, 140 pp.

RITSO (G. F.). Water supply and irrigation of the Canterbury Plains, New Zealand. M. I. C. E., 1883, vol. 74, pp. 238–245.

RITTER (C.). Method of representing hydrometric observations. M. I. C. E., vol. 61, p. 329.
Rapid approximate gauging of floods. M. I. C. E., vol. 89, p. 507.
Improvement in arrangement and rating of current meters, and in the methods of calculating discharges. M. I. C. E., vol. 82, p. 413.

RIVER CONTROL. (Including regulation of floods, levees, and jetties.)
Bayley, G. W. R., Levees. M. I. C. E., vol. 85, p. 300.
Brown, C. G., Tidal and stream observations. M. I. C. E.
Corthell, E. L., Jetties of the Mississippi. Trans. Am. Soc. C. E., and M. I. C. E., 1884.
Delprat, J. P., Water levels, Holland. M. I. C. E.
Du Boys, P., Rhone and rivers with beds liable to scour. M. I. C. E., vol. 59.
Fargue, River channels. M. I. C. E.
Fowler, John, River Tees, improvements. M. I. C. E.
Frisi, Paul, Treatise, rivers and torrents, 1861.
Geppert, A., Training rivers. M. I. C. E.
Graffenreid, de C., Jura regulation. M. I. C. E.
Herrish, C., Regulation river Theiss. M. I. C. E.
Intze, O. L., German water ways. M. I. C. E., 1882.
Jacob, A., Conservancy of rivers. M. I. C. E.
Janicel, M., Regulation and canalization. M. I. C. E., vol. 64.
Kuhl, Charles H. L., Mouth of Danube. M. I. C. E.

RIVER CONTROL—Continued.
Mazzocchi, L., River Olona. M. I. C. E., 1881.
Methods of improving rivers. M. I. C. E., 1881.
Montanari, T., Tiber. M. I. C. E., vol. 73.
Pestalozza, A., Embankments. M. I. C. E., vol. 75.
Roberts, William M., San Francisco River, Brazil. M. I. C. E., vol. 61.
Santine, B., Canalization. M. I. C. E., 1889.
Shelford, William, Tiber. M. I. C. E.
Tufnell, C. F., River training, India. M. I. C. E., vol. 72.
Vyse, G. W. River training. M.I.C.E., vol. 50.
Wheeler, William Henry, Conservancy of Rivers. M. I. C. E., vol. 67.

RIVER DISCHARGE. *See* Discharge.

RIVER RHONE, DISCHARGE OF. M. I. C. E., vol. 82, p. 307.

RIVER SEINE, THE. M. I. C. E., vol. 84, p. 212. Belgrand, M., 1873.

RIVERSIDE MODE OF IRRIGATION. Irrigation Age, vol. 1, Denver, 1891.

ROBERTS (T. P.). Is the destruction of forests a cause for increase in frequency and height of floods? M. I. C. E., vol. 79, p. 407.

ROBERTS (WM. H.). Note on the São Francisco River, Brazil. M. I. C. E., vol. 61, p. 256.

ROCK (JAMES L.) and **SMITH (W. I.).** , Southern and Western Texas Guide for 1878. St. Louis. 282 pp.

ROELANTS (T. J.). Changes in the mean surface levels of the rivers Rhine and Meuse. M. I. C. E., vol. 75, p. 336.

ROESLER (F. E.). Intensive farming on the Texas Staked Plain and how to make it pay. Odessa, Texas, 1888.

ROGERS (E. L.). The Berthoud Pass Canal, 2 pp. Trans. Denver Soc. C. E., Vol. 11, July to December, 1890, Denver, 1891.

ROGERS (PLATT). Administrative control of water. In The Commonwealth, Denver, 1889, vol. 2.

ROLLAND (G.). Hydrographie et orographie du Sahara Algérien. Bull. de la Société de Géographie de Trieste, de 1866.
L'Oued R'ir et la colonisation française au Sahara. Revue Scientifique, vol. 39, p. 769, Paris, 1887, continued in vol. 40.

RONNA (A.). Les eaux d'irrigation et les machines. Paris, 1888, 730 pp.

ROSS (A.). Reports and letters upon the rivers Cauvery and Coleroon. *See* Cotton, A. T.

ROSS (EDMUND G.). Report of the Governor of New Mexico to the Secretary of the Interior, 1885 (1888). U. S. Dept. Interior.

ROSS (JUSTIN C.). Report on the low Nile of 1888, and on the measures to be taken to prevent Sharaki in Upper Egypt, National Printing Office, Cairo, 1889. 96 pp., 13 tables.
Improvement in the Fayoum, Kom Ombo plateau. Irrigation report, 1887, Moncrieff, C. C. S.
Willcocks, W., London and New York, 1889.

ROSSI (L.). *See* Pestalozza, A.

ROUSSEAU PASHA. Report of the Ministry of Public Works on irrigation of Egypt, and an examination of a proposal relating to it. M. I. C. E., 1884, vol. 77, pp. 425–428.

ROYAL COMMISSION ON WATER SUPPLY. Deakin, A., Melbourne, 1885.

ROYAL ENGINEERS' INSTITUTE. Occasional Papers. London, 1884.

RUFFNER (E. H.). Reports upon Reservoirs on Lower Mississippi. Practice of improvement *of nontidal rivers of the United States.*

RUNDALL (F. H.) Irrigation works in India. Lectures delivered at Chatham in 1876.

RUN-OFF. Relation between drainage area and discharge, coefficient of discharge, maximum discharge, etc. *See also* Floods.

Beardmore, Manual of Hydrology, 1862.

Binnie, A. R., Rainfall observations. M.I.C.E.

Brackett, D., Rainfall on watersheds. M. I. C. E., vol. 88.

Coghlan, T. A., Discharge of streams. M. I. C. E., vol. 75.

Craig, James, Maximum discharge. M. I. C. E.

Crocs, J. J. R., Flow Croton River. M. I. C. E.

Drainage St. Jurgenfeld. M. I. C. E., 1886.

Fteley, Alphonse, Flow Sudbury River. 1875–1879.

Gerstel, Gustave, Drainage of olay mountains. M. I. C. E.

Johnson, J. B., River physics. Van Nostrand, 1885.

Kuichling, E., Relation rainfall and discharge. Am. Soc. C. E., vol. 20.

Lamairesse, M., Damming the Chiliff. M. I. C. E., vol. 39.

Mean coefficient of discharge. M. I. C. E., vol. 80.

Powell, Report arid lands, 1879.

Richou, G., Drainage Lake Copais. M. I. C. E.

Russel, T. Floods, in report of Chief Signal Officer, U. S. War Dept., 1889.

Suter, C. R., Report Missouri River, 1881.

Thelwall, Walter Hampden, Failure Kali Nadi Aqueduct, Ganges Canal. M. I. C. E.

Tripp, Wm. B., River Buffalo watershed. M. I. C. E., vol. 73.

Von Winter, H., Drainage system of Dantzic. M. I. C. E., vol. 39.

RUSSELL (H. C.). Notes on the floods in Lake George. New South Wales, 20 pp.

Notes on the history of floods in the river Darling, 1887, 56 pp.

RUSSELL (T.). Rainfall and river outflow in the Mississippi Valley, in report of Chief Signal Officer, U. S. War Department, 1889, pp. 159–172.

