TWENTY-FIRST ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1899-1900

CHARLES D. WALCOTT

DIRECTOR

IN SEVEN PARTS

PART IV—HYDROGRAPHY

F. H. NEWELL, CHIEF OF DIVISION

WASHINGTON

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TWENTY-FIRST ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

PART IV—HYDROGRAPHY

CONTENTS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, June 30, 1900.

SIR: I have the honor to transmit herewith the manuscript for a volume on hydrography, prepared for publication as one of the parts of the Twenty-first Annual Report of the Survey. The greater portion of this material consists of the results of investigations carried on during the calendar year 1899. The first paper discusses the results of measurements of the flow of various streams in different parts of the United States, the data being presented in diagrammatic form as well as by statistical tables. The arrangement adopted for this progress report is a geographic one, beginning in the extreme northeastern part of the United States and ending in the extreme southwestern. A number of papers prepared independently have been incorporated in this report, after such modification as was necessary to bring them into accord with the general arrangement. A considerable amount of data concerning the flow of streams has been obtained from various sources, particularly from the engineer officers of the Army and from individuals or corporations. All of these facts have been included, and reference made to the sources of information. The great body of facts, however, are those resulting from the field work of the hydrographers of the Geological Survey and from engineers cooperating with them.

Following the report of stream measurements is a paper, by Mr. N. H. Darton, giving the results of field work in the vicinity of the Black Hills in South Dakota and Wyoming. More precise and comprehensive knowledge of the artesian waters in the Dakota sandstone and other widely distributed water-bearing rocks rendered necessary a detailed study of the geologic conditions of the Black Hills area, where these beds are upturned upon the flanks of the mountains. The results obtained by Mr. Darton have interest and value not only to the citizens in the vicinity of the Black Hills, but to a still larger class who, in all parts of the country, are seeking an underground supply of water.

The third and last paper, by Mr. Willard D. Johnson, treats of the High Plains. It is the result of field work begun in 1896 in western Kansas and extending over portions of Nebraska, Colorado, Oklahoma, and Texas.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

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

REPORT OF PROGRESS OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1899

BY

F. H. NEWELL

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REPORT OF PROGRESS OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1899.

By F. H. NEWELL.

INTRODUCTION.

During the year 1899 measurements of streams and investigations of the water resources of the United States have been continued, as in preceding years. The methods of work and the results heretofore obtained have been described in the Twentieth Annual Report, Part IV, and in earlier volumes, listed on page 17 of that report. The

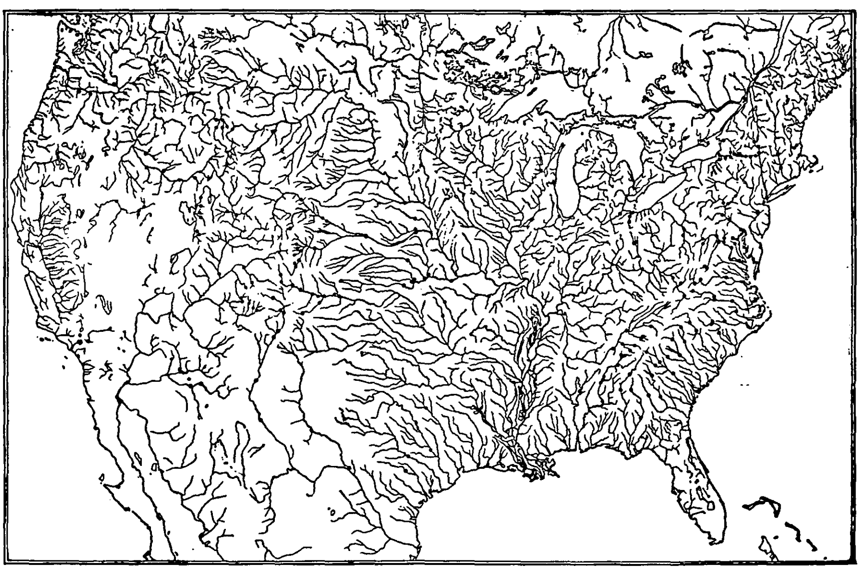


FIG. 1.—Map showing location of river stations in 1899.

operations at river stations for the year 1899 have been given in Water-Supply Papers Nos. 35 to 39, inclusive. Reference should be made to these papers for more detailed descriptions of the results given in the following pages. This double form of publication has been adopted, as explained in previous reports, on account of the necessity for making available at the earliest possible date the data obtained by field work. This has been found possible by publishing the results of the field work, without illustrations, in a series of Water-Supply Papers, and holding the computations from these results until the illustrations

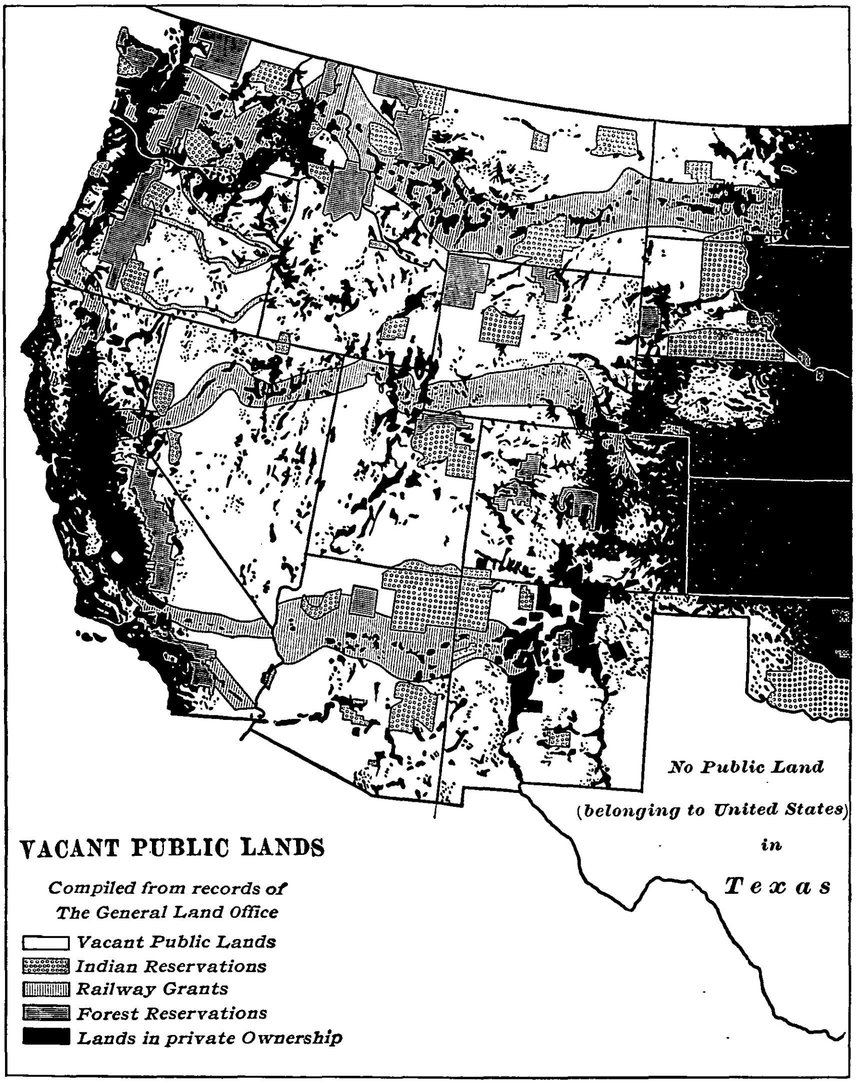


FIG. 2.—Map showing vacant public lands, etc.

for the annual report can be taken up and finished. A brief statement of the operations of the Division of Hydrography is also given each year in the administrative report of the Director of the Survey, the statement for 1899 having appeared in Part I of the Twenty-first Annual Report.

FIELD OF OPERATIONS.

The work of the Division of Hydrography has been carried on in all sections of the United States, from the Atlantic to the Pacific, and has embraced a variety of matters pertaining to water resources. The measurements of surface streams and the estimates of daily flow have, as in the past, occupied most time and attention; but consideration has also been given to underground waters, especially to those reached by deep borings. Surveys of reservoir sites have been continued, and also various investigations relating to the utilization of water for irrigation, power, and other industrial purposes. The general distribution of the work is best shown by fig. 1 (p. 25).

The largest problem the solution of which depends upon a thorough knowledge of the water resources of the country is that of the reclamation of the arid public lands. The water supply for these has been discussed in previous reports, notably in the Sixteenth Annual Report, Part II. In that volume a map of the vacant public lands is given as Pl. XXXV, showing, in colors, the lands disposed of, the forest and Indian reservations, and the vast extent of territory still unoccupied and at the disposal of Congress as the property of the people of the United States. At that time fully one-third of the United States, exclusive of Alaska and outlying possessions, was vacant. The amount of land disposed of since then is so small that this ratio remains practically the same. Fig. 2 shows graphically the position and extent of the vacant public lands, which include the greater part of the area west of the one hundredth meridian.

Area of land surface of the Western States and Territories.[1]

State.	Total area.	Vacant area.	Ratio.	Reserved area.	Ratio.	Appropriated area.	Ratio.
	Acres.	*Acres.*	*P. ct.*	*Acres.*	*Per ct.*	*Acres.*	*P. ct.*
Arizona	72,268,800	52,225,461	72	14,871,386	20	5,695,473	8
California	99,827,200	42,925,296	43	16,023,766	16	41,020,858	41
Colorado	66,332,800	40,185,991	61	5,469,853	8	20,692,316	31
Idaho	53,945,600	43,996,408	83	1,742,809	3	7,554,223	14
Indian Territory	19,840,000	....	......	19,840,000	100	....	......
Kansas	52,288,000	1,059,664	2	1,086,765	2	50,236,291	96
Montana	92,998,400	69,073,491	74	11,511,531	12	13,008,578	14
Nebraska	49,177,600	10,221,567	20	70,522	1	38,845,191	79
Nevada	70,233,600	61,326,740	87	5,983,409	9	3,026,491	4
New Mexico	78,374,400	57,050,650	73	5,952,048	7	15,426,102	20
North Dakota	44,924,800	19,928,030	44	3,493,831	8	21,488,219	48
Oklahoma	24,851,200	6,292,700	25	7,195,307	29	11,286,393	46
Oregon	60,518,400	35,328,338	58	5,500,821	9	20,448,281	33
South Dakota	49,184,000	12,107,114	25	12,908,977	26	24,190,309	49
Utah	52,601,600	43,804,507	83	5,038,971	10	3,697,962	7
Washington	42,803,200	11,756,785	28	12,530,560	29	18,459,535	43
Wyoming	62,448,000	48,777,343	78	8,113,396	13	5,542,541	9
Total	992,617,600	556,060,085	56	137,333,952	14	300,618,763	30

[1] From report of Secretary of Interior, 1899, page 4.