RUSSIA. Great irrigation works in. Scientific American, 1889, May 4. p. 273.

SACCHERI (G.). Experimental hydraulic station at Santhia. M. I. C. E., vol. 88, p. 498.

SADLER (RALPH). On the flow of water in earthen channels. M. I. C. E., vol. 103, p. 273, 1891.

SAHARA. *See* Algeria.

SAINJOU (M.). The improvements of the Sologne. M. I. C. E., vol. 40, pp. 306–307.

SAINT PULGENT (L.). The Forez Irrigation Canal, Montbrison. 1872, 64 pp.

SAN BERNARDINO. Irrigation systems of. Finkle, F. C., Engineering News, New York, 1891.

SAN DIEGO COUNTY (California). Gould, Hutton & Co., San Diego, Cal., 1890, 69 pp.

SAN DIEGO FLUME. McConoughy, O. H., San Diego, Cal., 1888.

SAN FRANCISCO CALL CO. California as it is. By seventy leading editors, etc., 1882 (contains artesian wells, p. 6, irrigation, pp. 9, 28, 113, 116, 121, 149; canals and irrigating ditches, pp. 5, 11, 18, 65).

SAN FRANCISCO CHRONICLE. California's Irrigation Systems, 1891, 30 pp.

SANITARY PROGRESS. Gatton, Capt. Douglass, London, 1876.

See also Hygiene.

SANKEY (*Maj.* R. H.). Irrigation in Mysore, professional papers, No. 141 and 150, Roorkee, India.

SAN LUIS PARK:

Agriculture by irrigation in the great garden of southwestern Colorado. Colorado Land and Loan Company, Denver, 1886, 23 pp.

Irrigation in, U. S. Dept. Agr. Report 1869. Washington, 1870, p. 603.

SAN LUIS REY FLUME COMPANY. Irrigation in southern California. Boston, 1887, 45 pp.

SAN QUENTIN DAM AND CANAL. Aull, Charles, Sacramento, 1890.

SANTINI (B.). Hydraulic and physical effects of the canalization of rivers. M. I. C. E., vol. 99, p. 428.

SCARAPRI (G.). Reservoir basins and sea sluices for draining low-lying lands. M. I. C. E., vol. 82, p. 424.

SCHERMERHORN (L. V.). Physical characteristics of northern and northwestern lakes of North America. M. I. C. E., vol. 90, p. 494.

SCHLICH (WM.). A Manual of forestry, 1889.

SCHMIDT (M. W.). Observations on the level of the Elbe in Saxony. M. I. C. E., vol. 56, p. 358.

SCHOTT (C. A.). Tables and results of precipitation in rain and snow in the United States and at some stations in adjacent parts of North America and in Central and South America. Schott's rainfall tables. Smithsonian contribution No. 353. Washington, 1881, 249 pp.

SCHUYLER (JAMES D.). The construction of the Sweetwater dam. Trans. Am. Soc. C. E., vol. 19, No. 398, New York, 1888, 18 pp., 9 pl.

Culture of sugar cane and report on water supply for irrigation on the Honouliuli and Kahuka ranches, island of Oahu, Hawaiian Islands, Oakland, Cal., 1889, 32 pp.

SCHUYLER (JAMES D.)—Continued.
Part 4, Annual Report State Engineer of California, Sacramento, 1880.

SCIENTIFIC AMERICAN. May 4, 1889. Great Irrigation Works of Russia, p. 273. **(Supplement.)**
Canals of Colorado. New York, 1886.
Dow, J. L. Irrigation in California. Vol. 17, p.6667.

SCIOLETTE (GIOVANNI B.). Note on the calculation of sustaining walls for high bodies of water. Rome, 1878.

SCOTT (JOHN). Irrigation and water supply, etc. Crosby, Lockwood & Co., London, 1883, 34 ills., 149 pp.

SCOTT MONCRIEFF. *See* Moncrieff, C. C. Scott.

SCOTTISH GEOGRAPHICAL MAGAZINE. Edinburgh, 1888. Irrigation in Samarkand and Bokhara, pp. 642–654.

SCOUGALL (H.). Modern ideas on irrigation. Aspinall & Bell, Salt Lake City, 1891, 20 pp.
The construction of canals for irrigation purposes and the reclamation of alkaline and saline lands, 14 pp. The Polytechnic Soc. of Utah, March, 1891.
The construction of dams, Irrigation Age. Denver, October 1, 1891.

SEBERT (M.). Registering the variation in level of a river. M. I. C. E., vol. 64, p. 367.

SECRETARY OF WAR. *See* United States War Department.

SEDDON (JAMES A.). Clearing water by settlement; observations and theory. Jour. Asso. Eng. Soc., St. Louis, October, 1888, p. 477.

SEDGWICK (THOMAS S.). Reservoir embankments, Irrigation Age. Denver, September 1, 1891.

SEDIMENT. *See* Silt.

SEEPAGE AND PERCOLATION:
Capit, M., Underground water courses, etc. M. I. C. E., vol. 81.
Evans, J., Percolation of rainfall. M. I. C. E., vol. 45.
Fanning's "Water-supply engineering," 1877.
Greaves, C., Evaporation and percolation. M. I. C. E., vol. 45.
Marsh, G. P., Rendering adjacent fields swampy.
Nettleton, E. S., Colo. State Eng. Report, 1885–'86.

SEINE:
Belgrand, M., 1873.
Hydrology of Seine Basin. M. I. C. E., vol. 84, p. 211.

SERS (L. A.). [On irrigation in mountainous countries.] France, 1861.

SEWAGE IRRIGATION:
Bazalgette, C. Norman. M. I. C. E., vol. 48.
Birch, R. S., Irrigation. 1879.
Burn, R. Scott, Utilization. Lockwood & Co.
Claye, A. Durand, Utilization of sewage water. M. I. C. E., vol. 39.
King, G., Irrigation. M. I. C. E., 1865.

SEWAGE IRRIGATION—Continued.
Müller, A., Effect upon water. M. I. C. E.
Scott, J. London, 1883.
Works of Berlin. M. I. C. E., 1885.

SHANNON (S. D.). Resources of Wyoming, 1889, 77 pp, 5 pl., 1 map.

SHARAKI. *See* Alkaline Lands; *also* Moncrieff, C. C. Scott.

SHELFORD, (WM.). Rivers flowing into tideless seas illustrated by the River Tiber. M. I. C. E., vol. 82, p. 2.
Graphic mode of ascertaining the flow of a mill stream. M. I. C. E., vol. 58, p. 337.

SHOUP, (GEO. L.). Report of the Governor of Idaho to the Secretary of Interior. 1889, 108 pp., U. S. Dept. Interior.

SIDHNAI CANAL. Records government of India. Calcutta, 1887.

SILT OR SEDIMENT (including impurities in water):
Boquet's mode of determining turbidity of water. M. I. C. E., vol. 53
Brewer, Wm. H., Particles in liquids, 1883.
Buckley, R. B. M. I. C. E., 1879.
Calinels, M., Removal from reservoir.
Corthell, E. L., Mississippi jetties, 1881.
Cunningham, Allan., Hydraulic experiments.
Fanning, Water-supply engineering. 1877.
Frizell, J. P., Power running water. M. I. C. E.
Geikie, A., Text-book of Geology.
Gordon, R., Report, Irrawaddy River, 1879.
Guérard, River Rhone. M. I. C. E., vol. 82.
Humphreys and Abbot's Report on Mississippi.
Johnson, J. B., River physics, 1885.
Keller, H., Formation sand banks. M. I. C. E.
Mangon, Herve, Experiments, 1869.
McMath, Robt. E., Mississippi.
Seddon, James A., Clearing water, 1889.
Smith, Baird, Italian irrigation, 1885.
Specht, G. J., Treatment. M. I. C. E., vol. 84.
Suter, C. R., Report, 1881.
Van Nostrand's Mag., Short article, p. 227, 1885.
Willcocks, Wm., Egyptian irrigation. 1889.

SIM (*Col.* D.). Report on Coleroon Annicut. Professional Papers. Madras, India, 1851.

SIND, PROVINCE OF. Annual irrigation revenue report, Bombay, India, 1888–'89, 62 pp.

SIRHIND CANAL. Benton, J. Hydraulic experiments to ascertain most suitable form for notches of the falls of the.
Gulliver, H. W. Revised estimates for the.

SKINNER (J. D.). Table of daily evaporation at the source of the Mississippi River, autumn, 1878. Report Chief Engineer. Washington, 1879, pp. 1226–1227.

SLAGG (C.). Discharge of water over weirs. M. I. C. E., vol. 90, p. 305.

SLIPS, EARTHEN EMBANKMENTS. LeMesurier, J. Bombay, India.

SMITH (E. GOODRICH). Irrigation. U. S. Dept. Agr., Report Comm. Patents, 1860. Agriculture, 1861, pp. 166–224.

SMITH (JOHN). An essay on the advantage of watering pasture and meadow grounds in the highlands. Edinburgh, 1792, 26 pp.

SMITH (HAMILTON, Jr.). Hydraulics. The flow of water through orifices, over weirs, and through open conduits and pipes, New York, 1886.

SMITH (MARCUS A.). Reclamation of the desert lands. Speech by Hon. M. A. Smith, of Arizona, House of Representatives, 1888, 8 pp.

Admission of Territories. Argument of the Delegate from Arizona, United States Congress, 1889, pp. 28–41.

SMITH (*Capt.* R. BAIRD). Irrigation in Madras, India. London, 1856. Italian irrigation. Wm. Blackwood & Sons, London, 1855.

SMITH (WM.). The improvement of boggy land by irrigation as carried into effect by Wm. Smith, 1806.

SMITH (W. L.). Southern and Western Texas Guide for 1878. See Rock, J. L., and Smith.

SMYTHE (WM. E.). Nebraska, irrigation in. Omaha Weekly Bee, 7 articles, Omaha, Nebraska, Jan. 15 to Feb. 25, 1891.

SNOW (F. H.). Is the rainfall increasing on the plains? Science, vol. 11, No. 269, p. 158.

SOILS (Treatment of). Water required by various—
- Duponchel, A., Pamphlet, 1864.
- Hilgard, Jones, and Furnas, Arid lands, Pacific slope, 1882.
- Lefebvre, R., Nature of. M. I. C. E., vol. 35.

SONNE (E.). Drainage of southern parts of Zuyder Zee. M. I. C. E., vol. 57, p. 367.

SORIN (T. M.). Handbook of Tucson and surroundings, etc., 44 pp.

SOSPIZIO (CARLO). Il canale Cavour ed il suo esercizio promiscuo coll' esercizio dei canali derivati della Dora Baltea, della Sesia e del Ticino. Amministrazione dei canali demaniali d' irrigazione. Torino, Italy, 1884.

SOUTH AMERICA, IRRIGATION IN:
- Cerdan y Pontero, A., Waters Lima Valley, 1793.
- Johnson, Charles M., Water supply, Peru. M. I. C. E., 1884.
- McElroy, S., Irrigation valley Chimbote, Peru.
- McGeachy, E., Irrigation West Indies, 1846.
- Schuyler, J. D., etc., Culture sugar cane, 1889.

SOUTH AUSTRALIA. Betaloo Dam. Engineering News, New York, 1891.

SOUTHERN EUROPE. Moncrieff, C. C. Scott. London, 1868. Same, 1865.

SOUTHERN INDIA. Markham, C. R. London.

SPAIN, IRRIGATION IN:
- Aymard, Maurice, Alicante irrigation works. M. I. C. E., 1876.
- Botella, F. de, Murcia and Albacete. M. I. C. E., vol. 45, p. 311, 1876.
- Higgins, G. Seville, Water supply. M. I. C. E., 1869.

SPAIN, IRRIGATION IN—Continued.
- Llaurado, Andres, Treatise on water, 1878.
- Login, Thomas, 1867.
- Markham, C. R., Irrigation report, 1867.
- Moncrieff, C. C. S., Irrigation in southern Europe.
- Ribeiro, C., Water around Libson. M. I. C. E.
- Vigan, Study on irrigation, 1867.
- Waring, Henry Robert, Drainage, etc., of the Albufera. M. I. C. E., 1878.
- Wilson, Allan, and others, Irrigation. M. I. C. E., 1869.
- Zoppi, Guiseppe, and others, Artificial lakes, 1888.

SPECHT (G. J.). Treatment of sediment carried in mountain streams in Europe, and its application to California. M. I. C. E., vol. 84, p. 480.

SQUIRE (WATSON C.). Report of the governor of Washington for 1884, 62 pp. U. S. Dept. Interior.

SPON'S DICTIONARY OF ENGINEERING:
- Canals, p. 907.
- Damming, p. 1119.
- Irrigation, p. 2139.

STANGER (J. S.). Agriculture in Colorado, irrigation. Read before Agricultural Congress. In report of Colo. State Agri. College, 1881–'82. Agricultural report for years 1881–'82, State of Colorado, p. 154. Denver.

STATISTICAL REVIEW. India, Buckley, R. B. Calcutta, India, 1889. Statistics. M. I. C. E., vol. 72, p. 210, discussion on irrigation, p. 213.

STEARNS (F. P.). On the current meter. Reason why maximum velocity of water flowing in open channels is below surface. Trans. Am. Soc. C. E., vol. 12, p. 301; *also* M. I. C. E., vol. 76, p. 341.

STEPHENS (GEO.). Practical irrigator and drainer. Edinburgh and London. 1834, vol. 7, 195.

STEVENSON (CHARLES L.). Irrigation statistics of the Territory of Utah. Salt Lake City, 1891, 36 pp., 5 tables.

STEVENSON (EDWARD A.). Report of the governor of Idaho to the Secretary of the Interior, 1888, 68 pp. U. S. Dept. Interior.

STEWART (BALFOUR). On the heights of the river Nile and Thames. Nature, London, vol. 25, 1881–'82, pp. 268, 269.

STEWART (HENRY). Irrigation for the farm, garden, and orchard. Orange Judd Co., New York, 1889, 272 pp., 127 ills.

STEWART (WM. M.). A bill to encourage irrigation, etc. U. S. Congress, 1887, 3 pp.

STINSON (EUGENE K.). Biennial report of the State engineer of Colo., 1881–'82, 26 pp. (on the necessity for irrigation).

STINE CANAL. Resources of California. San Francisco, Cal., Oct., 1888.

STOCKSLAGER (S. M.). The effect upon certain rivers in Colorado of the diversion of water for irrigation, 1889. U. S. Dept. Int.