Proportion of area irrigable and area irrigated.

State.	Total area.	Irrigable area. *a*	Ratio.	Irrigated area, 1890. *b*	Ratio.
	Acres.	*Acres.*	*Per ct.*	*Acres.*	*Per cent.*
Arizona	72, 268, 800	2, 000, 000	3	65, 821	0. 09
California	99, 827, 200	17, 000, 000	17	1, 004, 233	1. 01
Colorado	66, 332, 800	8, 000, 000	12	890, 735	1. 34
Idaho	53, 945, 600	7, 000, 000	13	217, 005	0. 40
Indian Territory	19, 840, 000	3, 000, 000	15	....	....
Kansas	52, 288, 000	1, 000, 000	2	20, 818	0. 04
Montana	92, 998, 400	11, 000, 000	12	350, 582	0. 38
Nebraska	49, 177, 600	1, 500, 000	3	11, 744	0. 02
Nevada	70, 233, 600	2, 000, 000	3	224, 403	0. 32
New Mexico	78, 374, 400	4, 000, 000	5	91, 745	0. 12
North Dakota	44, 924, 800	500, 000	1	445	0. 0001
Oklahoma	24, 851, 200	1, 000, 000	4	....	....
Oregon *c*	60, 518, 400	3, 000, 000	5	177, 944	0. 39
South Dakota	49, 184, 000	1, 000, 000	2	15, 717	0. 03
Utah	52, 601, 600	4, 000, 000	8	263, 473	0. 50
Washington *d*	42, 803, 200	3, 000, 000	7	48, 799	0. 23
Wyoming	62, 448, 000	9, 000, 000	14	229, 676	0. 37
Total	992, 617, 600	78, 000, 000	8	3, 613, 140	0. 36

a Estimated from water supply; see page 949 of Public lands and their water supply: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 494.
b From Report on Agriculture by Irrigation, Eleventh Census, p. 2.
c Sixteen eastern counties only.
d Thirteen eastern counties only.

METHODS OF INVESTIGATION.

The methods of field work have remained substantially the same as in previous years, slight improvements in equipment being brought about from time to time. Current meters are used almost exclusively for measurements of river flow, although in some instances, as noted in Water-Supply Paper No. 35, beginning on page 19, estimates of discharge over milldams have been employed. This latter method is more fully discussed further on.

EUROPEAN CURRENT METER.

For comparison with the instruments in general use by the Survey, drawings of devices used abroad have been obtained. Particular interest attaches to the meter known as Moulinet, type H, employed in the extensive investigations of the rivers of Hungary, drawings of which have been furnished by Mr. Josef Péch, councilor to the Royal

Hungarian minister of agriculture and chief of the hydrographic surveys. Figs. 3 and 4 show the method of construction of this instrument.

CIPPOLETTI WEIR.

Although for general investigations of flowing streams the current meter has been found to be the instrument of widest application, for

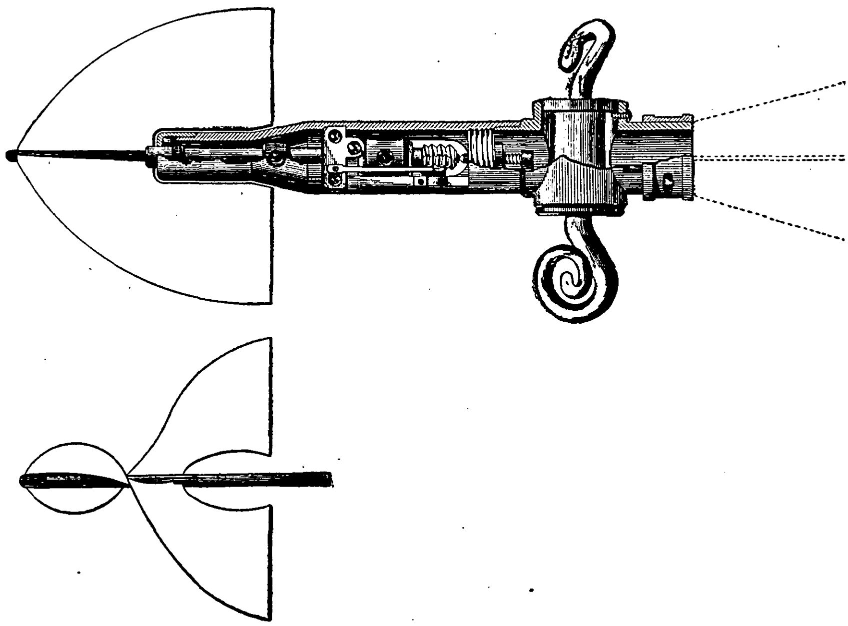


FIG. 3.—Current meter, Moulinet, type H.

special cases, where it is practicable to make a detailed and careful study of the available water, the weir undoubtedly gives the most accurate results, especially when used in connection with a self-recording instrument or nilometer giving a continuous record of the height of the water. In the work of the Survey, the weir which has been found most convenient to install is that made by placing planks or boards across the stream and cutting in them a suitable notch, the area of which is relatively small to the size of the structure. The notch may be rectangular or have sloping sides, the latter form being preferred on account of the simplicity of computing the flow. The accompanying

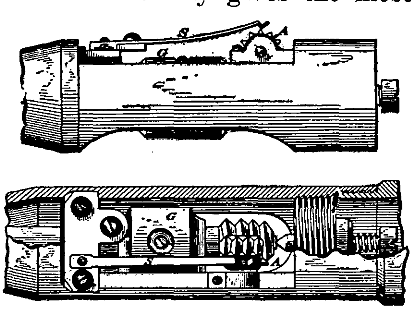


FIG. 4.—Details of mechanism of current meter, Moulinet, type H. A is pin on vulcanite wheel; G, counterweight on revolving shaft; S, spring closing contact with pin A.

figures (5 and 6) show, in elevation and section, a form of weir constructed by Mr. Frank C. Kelsey, of Salt Lake City, Utah, to measure the flow of small streams in that vicinity. These weirs are made of three-fourths inch matched redwood ceiling, supported by 4-inch by 4-inch timbers suitably braced from the back. A metal plate 0.1 inch in thickness and 6 inches wide, with sharp edge, forms the weir, being held in place by half-inch carriage bolts with square shoulders. The

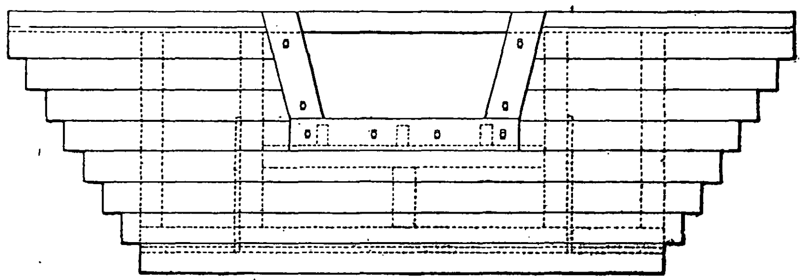


FIG. 5.—Elevation of Cippoletti weir.

holes in the plate are slotted for 1.5 inches, to allow accurate adjustment of the plate. The length of plate for the smaller weirs is 2.5 feet, for the medium weirs 5 feet, and for the larger weirs 7.5 feet, measured along the bottom of the opening in the plate. The angle of inclination of the sides of the plate is as follows: For the smaller weirs, the bottom of the slot being 2.5 feet long, at a vertical height of 1.33 feet the opening is 3.17 feet; for the 5-foot weirs, at a vertical height of 2.0 feet the width of the opening is 6.0 feet; for the 7.5-foot weirs, at a vertical distance of 2.0 feet the width of the opening is 8.5 feet.

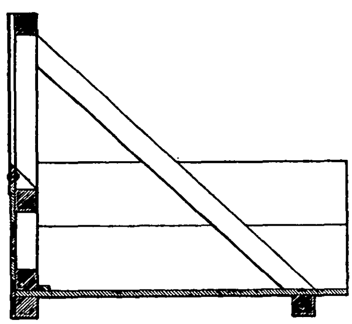


FIG. 6.—Section of Cippoletti weir.

A similar weir has been used by Mr. Kelsey in combination with an ingeniously constructed head gate which permits the weir to be lifted, allowing the stream to flow unchecked, and thus washing out any accumulated sand. This is an important feature, for in many localities the ditch superintendents object to a permanent weir, and often the accumulation of sand renders the measurements unreliable unless the pool above the weir is dug out at short intervals. This combined head gate and movable weir is shown in figs. 7 and 8, elevation and section, respectively. It is firmly embedded in the bank, and puddled clay placed in front of the sills. The timbers used to strengthen it are 12 inches by 12 inches. The gate can be readily raised and lowered by the windlass.