STOOKE (THOMAS SULLOCK), Rural water supply. M. I. C. E., vol. 61, p. 252.
Heavy rain during gale of Oct. 13, 1881. Symons' Met. Jour., London, 1884.

STORAGE. Doumerc, J., In Algeria. Revue Scientifique, vol. 40, p. 235.
Gordon, George. London, 1883.
Gould, E. S., Van Nostrand, 1888.
Great Divide. Oct., 1890. Castlewood reservoir.
Le Conte, L. J., Contamination of water.
Powell, J. W., Washington, 1888.

STRAIN. On the strains in curved masonry dams. *See* Vischer, H.

STRAUGHN (JOSEPH C.). Map and statement from, U. S. surveyor general Idaho.

STREERUWITZ (W. von.). Irrigation and drainage. In Bull. of Texas State Geol. and Sci. Asso., 1888. Houston, Tex..

STRIBLING (THOMAS H.). Irrigation in Texas. U. S. Dept. Agr. Report for 1870, pp. 583, 584.

STRIERY. Remarks concerning a "cloud burst" in Colorado during the evening of the 25th of July, 1885. U. S. Month. Weather Rev., Washington, 1885.

SUBSURFACE WATERS. *See* Seepage and percolation.

SUN, THE NEW YORK. Deserts made to blossom, April 5, 1891.

SUTER, C. R. General statement of results at St. Charles, Mo. Report Chief of Engineers, U. S. A., for 1879. Part 2, p. 1083.

SWAIN, (GEO. F.). Notes on hydraulics. Boston, 1885, 84 pp.

SWEETWATER DAM. Construction of. Schuyler (James D.), New York, 1888.

SWITZLER (WILLIAM T.). Report on the international commerce of the United States for the year 1889; part 2, Commerce and Navigation. U. S. Treas. Dept., Bureau of Statistics.

SYMES (GEORGE G.). A bill to grant right of way through public lands for irrigation purposes. 1888, 2 pp., U. S. Congress.

SYMONS METEOROLOGICAL MAGAZINE. The characteristics of one of the greatest droughts of the century. London, vol. 22, 1887.
The dry summer, 1887. London, vol. 22, 1887.
Heavy rains at Cape Town, March 8, 1886. London, vol. 21, 1886.
Heavy flood in Alabama and Georgia, March 28–31, 1886. London, vol. 21, 1886, p. 52.
The drought of July, 1885. London, vol. 20, 1885, pp. 120–123.
Heavy rain in northwest of Scotland. London, vol. 19, 1884, pp. 167, 168.
Thunderstorms and heavy rains on September 3 to 5. London, vol. 21, 1886, pp. 133–137.
The recent drought, 1887. London, vol. 22, 1887, pp. 81–86.

SYMONS (GEORGE J.). Rainfall and evaporation. On the floods in England and Wales during 1875, and on water economy. M. I. C. E., vol. 45, 1875–'76.
Agricultural depression and bad seasons. Symons' Brit. rainfall. London, 1876–'77, pp. 24–30.

TABLES (HYDRAULIC) based on the formulæ of D'Arcy and Kutter. *See* Flynn, P. J.

TAIT (P. G.). On evaporation and condensation (1885). Proc. Royal Soc., Edinburg, vol. 13, 1884–'85, 91–94.

TANK IRRIGATION. Conybeare, H., M. I. C. E., vol. 17.
Home (*Lieut.* F.), Roorkee, India.
Molesworth, Roorkee, India, 1889.

TARGET (JOHN L. F.). Experiments on a new form of module for irrigation purposes. M. I. C. E., London, vol. 65, pp. 313–322.

TATHAM (WILLIAM). The political economy of inland navigation, irrigation, and drainage, etc. London, 1799.
National irrigation, or the various methods of watering meadows, etc. London, 1801.

TELLER (HENRY M.). A bill to promote the interests of agriculture by irrigation, etc., Washington, 1888. U. S. Congress.
A bill to grant the right of way through the public lands for irrigation purposes. 3 pp., Washington, 1888, U. S. Congress.

TEMPERATURE: WATER. Discussion of the, at various depths and temperature of mines. Trans. Am. Soc. C. E., vol. 13, 1884, p. 78.

TENNENT (THOMAS). Rainfall in San Francisco, 1849–1880. Tennent's Nautical Almanac, 1881.

TERP (OLAF). Improvements in deep earth boring. M. I. C. E., vol. 75, p. 386.

TEXAS:
Brant, B. K., Profit by irrigation, 1888.
Dumble, E. T., Irrigation, 1889.
Gage, R. D., Pecos Valley, 1888.
Hill, R. T., Geology, 1890.
Rock, James S., and others, Guide, 1878.
Roesler, F. E., Staked Plain, 1888.
Smith, W. L., and others, Guide, 1878.
Steeruwitz, W. von., Irrigation and drainage, 1888.
Stribling, Thomas H., Irrigation report, 1870.
Ward County Irrigation Co., Alfalfa, 1889.

THAMES. Mechanical principle on which the current meter is constructed. M. I. C. E., vol. 45, p. 239.

THELWALL (WALTER H.). Failure of Kali Nadi Aqueduct on Lower Ganges Canal. M. I. C. E., vol. 95, p. 283.

THIRE (A.). Canals for supplying water meters. M. I. C. E., vol. 91, p. 522.

THOMAS (B.). Irrigation in agriculture, 1850.

THOMAS (H.). New artesian well in Paris. M. I. C. E., vol. 94, p. 338.

THOMASON. Medley, J. G., civil engineering manuals, Roorkee, India.

THOMPSON (A. H.). Irrigable lands of that portion of Utah drained by the Colorado River and its tributaries. In Powell's report on arid regions of U. S., Washington, 1879. pp. 150–164.

Topography in 10th Annual Report of the U. S. Geological Survey to the Secretary of the Interior, 1888-89, by J. W. Powell, director. Part 2: Irrigation, Washington, Government Printing Office, 1890.

THOMPSON (S. R.). The rainfall of Nebraska, Am. Met. Jour., Detroit, 1884–'85, pp. 56–58.

THORNTON (W. T.). Irrigation a preventive of Indian famine. Journal of the Society for the encouragement of arts, manufactures and commerce, p. 272, London, 1878.

Irrigation works in India. Eclectic Eng. Mag., New York, vol. 15, p. 113, and vol. 17, p. 140.

TICE (J. H.). The great rainfall of the summer of 1875. Am. Met., St. Louis, 1876, pp. 50–56.

TICKELL (R. P.). Head works of the Ganges Canal. M. I. C. E., vol. 54, p. 294.

TIDE GAUGE. New self-registering tide gauge. M. I. C. E., vol. 75, p. 342.

See also Nilometers.

TIMBER-CULTURE AND IRRIGATION LAWS. Dept. of Interior, General Land Office, Washington, 1891.

TITCOMB (JOHN S.). Some aspects of irrigation, Trans. Denver Soc., Civil Engineers and Architects. C. J. Kelly, Denver, 1890. 3 pp.

TOGLIASECCHI (G.). Canals of Upper Lombardy, Milan, 1872.

TOLBORT (F. W. H.). The District of Dera Ismail Khan, Trans-Indus. Journal Asiatic Soc. of Bengal, Calcutta, 1871, vol. 40, pp. 1–21.

TONG (*General* TCHENG KI). Irrigation in China. In Popular Science Monthly. New York, 1890, pp. 821–827.

TOPOGRAPHY.