DIFFICULTIES ENCOUNTERED IN MEASURING THE FLOW OF STREAMS OVER DAMS.[1]

Uncertainty in regard to formulæ and coefficients.—Until recently the greatest uncertainty prevailed in regard to the best formula to be used in computing the flow over wide-crested weirs. Very little has been done in the way of experimentation upon flat-crested weirs, so that in most cases engineers have used either Francis's formula for a

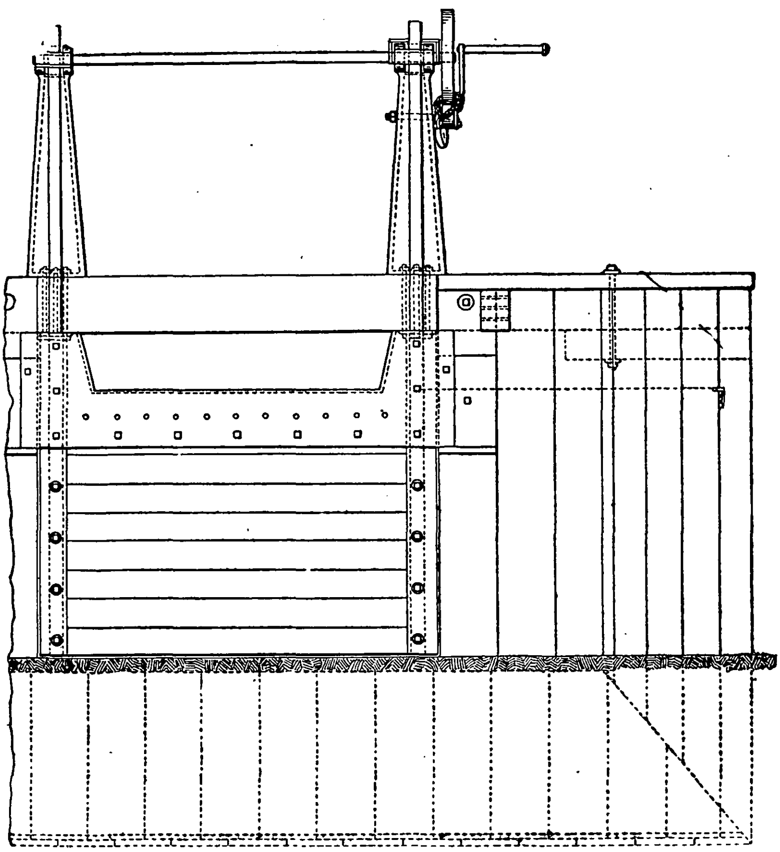


FIG. 7.—Front elevation of combined head gate and movable weir used by F. C. Kelsey, of Salt Lake City, Utah.

sharp-crested weir or his formula for a wide-crested weir. It is well known that the formula for flow over a sharp-crested weir is only roughly approximate when applied in computing the discharge over a dam or broad-crested weir. Recent experiments have shown that a dam having a graceful rounded section, without angles or sharp edges, may discharge as much as 20 per cent more water under a given head than would flow over a sharp-crested weir. Again, a flat, broad crest,

[1] From a report by H. A. Pressey, hydrographer.

with sharp angles, may not discharge more than 75 per cent of the amount which would flow over a sharp-crested weir under similar head, so that Francis's formula for a flat-crested weir should only be applied to a weir of the exact form of the one upon which he experimented. Although this fact has been recognized, still there seems to be nothing better for engineers, and the Francis formula has been more widely adopted than any other.

There are several formulæ which may be used for the flat-crested

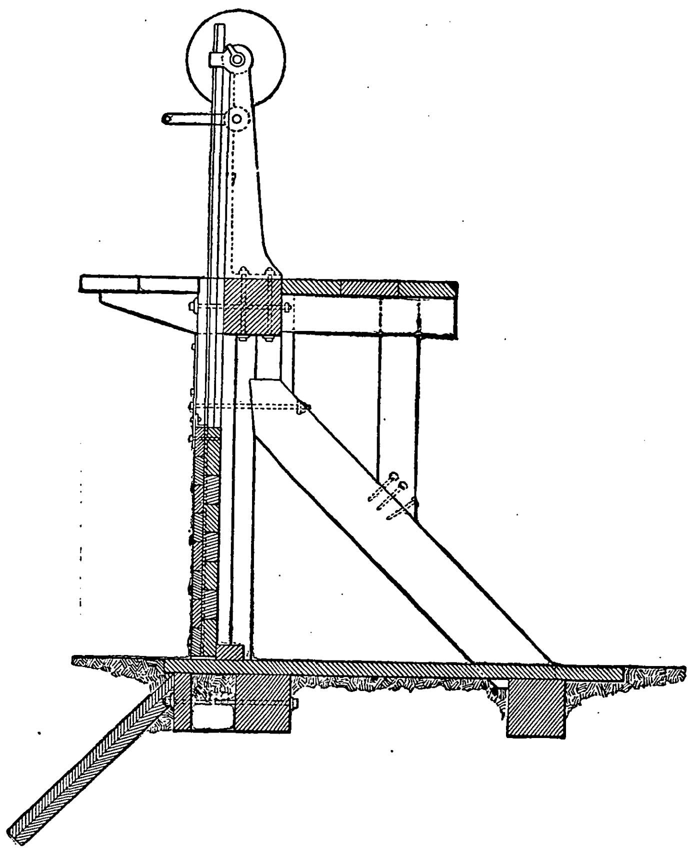


FIG. 8.—Section of combined head gate and movable weir used by F. C. Kelsey, of Salt Lake City, Utah.

weirs, viz, the Francis, the Fteley and Stearns, the Hamilton Smith, the Blackwell, the East Indian Engineers' formula, and others. It has also been recognized that the coefficient varies materially with the head, though until the experiments of Bazin little was known regarding these variations. Bazin carried his experiments to a head of 1½ feet, and obtained results which are of the greatest value in practical work. The Cornell experiments were carried on by the Board on Deep Waterways, at Cornell University, under the direction of George W. Rafter. In these experiments the coefficients were determined for heads as high as 6 feet.[1] In order to determine the actual quantity of water passing over the experimental weirs, a sharp-crested weir was constructed, of the exact design described by Bazin, and water was passed over it, with heads not greater than those for which Bazin had determined the coefficients. A shorter weir was placed below, in the same flume, over which the same quantity of water was passing. In this way the head over the shorter weir was carried as high as 6 feet, giving accurate coefficients for the computation of flow over a sharp-crested weir to that height. This weir was then used for measuring the flow over flat-crested dams of various designs. It is unfortunate that these coefficients could not, owing to lack of time, be checked by meter measurements or by floats.

In reducing the Cornell experiments the formula of Bazin for flow over a sharp-crested weir was assumed to be correct within the limit of his experiments, and was used as a basis for calibrating the standard weir. It is the intention of Prof. Gardner S. Williams, engineer in charge of the Cornell hydraulic laboratory, to calibrate the Cornell weir by volume measurements in the water-tight canal basin below, and when this has been done a recomputation of the Cornell experiments can, if necessary, be made. Their accuracy, owing to the limited number of experimental discharge coefficients which were determined for each weir section, is not as great as might be desired. At the same time the results which they give, when applied to dams of suitable cross sections, are beyond doubt more reliable than any heretofore obtainable.

Experimental weirs, of cross sections similar to most of the dams used in New York State as measuring weirs, were constructed in the hydraulic flume, and coefficients were determined for various heads ranging from 6 feet down to zero. The work was done very hurriedly, owing to limited time and lack of money, each section being given only one day for construction and experiments. Bazin, in his experiments, found that for many forms of dams, when the head on the weir was raised the nappe adhered to the dam up to a certain point, varying with the form of the crest, and that from that point, as the head was increased, the nappe became detached. If the head was reduced the nappe remained detached, with heads considerably lower than with the rising head. The quantity of flow is somewhat dependent upon the condition of the nappe, so that in the determination of the flow over the broad-crested weirs considerable uncertainty prevails at the critical heads.

There are some forms of dams in which the nappe remains the same for all heads. This is often the case with broad-crested dams having flat, sloping aprons, or ogee faces and rounded edges, so that the

[1] Proc. Am. Soc. Civ. Eng., March, 1900, Vol. XXVI, No. 3, p. 311.

nappe always adheres to the crest and hugs the apron closely. For many shapes or sections commonly found in milldams the nappe may assume a variety of conditions as regards the crest or apron. Two conditions which are diametrically opposed are the free nappe and the adhering nappe. In the former instance air is admitted freely underneath the overfalling sheet; in the latter case it is entirely excluded; between these extremes the nappe may assume two intermediate modifications, denominated "depressed nappe" and "nappe wetted underneath." In addition, most dams have a crest of sensible width, with reference to which the nappe may be either detached or attached. Either of these conditions may occur cotemporaneously with any of the four previously mentioned, making in all eight possible modifications of the nappe form. Bazin found that for a sharp-crested weir 2.5 feet high, with a head of 0.65 foot, the coefficient C in the formula $Q=CLH^{\frac{3}{2}}$ might have the following values:

(1) Free nappe, under surface always subjected to atmospheric pressure... C=3.47
(2) Depressed nappe, air imprisoned underneath at a pressure less than that of the atmosphere .... C=3.69
(3) Nappe wetted underneath .... C=3.99
(4) Nappe adhering to face of weir........ C=4.45

It may be said, however, that these changes in the nappe are for the most part phenomena belonging to relatively low heads; while for heads of 2 feet or upward the nappe will usually assume a stable form, which will persist for all higher heads; moreover, the effect of peculiarities in the cross section of the dam diminishes as the heads increase, so that the coefficients for different sections will agree more closely than for lower heads. As a result, measurements over dams under the higher heads, with conditions otherwise favorable, may be more reliable than they have hitherto been supposed to be. To prevent the nappe clinging to the weir at Cornell, the experiments were begun at high heads and the head was gradually reduced to zero. In this way the nappe remained detached the longest possible period. The coefficients derived from Bazin's experiments and those obtained at Cornell differ somewhat. This may be largely due to the different condition of the nappe. This brings out one serious difficulty that is experienced in measuring the flow over dams, namely, the flow may vary considerably with the same head, depending upon whether the river is rising or falling. The slope of the apron also affects the flow materially, by changing the form of nappe.

During high water the velocity of approach is sometimes very great, affecting the flow to a marked degree. In no case has this been taken into account in making computations of the flow of the New York streams. It is probable that the error due to this cause is entirely within the limit of error of the computations. In low-water seasons there is usually enough pondage back of the dam to eliminate the velocity of approach.

It has been found that a number of low dams become submerged, either partially or completely, during high water, and the computation at that time is very uncertain. Nothing can be done except to make the regular computations for submerged weirs; but as these are only approximations the doubt as to the accuracy of such results is well founded. There seems to be only one thing to do in case a dam is submerged, and that is to abandon the station. The dam at Rexford Flats, on Mohawk River, and the one at Fort Hunter, on Schoharie Creek, are of this type, so that the records for high water are of little value.

In selecting dams for this purpose it is usually necessary to take the ordinary timber dams built to furnish power for manufacturing plants. These are more or less leaky. The leakage is always difficult to determine and varies at different seasons of the year. During low water, when there is no flow over the crest, it is often an easy matter to measure by current meter the flow through the dam, but we have no assurance that this flow is constant throughout the year with the varying heads. The leakage is apparently a function of the head on the openings, or, in other words, of the difference of elevation between the water surface above and below the dam. This factor in turn varies greatly with the different stages of the river. For New York streams the backwater in the stream channel often rises more rapidly than the head on the crest, so that the effect of high water is to diminish the leakage. Exceptions to this rule will occur whenever the length of the clear overfall is small in proportion to the stream volume or discharge, or when the slope of the water surface below is so great as to prevent appreciable backwater. On the other hand, when the dam is exposed to the summer heat the wood contracts, and in many cases the size of the opening increases. The amount of the leakage, therefore, must always remain more or less uncertain.

Some timber dams and many masonry dams are practically watertight. We can not, however, always assume that the most carefully constructed masonry dams are tight. The Watertown dam, on Black River, has been found to leak—as near as can be judged 200 cubic feet per second—through two large openings under the foundation. No dam which has a large leakage is fit to be used for measurements of flow. In New York State five of the dams used for this work have been abandoned owing to the leakage.

Irregularity of crest.—Most timber dams settle more or less irregularly, and often ice and floating logs cause boards to be knocked off, so that after a few years the crest of an ordinary timber dam is very irregular. This means that the depth on crest at various parts of the dam is different, and therefore the quantity of water flowing varies from shore to shore. Where money is available the safest plan is, without doubt, so to repair the crest that it will have a horizontal crest line; but in most cases this work is too expensive, and other means must be resorted to.

With very irregular crests, it is usually well to divide the crest into several sections in such a way that the crest line of each section may be considered horizontal. The flow over each of these sections is then computed independent of its neighbor, the flow over the several sections being added to obtain the total flow over the dam. This can be done at a number of different heads on crest, and a curve plotted, with gage heights as abscissæ and flow in cubic feet per second as ordinates. By plotting the results of computation at several points, and drawing a smooth curve through these points, we can interpolate and determine the flow at the various heads without further computation. Great care must be taken, however, to keep track of any changes made in the crest of the dam by the owner, as he may, from time to time, nail on new boards or replace old timbers, thereby changing the form of the crest and necessitating a new survey of the dam.

Irregular cross sections.—In many cases dams are constructed with varying cross sections. This is sometimes due to the difference in depth in the river bed, and sometimes to a peculiar design, as in the construction of log slides, ice slides, wasteweirs, etc. It is often necessary to compute the flow over these parts of the dam separately, using different coefficients, and sometimes even a different formula.

Dams which are arched upstream to secure added strength or which have an obtuse angle near the middle of their length are of common occurrence. Given an arched dam, the amount of discharge will undoubtedly be greater than would take place over a straight crest equal in length to the chord of the arc. On the other hand, there are reasons for believing that the flow is less than would take place over a straight crest of the same length as the circular arc. Which condition is the more nearly approached in practice depends somewhat on whether there is a broad, open pond or a narrow, uniform channel above the dam.

Flashboards and spillways.—One of the most serious difficulties encountered is the use of flashboards on the crest of the dam. These are from 6 to 8 inches in height, and change the condition of flow completely. When flashboards are placed over the entire length of the dam it is probably safest to use, in computation, Francis's formula for sharp-crested weirs. Many manufacturers, finding that they are short of water, place flashboards on only a part of the dam, so that the greater flow passes over the ordinary crest, while there is a lesser flow over the top of the flashboard. These conditions become quite complicated, and it is often difficult to get proper reports as to the flashboards in place. It is usually necessary to construct a new curve of flow for each condition of the flashboard. The flashboards are placed on top of the stone or timber dam, and in most cases there is a large leakage beneath them. This is variable, but is often large in amount. This leakage is checked to some extent by grass, twigs, etc., caught from the running water, being sometimes entirely stopped from this cause.

Spillways, wasteweirs, overflows, etc., often cause considerable uncertainty in the computations. Their crests are sometimes irregular and of such form that the coefficient of discharge is doubtful. They are also likely to be obstructed by ice, logs, or other floating material. Considerable care must be exercised in the surveys of these accessories, and they must be carefully examined at each inspection of the station in order to note any changes which may have occurred.

Obstructions.—In the winter the accumulation of ice on the crest and at the gages is a very serious hindrance. It is sometimes necessary to abandon the station temporarily on this account. Very often the observer, by chopping away the ice as it accumulates, is able to keep the station clear, but this means additional work and expense, and when the hydrographer is not present it is very likely to be neglected. This is particularly serious, because the ice collects gradually and the readings on the gage increase regularly, so that nothing wrong is suspected, while the computations made may be considerably in error. In the Northern States there seems to be no remedy for this difficulty, which, for winter observations, may be considered one of the greatest drawbacks to this method of measurement.

Logs, driftwood, and snags often float down the stream and are caught on the crest of the dam, hanging there for days and sometimes for months, affecting the flow, in the case of small streams, to a considerable extent. When possible, these should be cut away; but at times of high water it is often very difficult to get at them.

During the summer months, when the water is low, the milldams often hold back the total flow of the river during the night. This water is used the next day, passing through the mill wheels and the tailrace back into the stream. Frequently the water is at such a stage that none passes over the dam during a part of the day, and then, when the mill pond is full, there is first a slight flow, which gradually increases to a head of several inches. Under such conditions the ordinary gage readings taken two or three times a day are not proper indexes of the flow of the stream. Day after day the flow over the dam may commence at a certain hour and the gage not be read until three or four hours later. There is nothing in the record, as ordinarily taken, to show when this flow over the dam begins or how rapidly it increases.

If an automatic gage were installed at each station we should have better information on this point; but so much difficulty has been experienced with the automatic gages in work of this character that it seems inexpedient to install them. It is also difficult to have an observer note the time when the water begins to flow over the dam, as he is often located some distance away, and it would require long and patient waiting. This difficulty, therefore, seems to be inherent in the method and unavoidable without considerable extra outlay of money at each station. At some stations this is not a serious objection, because the water seldom gets so low that there is not a flow over the crest; but frequently the water flows over the dam an hour or two only during the day, from one to three months each year, making the low-water, or critical, readings uncertain if not useless. At such a station it is particularly important that a painstaking observer be engaged, and that he make careful notes in regard to the stages of the water throughout the day. This matter is still further complicated by the fact that unusual conditions exist every seventh day, and though no water has passed over the dam during the week, on Sunday, when the mill wheels are shut down, the surface of the water will often reach the crest and begin to flow over.

Most of the observers are necessarily machinists or other employees in mills, and they are frequently not at the gages on Sunday, so there may be a flow over the dam for ten or twelve hours without any record to show it. On Monday morning the mill pond will usually be filled to the crest, and this pond will be gradually drained. Computations of flow past the station will, therefore, give abnormal results. On Sunday very little water may flow past, while on Monday the flow will be very large. With careful records these irregularities will balance themselves in a month's run, but it makes the record of daily flow of very little value, as it depends entirely upon whether or not the mill is running.

Diversions of water.—At most dams water is diverted for manufacturing purposes, to supply canals, for lockage, etc., and the amount of diversion is often very difficult to determine. There are usually feeder gates located above the dam, which are opened at various fractions of full gate at different times during the day. It is usually desirable to have gage readings taken just outside of these gates and in the feeder below them, in order to determine the head on the gates. The flow through the gates is then computed as flow through an orifice, noting the head and size of the orifice. The setting of the gate, however, is often changed, and at irregular hours, and the height of water in the canal varies more or less from day to day, so that considerable care must be taken in order to get data for accurate computations. There is also some uncertainty as to the coefficients to be used in gates of peculiar form or construction. In this case, as in that of the flow over the dam, a few readings taken during the day may give an incorrect idea of the conditions of the gate. Another difficulty encountered with water wheels arises from partial clogging of the chutes or wheel gates. This is likely to occur in rapid streams carrying silt and drift, or where long, closed conduits or wrought-iron trunks lead from the dam to the turbines. At Dolgeville, New York, for example, at one of the most modern and best-designed plants where gagings are being made, the water wheels become so clogged at times that with gates nearly wide open the turbines discharge only a small fraction of the amount of water which they are rated to use. In such cases computations based on wheel-gate records are worthless.

It is important that these computations should be checked occasionally by current-meter measurements in the canal feeder. The error due to mistakes in the assumption of the amount of diversion is one of the most serious in the computation of the flow of the New York streams.

In some cases the loss of water due to leakage, seepage, and evaporation from canals, flumes, and penstocks may be considerable. But in most cases it is a very small part of the total flow of the stream, and therefore can not be considered an important factor. It should be borne in mind, however, for in some cases the leakage has been found to be an appreciable proportion of the total flow.

Water wheels.—When the station is located at a dam built to store water for manufacturing purposes, it is necessary to determine not only the flow over the dam, but also the flow through the mill wheels. In many cases the flow through the wheel may be a very large part of the total flow of the stream, and sometimes the total flow for several months of the year. To determine the flow through the water wheel, it is necessary to treat it as a water meter. If the wheel is of a modern type, carefully built and properly tested, the results may be accurate and reliable. The best ratings we have are on the wheels tested at the plant of the Holyoke Power Company, and whenever these records can be obtained the results of measurements may be considered to be as good as most methods of measurements of stream flow; but at many stations some or all of the wheels in use are not of modern manufacture, have never been properly rated, and we have but little information concerning them. Whenever the results of the Holyoke or other tests are available, the figures there given should be used for determination of quantities, but unless those figures are available it will often be necessary to rely upon the makers' catalogues, or even to estimate by analogy the quantity that would flow through the wheels after making proper measurements and comparing with other types of wheels concerning which we have more information.

The head on the wheels is constantly changing, and in order to keep track of these changes it is necessary to read a gage in the headrace and another in the tailrace, from which the actual head on the wheels at the time of reading can be determined. We must assume that the head varies in a regular manner between the readings. The wheels may be run from one to twenty-four hours a day, and the head and time of running must be known for the computations. In time of low water the head will often reduce rapidly during the day, sometimes necessitating the shutting down of one or more wheels in the afternoon, while during the night the pond will fill, so that in the morning the wheels start with a maximum head. It is difficult to get readings on the gages which will give the necessary information and will represent the true conditions.

A record of the gate opening for each wheel must be kept and the time of change of gate noted. In computing the flow for various fractional gate openings, information in regard to the relation of flow to the gate opening is lacking for most wheels. The quantity passing through the wheels does not vary exactly with the opening, as shown by many tests, and this ratio varies with each type of wheel, and often with each size of a type. When dealing with wheels upon which tests have been made, the ratio derived from the tests can be used. Otherwise we must assume that at quarter gate the flow is one-fourth that at full gate, etc.; or, in comparing the wheel with one of similar make, construct an approximate curve for that particular wheel. By making careful weir or current-meter measurements, it is possible to rate these wheels with various gate openings, and in case of doubt this should always be done.

There is often considerable leakage in the flume and penstock, and even through the wheels themselves. Usually this can only be estimated, and will, perhaps, in most cases be so small as not to bear an important relation to the total flow.