Davis, W. M. Mountain meteorology, 1886.

Fisher, Osmond. Physics of the earth's crust, 1881.

Powell, J. W. Arid lands, 1879.

Thompson, A. H. Topographic operation U. S. Irrigation Survey, 1891.

Wilson, H. M. Topographic maps in irrigation, 1891.

TORRICELLI (GIACOMO).

Sluices, scour culverts, and water weirs for irrigating storage reservoirs. M. I. C. E., vol. 83, p. 473.

Note upon more important features of large reservoirs for irrigation. M. I. C. E., vol. 84, p. 483; *also* Van Nostrand's Eng. Mag., vol. 35, pp. 445–447.

[On the discharge of waters from the bottom and from the surface of great reservoirs.] Genio Civile, 1885.

TRANIÉ (H.). On practical irrigation, irrigation canal of Lestelle (Haute-Garonne), etc. Toulouse, 1871, 33 pp.

Irrigation works in the Haute-Garonne M. I. C. E., vol. 42, pp. 276–278.

TREASURY, DEPT. OF. *See* United States, Department of the Treasury.

TREMENHEERE (G. B.). Wells versus canals in India, Abstr. M. I. C. E., London, vol. 17, pp. 495–497.

TREVELLINI (LUIGI). Venice waterworks. M. I. C. E., vol. 82, p. 428.

First artesian well boring in Roman Campagna. M. I. C. E., vol. 82, p. 426.

TRIPP (WILLIAM R.). The river Buffalo: its watershed and flow in connection with the rainfall. M. I. C. E., vol. 73, p. 414.

TUCKER and HOGUE. Fresno County, Cal.: its rapid development in the production of wine, raisins, etc. Fresno, Cal., 31 pp.

TUFNELL (C. F.). Economical river training in India. M. I. C. E., vol. 72, p. 177.

TULARE IRRIGATION DISTRICT. Reports on the projected works of the, by the board of directors and engineers. Tulare, 1890, 47 pp.

TULLOCK (*Major* HECTOR). History of the Bombay water supply, professional papers. Roorkee, India, 2d series, No. 77.

TURNER (HENRY T.). Gauging of flowing water. M. I. C. E., vol. 80, p. 318. Method of gauging by wire cable.

TURNER (NICHOLAS). An essay on draining and improving peat bogs, in which their nature and properties are fully considered. London, 1784, 86 pp.

With Boswell, George, A treatise on watering meadows. 3d ed., London, 1792.

TWEEDDALE (W.). Report on the subject of electrical irrigation, a proposed plan for irrigation of western Kansas, etc. Topeka, Kans., 1890, 17 pp.

Irrigation for homesteaders in western Kansas in seventh biennial report of the State Board of Agric., Kansas, part 2, p. 219, 1891.

TYNDALL (JOHN). The forms of water in clouds and rivers, ice and glaciers. International Science Series, New York, 1872, 4th ed., London, 1874.

UNDERFLOW. Hinton, R. J.. Progress report on irrigation in the United States, 1891.

Nettleton, Edwin S., Washington, 1891.

UNITED STATES CONGRESS:

Report of the special committee of the United States Senate on the Irrigation and Reclamation of Arid Lands, 51st Congress. 1st session, report 928, parts 1, 2, 3, 4, 5, and 6, Washington, Government Printing Office, 1890.

Part 1. Report of Committee and Views of Minority, 178 pp.

Part 2 (vol. 1). Northwest, 459 pp.

Part 3 (vol. 2). Great basin and California, 573 pp.

UNITED STATES CONGRESS—Continued.

- Part 4 (vol, 3) Rocky Mountain region and Great Plains, 608 pp.
- Part 5 (vol. 4). Statement of J. W. Powell and other officers of the U. S. Geological Survey. Consular reports and miscellaneous papers, 384 pp., 14 maps.
- Part 6. Irrigation in the United States by R. J. Hinton, 2d edition of Doc. No. 15, 49th Congress. 386 pp.
- *See also* reports of U. S. Departments of Agriculture, Interior, State, and War.

UNITED STATES, DEPARTMENT OF AGRICULTURE.

- Annual reports of Commissioner of Patents:
  - 1854. Gardening (watering or irrigation, p. 332).
  - 1858. Browne, D. J., Drainage, its history, principles, advantages to the agriculturist, pp. 273–280.
  - 1859. Clemson, Thom. G., Fertilizers, pp. 136–178 (irrigation, pp. 146, 147).
  - 1860. Smith, E. Goodrich, Irrigation, pp. 166–224.
  - 1861. Bliss, Edward, Territory of Colorado: ist soil, its climate, its mineral products and resources, pp. 154–157 (irrigation, p. 156).
- Annual reports of the Commissioner of Agriculture:
  - 1862. The agriculture of Morocco, by V. D. Collins, pp. 499–508.
  - 1867. Irrigation, by Chas. D. Posten, pp. 193–200.
  - 1868. Irrigation (on a farm at Brattleboro, Vt.), p. 502.
  - 1869. Irrigation and agriculture in Utah, pp. 431, 432.
  - 1869. Irrigation, by Horace Greeley, pp. 510, 511.
  - 1869. Irrigation as a renovator of pasture lands, p. 526.
  - 1869. Irrigation in San Luis Park, Colo., p. 603.
  - 1870. Irrigation in many parts of Europe, pp. 501, 502.
  - 1870. Irrigation canals in California, Geo. Barstow, p. 517.
  - 1870. Modes and results of irrigation, pp. 576–584.
  - 1871. Practical irrigation in Colorado, pp. 254–275.
  - 1871. Irrigation systems of different countries, pp. 275–287.
  - 1872. Irrigation in England, pp. 559, 560.
  - 1873. Irrigation. pp. 282, 283.
  - 1873. Agriculture in Japan, by Horace Capron, pp. 364–374 (irrigation, pp. 366–374).
  - 1873. Irrigation and cotton culture in California, p. 378.
  - 1874. Irrigation in California, pp. 352–362. Irrigation: its evils, remedies, and compensations, by Geo. P. Marsh, pp. 362–381.
  - 1876. Irrigation in Maine, D. M. Dunham, abstr., pp. 380, 381.
  - 1881–'82. Irrigation as a remedy for chinch bug, pp. 88, 89.

UNITED STATES, DEPARTMENT OF AGRICULTURE—Continued.

  - 1885. Wheat culture in India; irrigation, pp. 580, 581, by *Rev.* J. L. Hauser, pp. 569–582.
  - 1886. Irrigation, p. 40.
  - 1887. Irrigation, pp. 44, 45.
  - 1888. Irrigation in Victoria, Australia, p. 469.
  - 1889. Irrigation problems, p. 268, influence of western forests on, B. E. Fernow, p. 275. Waters of California, p. 497.
  - 1890. Report of artesian and underflow investigations and of the irrigation inquiry, pp. 471–488.
- Report on the climate and agricultural features and the agricultural practice and needs of the arid regions of the Pacific slope, etc., by E. W. Hilgard, T. C. Jones, and R. W. Furnas. Washington, 1882, 182 pp.
- Artesian wells upon the Great Plains; report of geological commission appointed to examine portion east of Rocky Mountains, etc. Washington, 1882. (C. A. White and Samuel Aughey.) 38 pp.
- Preliminary report on the forestry of the Mississippi Valley and tree-planting on the plains, by F. P. Baker. Washington, 1883.
- Irrigation in the United States, by R. J. Hinton, under the direction of the Commissioner of Agriculture, Government Printing Office, Washington, 1887. 240 pp.
- Letter from Secretary, transmitting report of preliminary investigation to determine proper location of artesian wells within the area of 97th meridian and east of the foothills of Rocky Mountains. Government Printing Office, Washington, 1890.
- Progress report on irrigation in the United States. Part I. Prepared under the direction of the Secretary of Agriculture by Richard J. Hinton, special agent artesian underflow and irrigation investigation. Washington, Government Printing Office, 1891. 51st Congress, 2d session, Senate Ex. Doc. No. 53.
- Progress report of artesian and underflow investigation between the 97th degree of west longitude and the foothills of the Rocky Mountains, with maps and profiles. Part II. Prepared under the direction of the Secretary of Agriculture by Edwin S. Nettleton. Washington, Government Office, 1891, 14 pp. 51st Congress, 2d session, Senate Ex. Doc. No. 53.