Loss of head.—Where long flumes and penstocks have been installed the loss of head in friction may be considerable and may affect to a marked degree the results of computation. Where possible the exact head on the wheels should be determined by the gages after all losses by friction have been deducted.

Screen racks are often placed above feeder gates, and enough head is lost, due to friction of water in passing the racks, especially when clogged or dirty, seriously to modify the effective head on the gate orifices. This is notable at Oriskany, New York, where as much as 4 inches head is sometimes lost in the screen rack above the feeder gates. After passing through submerged gate orifices the water is exceedingly turbulent and does not soon return to a state of uniform flow in the short, narrow feeder channel. Owing to the presence of these eddies and vortices, accurate current-meter measurements are difficult to make, so that the determination of diversion to the canal presents some perplexing problems.

Observers.—It has been shown that the records necessary for proper computation of flow over dams are complicated and require great care and some skill. In selecting a gage reader it is usually necessary to employ some one working in the mill, in order that he may have access to the mill wheels, and commonly he is a man of ordinary attainments, having no technical skill and little education, so that mistakes and omissions in the records are likely to occur. This is true of this method of measurement to a greater extent than of any other method in common use.

Selection of stations.—In selecting the stations for measurements the hydrographer must bear in mind the purpose for which he is measuring the flow. He may wish to note the total flow of the stream, or the quantity flowing past a certain city, or that passing over certain falls. It is necessary that he should be entirely free in selecting the locations of his stations. In measuring the flow over dams he is usually restricted to one, two, or a half dozen dams on the stream, so that while the flow past a certain point can be determined by that means it may not be the most desirable place of measurement for his purpose, and he may often find it advisable to use some other method of measurement.

ACKNOWLEDGMENTS.

Most of the results presented in this volume have been obtained through local hydrographers, a comparatively small portion of the work having been conducted directly from the Washington office. Acknowledgment is due to each of these persons, and thanks are extended to individuals and corporations who have assisted the local hydrographers or have cooperated in any way, either by furnishing records of height of water or by assisting in transportation. The following list, arranged alphabetically by States, gives the names of the resident hydrographers:

Arizona: W. A. Farish, civil engineer, Phœnix.

California: J. B. Lippincott, civil engineer, Los Angeles.

Colorado: A. L. Fellows, civil engineer, Denver.

Georgia and Alabama: Prof. B. M. Hall, civil engineer, Atlanta, and Prof. W. S. Yeates, State geologist, Atlanta.

Idaho: N. S. Dils, civil engineer, Caldwell.

Kansas: W. G. Russell, Russell; Prof. E. C. Murphy, State University, Lawrence.

Maryland: Prof. W. B. Clark, State geologist, Baltimore.

Montana: Prof. Samuel Fortier, Bozeman; Prof. Fred. D. Smith, Missoula.

Nebraska: Prof. O. V. P. Stout, State University, Lincoln, assisted by Adna Dobson and Glenn E. Smith.

Nevada: L. H. Taylor, civil engineer, Golconda.

New Mexico: P. E. Harroun, civil engineer, Albuquerque.

North and South Carolina: Prof. J. A. Holmes, State geologist, Chapel Hill, North Carolina, assisted by E. W. Myers.

Texas: Prof. Thomas U. Taylor, State University, Austin.

Utah: Prof. Samuel Fortier, civil engineer, Corinne, assisted by J. L. Rhead and J. S. Baker; later, Prof. George L. Swendsen, Logan.

Virginia and West Virginia: Prof. D. C. Humphreys, Washington and Lee University, Lexington.

Washington: Sydney Arnold, civil engineer, North Yakima; William J. Ware, civil engineer, Port Angeles.

Wyoming: A. J. Parshall, civil engineer, Cheyenne.

In Colorado the State engineering department has cooperated to some extent, and valuable assistance has been given by the Denver and Rio Grande, the Union Pacific, the Colorado and Southern, the Rio Grande Southern, the Atchison, Topeka and Santa Fe, and the Burlington and Missouri River railroads. Special thanks are also due to the officers and employees of The Great Plains Water Company, one of whose engineers, Mr. C. W. Beach, has made many measurements on the Arkansas, The Amity Land and Canal Company and its chief engineer, Mr. Thomas Berry, The Buffalo Canal Company, and to Messrs. W. J. Southland, S. W. Cressy, J. M. Wolaver, C. W. Reece, W. E. Obert, Thomas Kneale, and L. H. Dickson, water commissioners in various parts of the State, also to Mr. Charles W. Allen, engineer of the Denver Union Water Company, as well as to many others who have furnished valuable information.

In California assistance in transportation has been rendered by Mr. William Hood, chief engineer of the Southern Pacific Company, who has also secured the assistance of bridge watchmen in observing the height of water in the rivers. Mr. Walter James, chief engineer of the Kern County Land Company, has supplied records of Kern River, and Mr. A. K. Warren, assistant engineer, has also furnished information. Mr. Burt Cole, engineer of the South Antelope Valley Irrigation Company, has given records of the flow of Littlerock Creek. Mr. H. F. Parkinson, superintendent of canals taking water from the San Gabriel River above Azusa, has furnished records of that stream; Mr. J. H. Carruthers, manager of the Anglo-American Canaigre Company, has furnished records of Lytle Creek; Mr. W. B. Clapp, city engineer, Pasadena, has furnished records of the Arroyo Seco, and Mr. K. Sanborn, engineer of the Riverside Water Company, has rendered valuable assistance in making low-water measurements during the summer of 1899. Mr. W. G. Nevin, general manager of the Southern California Railroad, has furnished transportation over the Sante Fe lines in California. The city of Los Angeles has maintained gagings of Los Angeles River, which have been furnished without charge through the courtesy of Mr. F. H. Olmstead, city engineer. In October, 1899, the California Water and Forest Association was formed, with headquarters in San Francisco, and over 400 delegates from various portions of the State were present at the organization. The purpose of this association is to cooperate with the Hydrographic

Division of the United States Geological Survey and with other Government organizations, for the conservation and protection of the water supply of the State. Mr. William Thomas was elected president, Mr. T. C. Friedlander, secretary, and Mr. F. W. Dohrmann, treasurer, all of San Francisco.

The association has proceeded to raise funds by private subscription for the advancement of this work, and has agreed to contribute the sum of $4,000 to the Geological Survey, to assist in carrying on its investigations of water supply during the summer of 1900. The work is to be done under the direction of the Geological Survey and joint reports are to be made to the association and to the Survey. The engineering departments of the University of California and of Stanford University have agreed to cooperate with the California Water and Forest Association and with the Geological Survey in aiding the investigations.

An association composed of canal owners obtaining water from Kings River and serving about 250,000 acres of land has been formed for the purpose of increasing the low-water supply of that stream. This association has cooperated with the Geological Survey and the California Water and Forest Association in investigations on Kings River, and has contributed $1,600 for that purpose.

The Chamber of Commerce of Willow, California, has contributed $250 to the Geological Survey to assist in an investigation of the storage possibilities on Stony Creek. A similar contribution has been made from the Chamber of Commerce of Woodland for investigations of the storage possibilities on Cache Creek, making in all $6,250 contributed by private subscriptions during the spring of 1900 to aid the work of the Geological Survey in investigating irrigation problems in the State of California.

For the accuracy and completeness of work in Georgia, Alabama, and Tennessee acknowledgments are due not only to Mr. B. M. Hall, resident hydrographer, but also to his principal assistant, Mr. Max Hall, who has entered into all the details and management of the work, much of the success being the result of his energy and enthusiasm. Thanks are also due to Prof. W. S. Yeates, State geologist of Georgia, who has paid observers at Madison, Blueridge, Juliette, Almon, and for part of the year at Macon, Oakdale, West Point, Canton, and Carlton; also to Dr. Eugene A. Smith, State geologist of Alabama, who has paid observers at Riverside and Milstead, Alabama. The officials of the United States Weather Bureau have also rendered assistance, particularly Messrs. J. B. Marbury, D. Fisher, F. P. Chaffee, and L. M. Pindell. They have maintained stations at Chattanooga, Charleston, and Knoxville, Tennessee; at Albany, Dublin, and Rome, Georgia; at Calhoun Falls, South Carolina; and for a part of the year at Macon, Oakdale, Resaca, Canton, West Point, and Carlton, Georgia. Mr. W. M. Towers, the observer at Rome, Georgia, is paid by the United

States Weather Bureau for half of the year and keeps the record for the remainder of the year without charge. Mr. H. S. Weems maintains observations at Carters, Georgia, without charge. The city of Augusta maintains the station at Augusta, and Mr. R. C. McCalla, jr., United States assistant engineer, keeps a record of river height at Tuscaloosa, Alabama, and has rendered valuable assistance in many ways. Prof. C. S. Wilkins, of the Alabama University, has made a series of discharge measurements at Tuscaloosa. The United States engineer corps at Montgomery, Alabama, has furnished records of water heights at Locks Nos. 4 and 5 on Coosa River, and Mr. D. M. Andrews, United States assistant engineer, Lincoln, Alabama, has rendered valuable assistance in the work. Transportation has been furnished to B. M. Hall and his assistants through the kindness of Mr. C. E. Spalding, vice-president, and Mr. Joseph McWilliams, general manager, Atlanta, Knoxville and Northern Railway; Mr. George C. Smith, president and general manager of the Atlanta and West Point Railway and of the Western Railway of Alabama; Mr. E. St. John, vice-president and general manager of the Seaboard Air Line; Mr. James T. Wright, general manager of the Macon, Dublin and Savannah Railroad; Mr. W. W. Finley, second vice-president, and Mr. J. S. B. Thompson, assistant general superintendent, Southern Railway Company; Mr. Thomas K. Scott, general manager Georgia Railroad; Mr. B. Dunham, general superintendent Plant System; Mr. D. E. Maxwell, general manager Florida Central and Peninsular Railroad; and Mr. J. R. Parrott, vice-president Florida East Coast Railway.

Thanks are due to the Chesapeake and Ohio Railway and to the Norfolk and Western Railway for annual passes over all lines in Virginia and West Virginia, issued to Prof. D. C. Humphreys; also to Mr. Decatur Axtell and Mr. F. B. Isaacs, Richmond, Virginia, to Mr. Charles S. Churchill, Roanoke, Virginia, and to Mr. J. Turner Morehead, Halcombs Rock, Virginia, for valuable suggestions.

In Idaho, the State engineer, Mr. D. W. Ross, has heartily cooperated. Transportation has also been furnished to Mr. N. S. Dils through the kindness of Mr. D. E. Burley, general passenger and ticket agent of the Oregon Short Line Railroad.

In connection with the work in Kansas, this Survey is under obligations to the Missouri, Kansas and Texas Railway, and to the officials of the Santa Fe Railroad for transportation furnished Mr. W. G. Russell.

In Montana assistance has been rendered by the Great Northern Railway, by the Bitterroot Stock Farm, of Hamilton, Montana, and by several county surveyors and civil engineers in the State.

In Nebraska various State boards and officials have cooperated with Prof. O. V. P. Stout, notably the agricultural experiment station, the State board of irrigation, and the State board of agriculture. The

Burlington and Missouri River Railroad, the Union Pacific Railroad, the Fremont, Elkhorn and Missouri Valley Railroad, and Mr. Frank Trumbull, president of the Colorado and Southern Railway, have continued to extend substantial courtesies which materially facilitated the hydrographic work and extended its scope.

In Nevada officials of the Southern Pacific Railroad Company have furnished transportation to Mr. L. H. Taylor, enabling him to extend his field of operations.

In Wyoming transportation has been furnished Mr. A. J. Parshall by Mr. E. Dickinson, general manager of the Union Pacific Railroad, by Mr. G. W. Holdrege, general manager of the Burlington and Missouri River Railroad, and by Frank Trumbull, general manager of the Colorado and Southern Railway. Thanks are also due to Col. W. D. Pickett, George W. Wise, and Nathan Rush, of Bighorn County, for transportation furnished Mr. A. J. Parshall and party during the reconnaissance of reservoir sites on upper Grey Bull River and Meeteetse Creek.

Thanks are due to Mr. Thomas Cooper, western land agent of the Northern Pacific Railway, for a pass for the year 1899 for the State of Washington, issued to Mr. Sydney Arnold, to assist in the work of river measurements.

A word of appreciation should also be said for the efficient service rendered by members of the Division of Hydrography in the preparation of this volume and the related Water-Supply Papers. Various portions have been prepared or revised by different persons, so that it is impossible to give credit for each item. It may be said in a general way that much of the description has been prepared by Mr. Cyrus C. Babb and Mr. H. A. Pressey, while the tables and computations and the measurements of drainage areas have been made by Mr. Gerard H. Matthes. The original records have been carefully arranged and compiled by Mrs. Jennie T. Davis, and the necessary stenographic work arising from voluminous correspondence has been performed by Miss Flora Knowlton and Miss Chloe D. Mantle.

RESERVOIR SURVEYS.

The surveys of reservoir sites described in the Twentieth Annual Report, Part IV, have been continued during 1899, the results being given in connection with the descriptions of river flow in general geographic order on the following pages. The principal sites examined during the year have been those in the Sierras of California and along the Rio Grande in New Mexico. The reservoir surveys in the latter State are more fully discussed on pages 265 to 277; the surveys in the former State on pages 445 to 446 and 450 to 465. For convenient comparison of the sizes of some of the best-known reservoirs of the United States with those of the sites surveyed in the West, figs. 9 to 13, inclusive, have been prepared.

COMPARISON OF RESERVOIR AREAS.

The outline diagrams, figs. 9 to 13, inclusive, of various reservoirs constructed and proposed are all on the same scale, and exhibit the difference in form of the water surface. The difference in capacity for a given height of water of a number of them is graphically shown in figs. 4, 5, and 6 of the Twentieth Annual Report, Part IV.

Descriptions of the reservoir at Clinton, Massachusetts, or, more properly, the Wachusett reservoir, designed to increase the municipal supply for Boston, Massachusetts, are given in various annual reports of the Metropolitan Water Board, particularly in the fifth annual, dated January 1, 1900. It receives the drainage from 118.23 square

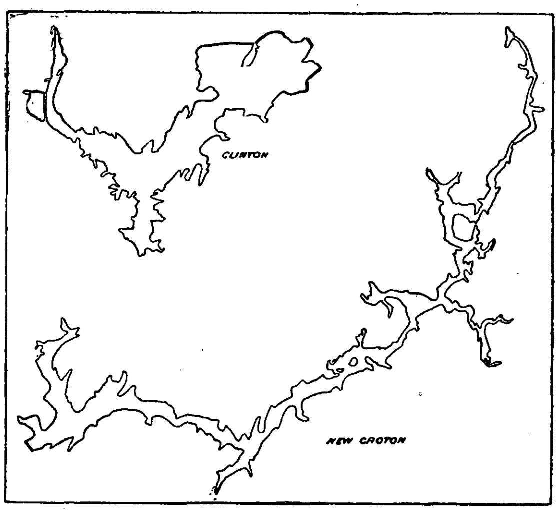


FIG. 9.—Clinton reservoir, Massachusetts, and new Croton reservoir, New York.

miles on the headwaters of Nashua River, conserving water tributary to Merrimac River, as noted further on (p. 59). The new Croton reservoir is to be formed by a dam placed below the old Croton dam, of such height as to flood the latter structure. Further details of this reservoir may be found on page 75. The reservoirs outlined in figs. 10 to 13 have been described in the various annual reports of this Survey, particularly in the paper by Mr. James D. Schuyler, entitled Reservoirs for Irrigation, contained in the Eighteenth Annual Report, Part IV.

RESERVOIR ON THE RIVER NILE.[1]

For comparison with conditions in America, it is interesting to note some data concerning the River Nile, which flows northerly through Egypt. In order to further utilize the water of this river for

[1] More fully described in Engineering News of December 28, 1899, Vol. XLII, No. 26, p. 418.

irrigation, it is proposed to construct a dam near Assouan, in Upper Egypt. A short distance above the site of the proposed dam is the island of Philæ—famous for its ancient temple of Isis—which, with the most effective height of dam, will be submerged. It has been decided, therefore, to limit the height of the stored water to a maximum head of 68 feet, providing a reservoir capacity of 863,400 acre-feet. This reservoir will be filled between November and April, after the floods have subsided, and will furnish water for irrigating in May, June, and July. The loss by evaporation is assumed to be about 39 inches vertical, or 7 per cent of the total contents, amounting to 60,800 acre-feet. This leaves 802,600 acre-feet, from which should be deducted the losses, from various causes, in its thirteen and one-half days' journey (331 miles) to the barrage at Assiout, leaving available 618,500 acre-feet to be utilized at the latter point. Mr. W. Willcocks contends that this volume is inadequate for the complete supply for perennial irrigation, and that other reservoirs must be constructed or the outlets of the great lakes at the sources of the Nile must be regulated.

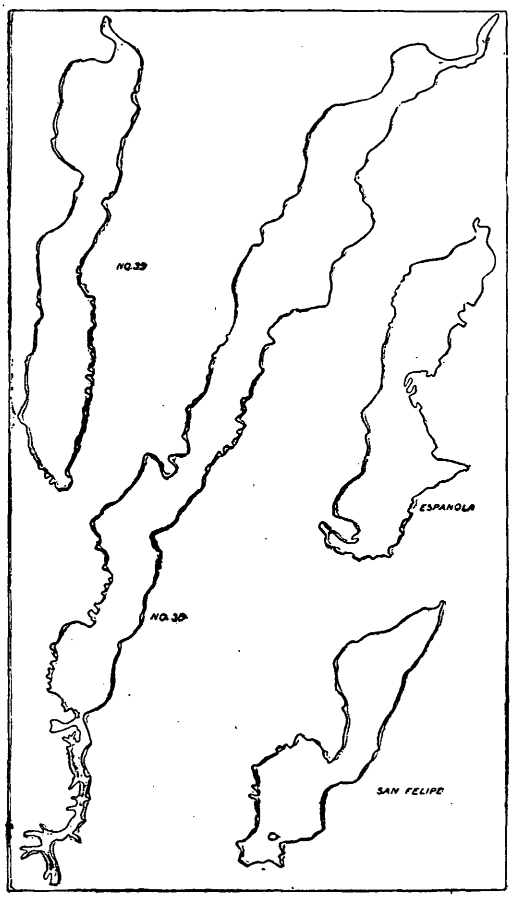


FIG. 10.—Espanola Valley reservoirs Nos. 29, 38, and 39, and San Felipe reservoir, New Mexico.

The Assouan dam is to be straight, 6,398 feet long, and founded throughout of solid granite. The greatest height will be 92 feet, with 66 feet maximum head against the dam. The dam is 23 feet wide on top and 80 feet wide at the bottom. These dimensions meet the requirement that the maximum theoretical pressure on the downstream toe of the dam shall not exceed 1,025 pounds per square foot. The dam is not to be submerged. It is pierced with 140 under sluices, each 6.6 feet wide by 23 feet high, and by 40 upper sluices, of half this area; all of the upper and 20 of the under sluices to be lined with cast iron. During the flood season all of these sluices will be open and the whole flood of the Nile will be discharged through them, the extraordinary maximum discharge being 494,400 second-feet, the mean maximum 353,140 second-feet. The under sluices will be regulated by Stoney's self-balancing gates.

Navigation around the dam will be provided for by a canal 5,250 feet long, on the left bank of the Nile. This canal will have four locks, and will be partly in the solid rock and partly between banks. It will have a bottom width of 49 feet. Three of the locks will have

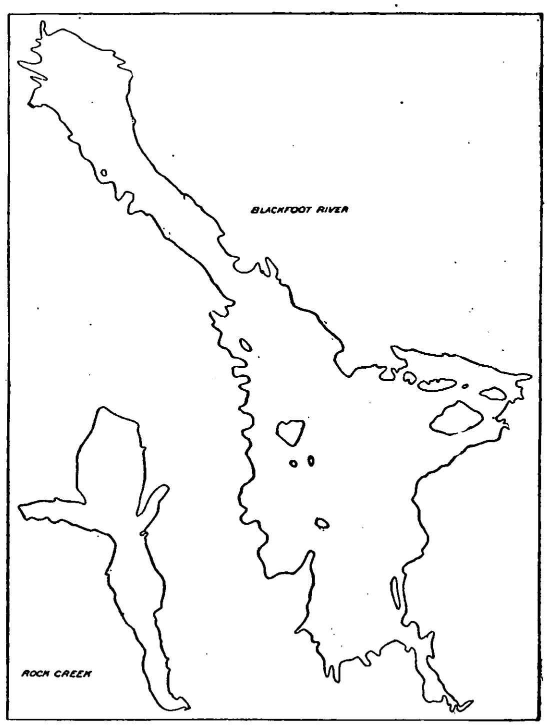


FIG. 11.—Blackfoot reservoir, Idaho, and Rock Creek reservoir, Nevada.

a rise of 20 feet each, and one of them a rise of 10 feet. Each lock will be 246 feet long in the clear and 31 feet wide. The height of the lock gates will range from 62 to 20 feet, as the canal must be used when the dam is full as well as when it is empty.