UNITED STATES, DEPARTMENT OF THE INTERIOR:

- Report of Commissioner of Patents for the years 1850–'61, part 2. Agriculture. (*See* U. S. Dept. Agriculture).
- U. S. geographical and geological survey of the Rocky Mountain region. Report on the lands of the arid region of the U. S., with a more detailed account of the lands of Utah, with maps, by J. W. Powell. Washington, 1879. (Water supply, by G. K. Gilbert, pp. 57–58; Irrigable lands of the Salt

UNITED STATES, DEPARTMENT OF THE INTERIOR—Continued.

Lake drainage system, by G. K. Gilbert, pp. 113-127; Irrigable lands in the valley of the Sevier River, by Capt. C. E. Dutton, pp. 128-149; Irrigable lands in that portion of Utah drained by the Colorado River and its tributaries, by A. H. Thompson, pp. 150-164; Land grants in aid of internal improvements, by Willis Drummond, jr., pp. 165-182.)

Report of the governor of Washington Territory, Watson C. Squire, for the year 1884. Washington, T. J. Brashears, 62 pp.

U. S. Geological Survey. Tenth annual report of the U. S. Geological Survey to the Secretary of the Interior, 1888-'89, by J. W. Powell, Director, part 2, Irrigation. Washington, 1890, 123 pp.

Eleventh Census of the United States. Agriculture. Bulletins upon irrigation. *See* Newell, F. H.

UNITED STATES, NAVY DEPARTMENT.

Narrative of the expedition of an American squadron to the China seas and Japan, performed in the years 1852-1854, under the command of Commodore M. C. Perry, U. S. Navy, vol. 2. (Contains irrigation in Lew Chew. Washington, 1856. pp. 19-20.)

UNITED STATES, DEPARTMENT OF STATE.

Letter to the honorable Secretary of State on the general outline for a proposed scheme for an international dam and water storage in the Rio Grande River near El Paso, Tex., for the control of the annual floods, etc., and preservation of the national boundary to the Gulf, and for other purposes. Washington, Dec. 10, 1888.

Report of the U. S. Commissioners to the Centennial International Exhibition, Melbourne, 1388. Published under direction of Secretary of State, by authority of Congress. Washington, 1890, 452 pp. (Report on irrigation, T. B. Merry, pp. 291-294.)

UNITED STATES, TREASURY DEPARTMENT.

Bureau of Statistics. Report on the internal commerce of the United States for the fiscal year, 1889, part 2. Commerce and irrigation, by Wm. F. Switzler, Washington, 1889, 897 pp.

Bureau of Statistics. Report of the internal commerce of the United States for the year 1890, part 2 of Commerce and Navigation. The commercial, industrial transportation and other interests of Alaska, Arizona, California, Idaho, Nevada, Oregon, Utah, and Washington. Washington, 1891, 1174 pp.

U. S. Coast Survey. Letter from Secretary of Treasury, transmitting in answer to a Senate resolution of May 19, 1876, a copy of the report of George Davidson, on the methods employed in irrigating lands in India and Southern Europe. Washington, 1876, Government Printing Office. 73 pp.

UNITED STATES, WAR DEPARTMENT.

Engineer Dept. Ministry of agriculture, irrigation in Egypt, by J. Barois, Paris, 1887, translated by Maj. A. M. Miller, U. S. Army, 1888. Washington, 1889, 113 pp., 23 pl.

Report of the Secretary of War, 1888-'89, 4 vols. Vol. 1. Washington, 1890. (Irrigation in New Mexico and Arizona, by Col. B. H. Grierson, pp. 180-188.)

U. S. Signal Service. Report on the interior wheat lands of Oregon and Washington Territory, by Lieut. Frank Greene. Washington, 1888, 25 pp.

U. S. Signal Service. Tables showing monthly precipitation at various points throughout the dry area, by Capt. S. M. Mills. Report on internal commerce of the U. S. Washington, 1885, pp. 212-216.

U. S. Signal Service. Precipitation in the United States. U. S. Monthly weather review. Washington, 1882-1887.

U. S. Signal Service. Rainfall of the Pacific slope and Western States and Territories, by A. W. Greely, Chief Signal Officer, etc. Washington, 1888. (Includes report of Lieut. W. A. Glassford on rainfall of Pacific slope, and Capt. H. H. C. Dunwoody on normal monthly rainfalls throughout the United States). Washington, 1891, 100 pp., 15 maps, 50th Cong., 1st session, Senate Ex. Doc., 91.

See also Greely, A. W.

UNITED STATES, Irrigation in:

Barrows, W., Great American Desert.
Deakin, Albert, Progress report, 1885.
Dorsey, Edward Bates, Irrigation, 1887.
Dunham, D. M., Irrigation in Maine, 1876.
Dutton, C. E., Valley Sevier River, 1879.
Furnas, R. W., Report arid lands Pacific Slope.
Gilbert, G. K., Salt Lake drainage system, 1879.
Greene, Frank, Report Oregon and Washington, 1888.
Hazen, Wm. B., Our barren lands, 1875.
Hilgard, and others, Report arid lands Pacific slope, 1882.
Hinton, R. J., Irrigation in the United States.
Jones, J. E., Report Nevada surveyor-general, 1887-'88.
Martindale, Moses A., American Irrigation system, 1883.
Nimmo, Joseph, Uncle Sam's farm, 1889.
Powell, J. W., Irrigation.
Railroad and Engineering Journal, Irrigation.
Switzler, Wm. F., Report, 1889.
U. S. Dept. Agri. reports for years.
Walker, J. B., Irrigation, 1877.

UNITS OF WATER MEASUREMENTS (including miners' inch, acre-foot, methods of measurements, etc. *See* Module.):

Hall, W. H., Irrigation in California.
Merriman, M., Hydraulics, 1889.
Nettleton, E. S., Reports Colorado State engineer.
"Oncia" Italy's unit. M. I. C. E.
Smith, Irrigation in Italy, p. 155.

UNIVERSAL EXPOSITION, 1889, PARIS:

Conquête du désert. Colonisation du Sahara. Notice sur la Société agricole et industrielle de Batna et du Sud Algérien. Paris, 1889, 87 pp.

Départements de la Drome et de Vaucluse. Arrondissements de Montélimar, d'Orange et d'Avignon. Canal d'irrigation de Pierrelatte. Notice descriptive. Avignon, 1889, 29 pp.