In order to properly utilize the water stored by the Assouan dam, it became necessary to construct the Assiout barrage across the Nile, 331 miles below the dam and below the mouth of the Ibrahimia Canal, and to place a regulator at the mouth of the canal. This barrage will consist of 120 openings of 16.4 feet each, with piers 6.6 feet wide between. There is also a lock 262 feet by 52.5 feet, sufficient to pass the largest steamers on the Nile.

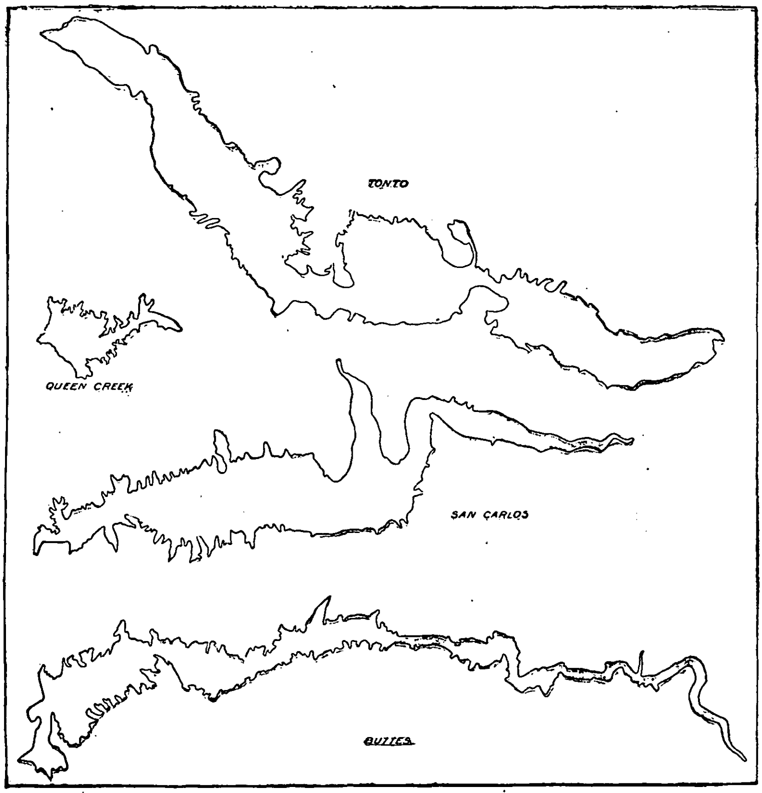


FIG. 12.—Tonto, Queen Creek, San Carlos, and Buttes reservoirs, Arizona.

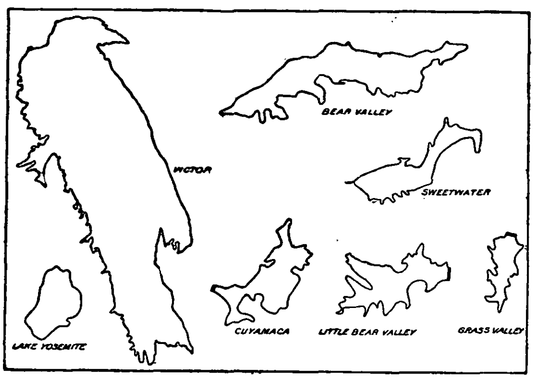


FIG. 13.—Cuyamaca, Little Bear Valley, Grass Valley, Lake Yosemite, Sweetwater, Bear Valley, and Victor reservoirs, California.

The estimated cost of the work is as follows:

Assouan reservoir:	
Dam	£834,000
Lock	143,000
Contingencies	40,700
Land, etc	248,000
Assiout barrage:	
Regulator	333,700
Lock	74,600
Ibrahimia Canal head:	
Regulator	32,900
Lock	36,100
Contingencies	7,000
Total	1,750,000

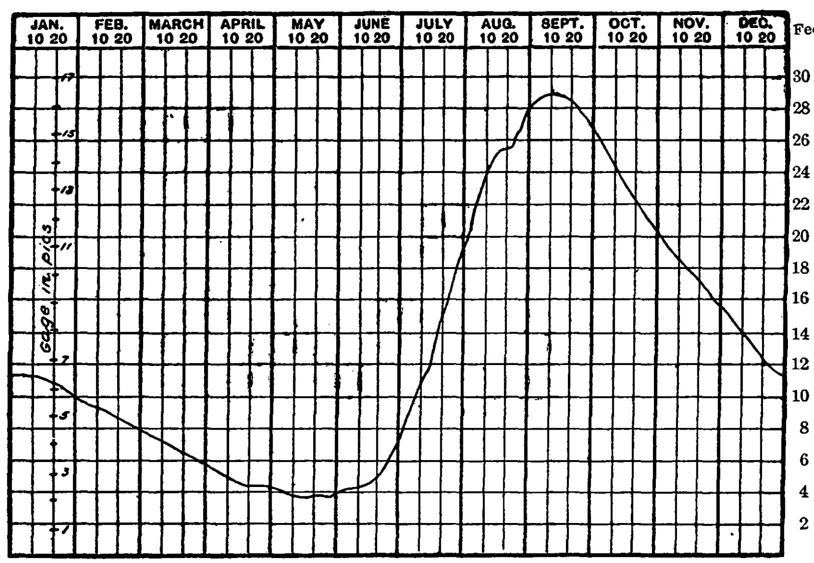


FIG. 14.—Diagram of gage records, mean for ten years (1874-1883), of River Nile at Assouan, Egypt.

NORTHERN ATLANTIC COAST DRAINAGE.

Under this heading have been included data concerning the rivers entering the Atlantic Ocean from Maine to Virginia, inclusive, an arbitrary line being drawn between James River and Roanoke River, the latter being included under the Southern Atlantic coast drainage.

The rivers of New England have been studied by Prof. Dwight Porter, as noted in previous publications, the results for Maine having been printed in the Nineteenth Annual Report, Part IV. Similar facts for the southern rivers of this area have been brought together for the next annual report. Additional figures of discharge have also been obtained for Kennebec and Androscoggin rivers, from engineers of companies owning water powers along those streams.

KENNEBEC RIVER.

This river has its source in Moosehead Lake, the largest in New England, on the west border of Piscataquis County. It runs southward through Somerset, Kennebec, and Sagadahoc counties, and dis-

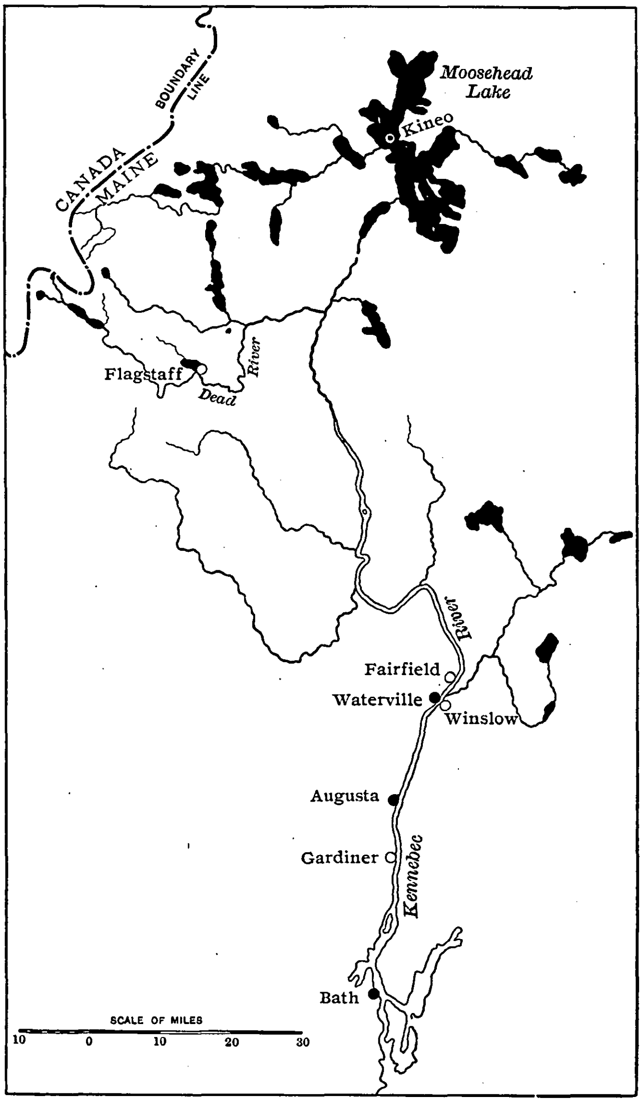


FIG. 15.—Drainage basin of Kennebec River.

charges into the Atlantic Ocean 35 miles northeast of Portland. During two-thirds of the year the river is navigable from its mouth to Augusta, a distance of 26 miles. The upper basin is heavily timbered, and though less elevated than that of the Androscoggin, to the west, is mountainous in character and includes various isolated peaks which are among the highest in the State. In the mountainous portions the soil is sandy and gravelly, succeeded by a greater proportion of loam and clay to the southward. Computations of discharge are made at Waterville, Maine, by James L. Dean, engineer of the Hollingsworth and Whitney Company.

Estimated monthly discharge of Kennebec River at Waterville, Maine.