Congrés international de l'utilisation des eaux fluviatiles. De l'avenir des canaux d'irrigation. Rapport de M. André de Llaurado. Paris, 1889, 12 pp.

URWIN (W. C.). Current meter observations on the Thames. M. I. C. E., vol. 71, p. 338.

UTAH, Irrigation in:

Bear River Canal Co., Irrigated lands, Bear River Valley, 16 pp.

Caine, John T., Irrigation, 1889.

Dana, F. L., The Great West, 1889.

Fabian, Bentham, Resources, 1872.

Hollister, O. J., Resources and attractions, 1882.

Kennison, Robt. L., Irrigation, 1870.

Mears, Geo. A., Prize essay.

Newell, F. H., Census Bulletin, 1891.

Powell, J. W., Report arid lands, 1879.

Resources and attractions, 1879.

Stevenson, Charles L., Irrigation, statistics, 1891.

Thompson, A. H., Irrigable lands, 1879.

Trans. Am. Soc. C. E., vol. 16, art. 354, March, 1887, p. 124.

VAN DYCK (T. S.). Irrigation law. District law of California. Irrigation Age, vol. 1, Denver, 1891.

San Diego, city of, county of, written for the San Diego Chamber of Commerce, 1890, 69 pp.

VAN NOSTRAND'S MAGAZINE. Irrigating canals in California. New York, 1885, vol. 33, p. 434.

Irrigating works in Italy, vol. 30, p. 83.

VELOCITIES OF WATER IN STREAMS AND CANALS (effect in erosion, etc.):

Cunningham, Allan, Hydraulic experiments. M. I. C. E.

McMath, Robt. E. A. S. C. E., 1882.

Smith, Irrigation in Italy.

Reasons for the filament of maximum velocity being below the surface, discussed by a number of engineers. M. I. C. E., 1878, 1879, 1883.

VENANT (N. de ST.). Equations of varied motions of flowing water. M. I. C. E., vol. 90, p. 509.

VERNON-HARCOURT (L. F.). Fixed and Movable weirs. M. I. C. E., vol. 60, part 2, London, 1880.

VICTOR (H.). Notes on irrigation, Bombay Presidency. Professional papers, Roorkee, India, No. 181.

VICTORIA. *See* Australia.

VIDALIN (F.). Practice of irrigation in France and Algeria. Paris, 1874.

VIDALIN (F.)—Continued.

Rhone irrigation canal. M. I. C. E., London, vol. 48, pp. 315–318.

VIGAN (——). Study on irrigation in the eastern Pyrenees. Paris, 1867.

VIGNERTE (BENJAMIN and C. A.). [Legal and practical manual of irrigation, with plans.] Paris, 1846.

VIGNOTTI (A.). On the irrigation of Piedmont and Lombardy. Paris, 1863.

VILLEROY (FELIX) and MÜLLER (ADAM). [Irrigator's manual; followed by the code of irrigation], by Bertin, 1850. Same. Paris, 1867.

VISCHER (HUBERT) and WAGONER (LUTHER). On the strains in curved masonry dams. Trans. Tech. Soc. Pacific Coast, No. 3, vol. 6, p. 75. Geo. Spaulding & Co., San Francisco, 1890.

VITARD (A.). [Treatise on the management of water in general—on irrigation, and on drainage.] Beauvais, 1851.

VOSIN (——). Hydrometric service and announcement of floods of Liane Basin. M. I. C. E., vol. 93, p. 516.

VON WAGNER (Prof.). New current meter. M. I. C. E., vol. 61, p. 326.

Hydrometry. M. I. C. E., vol. 59, p. 364.

VON WINTER (H.). Drainage system of Dantzic. M. I. C. E., vol. 39, p. 379.

VYSE (G. W.). River training of the Indus at Shah Jamal. M. I. C. E., vol. 50, p. 213.

WADI RAIAN *or* WADY RAYAN:

Liernur, G. A.

Moncrieff, C. C. Scott.

Western, J. H.

WAGONER (LUTHER). Strains in curved masonry dams. *See* Vischer, H.

Notes on the Walnut Grove dam, 6 pp., 2 ills. Trans. Tech. Soc. Pacific Coast, vol. 5, No. 3, p. 73. Geo. Spaulding & Co., San Francisco, Cal., 1888.

WAHNSCHAFFE. Study of soils. "Anleitung zur wissenschaftlichen Boden Untersuchung."

WALKER (J. B.). Irrigation. A paper read before the New Hampshire Agricultural College, Hanover, N. H., 1877.

WALKER (J. P. H.). Mahanuddy anicut. Professional papers, vol. 7, Roorkee, India, 1870.

WALLIS, H. S., Remarkable showers. Symons' Met. Mag., London, 1886, pp. 144–147.

WALNUT GROVE DAM. Blake, William P., New York, 1889.

Wagoner, Luther, San Francisco, 1888.

WAR DEPARTMENT. *See* United States, War Department.

WARING (HENRY ROBERT). The drainage, irrigation, and cultivation of the Albufera of Alcudia, Majorca, etc. M. I. C. E., 1878, vol. 52, pp. 243–249.

WARREN (*Gen.* **G. K.**). Surveys of the Connecticut River between Hartford, Conn., and Holyoke, Mass. Appendix B 14 of Annual Report of Chief of Engineers, 1878.

WASTE WEIR. An automatic. Foote, A. D., New York, 1888.

WATER ECONOMY. Symons, G. J., rainfall and evaporation; on the floods of England and Wales during 1875, and on water economy.

WATER METER. Foote, A. D., Trans. Am. Soc. C. E. *See also* Module.

WATER RIGHTS (Riparian rights, etc.). *See also* Legislation.
Anderson, G. G., Denver, 1890.
Mead, Elwood, Denver, 1891.
Powell, J. W., Report of arid lands, 1879.

WATER SUPPLY:
Antwerp water supply. M. I. C. E., 1885.
Deakin, A., Melbourne, 1885.
Fanning, J. T., Engineering, 1877.
Treatise on engineering, 1882.
Gamble, John G., Cape Colony. M. I. C. E.
Guésoult, P., Water works at St. Denis. M. I. C. E.
Haskoll, W., Davis, Water works, 1875.
Hench, S., Weissenfels. M. I. C. E.
Hilgard and others, of Pacific slope, 1882.
Hughes, S., Treatise.
Lindley, W. H., Utilization of river water. M. I. C. E., 1890.
Loisne, M. de, Towns of Lille. M. I. C. E.
Powell, J. W., Report of arid lands, 1879.
Rippi, W., Storage reservoirs. M. I. C. E.
Scott, John, Irrigation and water supply, 1883.

WATER WHEELS, UNIQUE. Hall, Willis L., Irrigation Age, Denver, 1891.

WATER WORKS:
Fanning, J. T., A practical treatise on, hydraulic and water-supply engineering relating to water works, etc.
Hughes, S., A treatise on water works for the supply of cities and towns, etc.

WEGMANN (EDWARD, Jr.). The design and construction of masonry dams. 112 pp., 17 ills., 62 pl. John Wiley & Sons, New York, 1889.

WEIR:
Bazin, H., New experiments. M. I. C. E.
Buckley, R. B., Movable dams. M. I. C. E.
Carro, T., Canalization. M. I. C. E.
Cipoletti, C., Villarese canal. M. I. C. E.
Collyer, G. C., Cheyaur annicut and channels.
Cotton, A. T., Professional papers, 1851.
Debeil, M., New system. M. I. C. E.
Donkin, B., Experiments. M. I. C. E.
Foote, A. D., Automatic Weir.
Francis, J. B., Experiments. M. I. C. E., 1884.
Franie, H., Practical irrigation, 1871.
Herschell, C. M. I. C. E., 1885.
Kindermann, F., River Nile. M. I. C. E.
Lake, A., Annicut across the river Kistna, etc.
Mohr, E., Charlottenburg. M. I. C. E.
Mulatière weir on the Saôn at Lyons. M. I. C. E.

WEIR—Continued.
Rhind, R. H., coefficients of discharge. M. I. C. E.
Sim, D., Report on Coleroon annicut.
Slagg, C., Discharge of water. M. I. C. E.
Smith, Baird, Italian irrigation.
Smith, Hamilton, Hydraulics.
Vernon-Harcourt, L. F. M. I. C. E. London, 1880.

WELL SINKING. Gordon, W. B., Allahabad, India, 1883.

WELLS (Irrigation and water supply from). *See also*, Artesian water and seepage.
Tremenheere, S. B., Wells *vs.* canals in India. M. I. C. E.

WELLS (W. H.). Construction, maintenance, and operation of large irrigating canals. 10 pp. Trans. Denver Soc. C. E. and A., vol. 1, p. 42. C. J. Kelly, Denver, 1890.

WEST SHORE, THE, Portland, Oregon, contains:
1887, Oct. The Big Horn irrigating ditch in northern Wyoming, p. 758.
1888, Jan. Baker county irrigation, p. 47; artesian wells for irrigation in Montana, p. 49.
1888, April. Senate bill to provide for irrigation, p. 221.
1888, May. Wood River (irrigation) reservoirs, p. 284.
1888, July. Irrigation reservoirs, p. 397; irrigation in Yakima, p. 398.
1888, August. Irrigation in southern Idaho, p. 453.
1888, September. Water on the Idaho deserts, p. 509; Yakima irrigation, p. 512.
1888, October. Irrigation in the Gallatin Valley, Montana, pp. 563.
1890, August. The Boisé City Waterworks Co., Boisé City, Idaho.

WESTERN, (J. H.). Notes on the Wady Rayan. National Printing Office, Cairo, 1888.
Rules for Rajbuha estimates, Punjab, India.

WESTERN AMERICA, Irrigation in. Deakin, A. Melbourne, 1885.

WESTERN FLOODS, The unavoidable. Scientific American, New York, 1884, 137.

WESTERN IRRIGATION. Daily Sun, New York, April 12, 1891.

WEX (G. RITTER VON). The regulation of rivers and water ways with a view to prevention of floods. M. I. C. E., vol. 69, p. 323.
First treatise on decrease of water in springs. Translated by G. Weitzel. U. S. Army. Washington, 1881, 57 p.

WHEELER (WM. HENRY). The conservancy of rivers; the Eastern midland district of England. M. I. C. E., vol. 67, p. 201.

WHEELER (O. R.). Reduction of water-level observations (made since May 1, 1877). Washington, 1878.

WHITE (C. A.) and AUGHEY (S.). Artesian wells upon the Great Plains. U. S. Dept. Agriculture, 1882. 38 pp.

WHITEHOUSE (COPE). The Raiyan project. School of Mines Quarterly, No. 3, vol. 11, pp. 201-217, New York, 1890.

WHITING (J. E.). The Nira Canal. M. I. C. E., vol. 77, p. 423, London.

WIDNEY (J. P.). The Colorado desert. Overland Monthly, 1873, vol. 10, pp. 44-50.

WILD (Dr. H.). Repetorium für Meteorologie, 1883. Band 8, part 3, etc.

WILLCOCKS (W.). Berari reclamations. Moncrieff, C. C. Scott.

Sharaki report, 1888. Moncrieff, C. C. Scott.

Egyptian irrigation, 367 pp., 69 ills., 45 tables, 26 pl. Intro., by Ross, Justin C., 22 pp. E. & F. N. Spon., London and New York, 1889.

Egyptian irrigation, M. I. C. E., vol. 88, pp. 300-358.

WILSON (ALLEN). Irrigation in India. M. I. C. E., vol. 27, p. 454.

WILSON (G.). Irrigation in south of France. M. I. C. E., vol. 51, p. 213.

WILSON (H. M.). Topographic maps, in irrigation. Irrigation age, vol. 1. Denver, 1891.

Pecos valley canals. Engineering News, New York, Oct. 17, 1891.

American irrigation engineering. Numerous ills., 56 pp. Trans. Am. Soc. C. E., vol. 24. New York, 1891.

Irrigation engineering. School of Mines Quarterly, vol. 11, No. 2. New York, 1889.

Irrigation problem in Montana, National Geographic Soc., vol. 2, No. 3. Washington, 1889, 21 pp.

Irrigation in India, Trans. Am. Soc. C. E., vol. 23, numerous ills., 53 pp. New York, 1890.

Irrigation in India. Its value and necessity. Engineering News, New York, Nov. 21, 1891.

What the Government is doing to advance Irrigation. Engineering News, New York, Dec. 19 and 26, 1891.

WILSON and LOGIN. Irrigation in India and Spain. M. I. C. E. excerpts, 1867-'69. London.

WINCHELL (ALEXANDER). Absorption of earth's water and atmosphere. "World-life," pp. 460-473. Chicago, 1883.

WINGATE (ANDREW). Note on Ahmednager irrigation, in India. Report of commission of inquiry on Indian famines. London, 1881.

WITHAM, rainfall in the basin of the, Welland, Nine, and Ouse rivers and at Boston, and its effect in causing floods. M. I. C. E., vol. 101, p. 228.

WOLFFRAM (H.). Enlargement of basin and construction of lock canal at Oberlahnstein. M. I. C. E., vol. 88, p. 503.

WOOD (C. J.). Tunnel outlets from storage reservoirs. M. I. C. E., vol. 59, pp. 37, 50, 75.

The Molteno reservoir. M. I. C. E., vol. 89, p. 285.

WOODS (EDWARD). Address. Nile irrigation works, M. I. C. E., vol. 87, pp. 1-59.

WRIGHT IRRIGATION BILL AND AMENDMENTS, 1889. An act to provide for the organization and government of irrigation districts, etc., approved March 7, 1887. Sacramento, Cal., 1887, 31 pp.

WYCKOFF (U.). Irrigation in Yolo County, California. Transactions California State Agricultural Society, 1864-65. Sacramento, 1866, pp. 302-303.

WYOMING:

Agriculture and irrigation in. U. S. Treasury Dept., Bureau of Statistics. Report 1889, part 2, pp. 822-827.

Mead, Elwood. Report of engineer to governor, 1889-'90.

Shannon, S. D. Resources, 1889.

YUMA. Citizens' executive committee of Yuma County, report of the, Yuma, Arizona, Crocker & Co., San Francisco, Cal., 1889, 48 pp.

YSAREAU (ALEXANDER). Clearings, irrigation, and drainage. Paris, 1861, 104 pp., 4 pl.

ZHARA KAREZ IRRIGATION SCHEME, Belauchistan. Records government of India. Calcutta, 1887.

ZOPPI (GIUSEPPE) *and* **TORRICELLI (GIACOMO).** [Irrigation and artificial lakes of Spain.] Firenze, 1888.

INDEX.