[Drainage area, 4,410 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January	5,434	1,738	3,213	197,560	0.73	0.84
February	4,387	2,133	3,402	188,937	0.77	0.80
March	27,432	12,997	11,287	694,011	2.56	2.95
April	52,119	6,563	29,833	1,775,187	6.76	7.54
May	39,372	14,611	25,120	1,544,569	5.70	6.57
June	14,341	4,326	9,983	594,030	2.26	2.52
July	5,464	1,745	3,908	240,294	0.89	1.02
August	4,432	913	3,133	192,641	0.71	0.82
September	5,443	1,437	2,618	155,782	0.59	0.65
October	15,319	961	4,047	248,840	0.92	1.06
November	10,037	2,758	5,178	308,112	1.17	1.31
December	3,752	1,723	2,620	161,098	0.59	0.68
The year	52,119	913	8,695	6,301,061	1.97	26.76
1899.						
January	2,757	1,245	2,357	144,926	0.53	0.61
February	3,362	1,420	2,364	131,290	0.54	0.56
March	6,820	1,960	3,218	197,867	0.73	0.84
April	45,422	5,945	23,429	1,394,122	5.31	5.93
May	41,348	11,380	21,228	1,305,259	4.81	5.54
June	13,292	5,593	8,807	524,053	2.00	2.23
July	6,386	2,400	5,036	309,652	1.14	1.31
August	4,968	1,620	3,217	197,806	0.73	0.84
September	2,565	1,200	1,906	113,415	0.43	0.48
October	1,823	561	1,224	75,261	0.28	0.32
November	4,025	1,100	2,021	120,258	0.46	0.52
December	4,898	900	2,254	138,593	0.51	0.59
The year	45,422	561	6,422	4,652,502	1.46	19.77

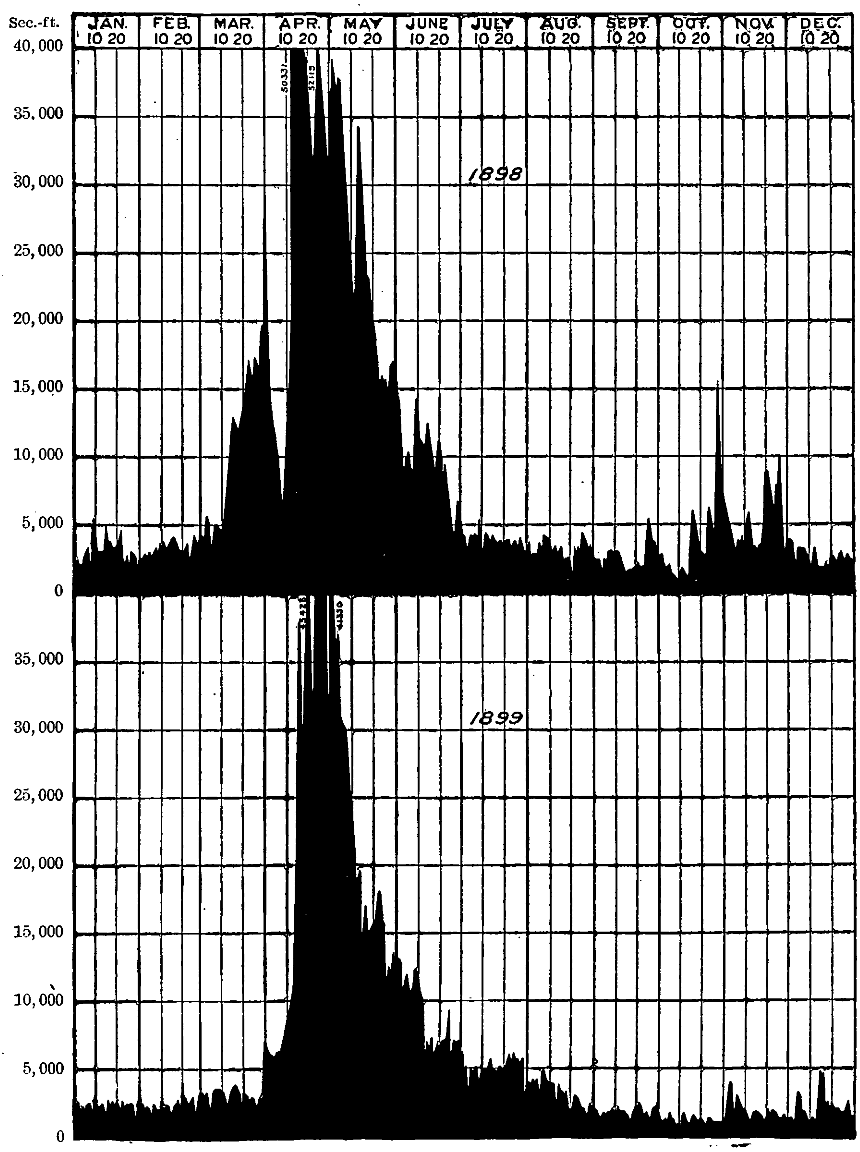


FIG. 16.—Discharge of Kennebec River at Waterville, Maine, 1898 and 1899.

COBBOSSEECONTEE RIVER.

This river is the outlet of Cobbosseecontee Waters, a beautiful sheet of water in the southern part of Kennebec County, Maine. It empties into Kennebec River 8 miles below Augusta. Measurements are made at the reservoir dam in Gardiner by Alexander H. Twombly, engineer of the Forest Paper Company, Yarmouthville, Maine.

Estimated monthly discharge of Cobbosseecontee River near Augusta, Maine.

[Drainage area, 230 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
January	250	250	250	15,372	1.09	1.29
February	250	250	250	13,884	1.09	1.13
March	306	250	252	15,495	1.10	1.27
April	650	14	438	26,063	1.91	2.13
May	914	6	425	26,132	1.85	2.13
June	679	6	397	23,624	1.73	1.93
July	280	100	273	16,786	1.19	1.37
August	280	280	280	17,217	1.22	1.41
September	280	280	280	16,661	1.22	1.39
October	280	270	276	16,971	1.20	1.38
November	270	270	270	16,066	1.17	1.31
December	280	21	265	16,294	1.15	1.33
The year	914	6	305	220,565	1.33	18.07
1898.						
January	280	280	280	17,217	1.22	1.41
February	504	280	324	17,994	1.41	1.47
March	1,261	387	843	51,834	3.67	4.23
April	1,038	326	633	37,666	2.75	3.06
May	478	273	337	20,721	1.47	1.69
June	280	280	280	16,661	1.22	1.36
July	280	19	270	16,602	1.17	1.35
August	280	270	275	16,909	1.20	1.38
September	270	250	252	14,995	1.10	1.23
October	250	220	238	14,634	1.03	1.19
November	250	250	250	14,876	1.09	1.22
December	270	250	268	16,479	1.17	1.35
The year	1,261	19	354	256,588	1.54	20.94
1899.						
January	270	270	270	16,602	1.17	1.35
February	270	270	270	14,995	1.17	1.22
March	270	270	270	16,602	1.17	1.35
April	1,427	300	803	47,782	3.44	3.84
May	300	20	281	17,278	1.22	1.41
June	280	280	280	16,661	1.21	1.35
July	280	19	270	16,602	1.17	1.35
August	280	270	275	16,909	1.15	1.33
September	270	220	252	14,995	2.40	2.68
November	180	150	162	9,640	0.70	0.78
December	180	120	144	8,854	0.63	0.69

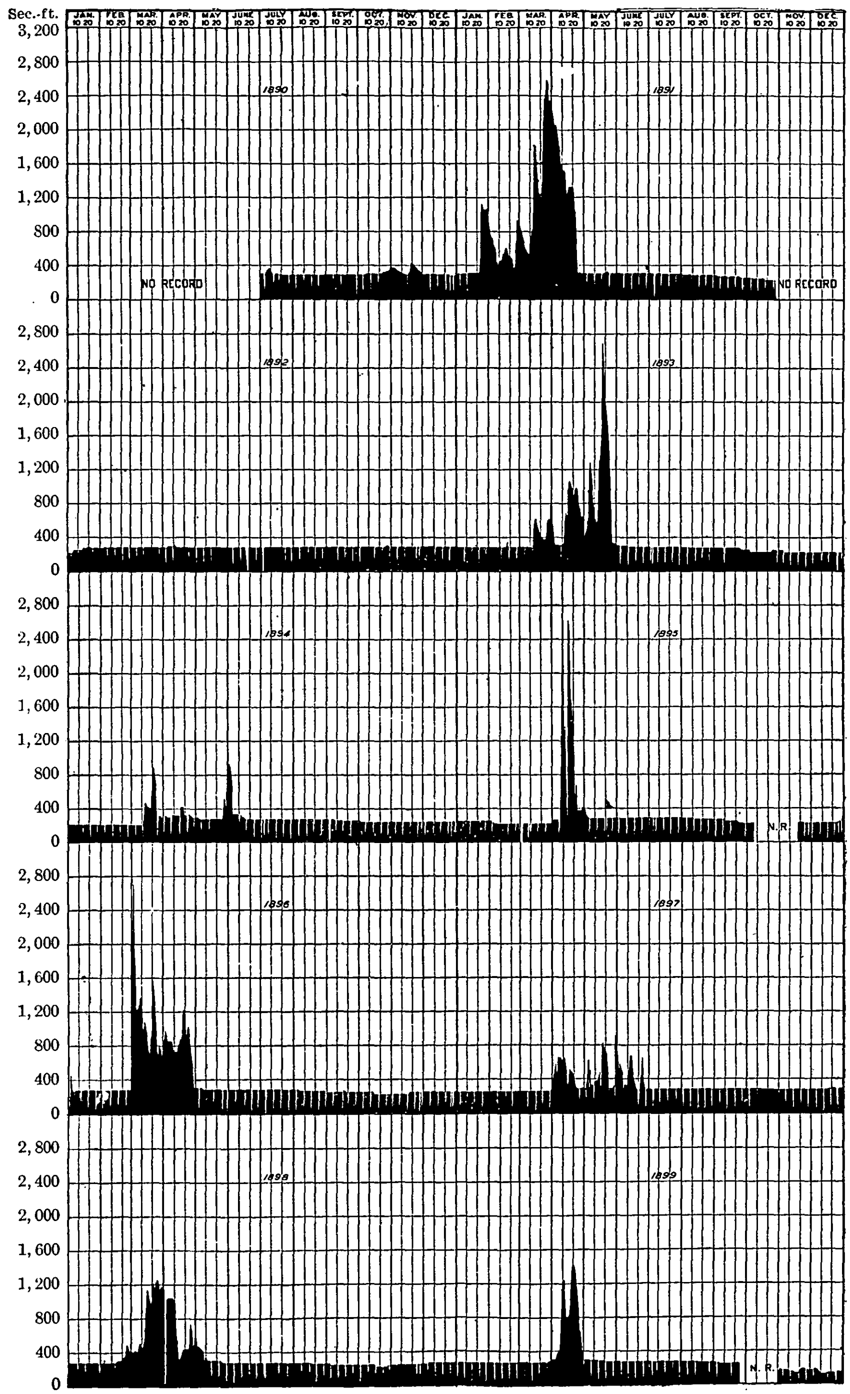


FIG. 17.—Discharge of Cobbosseecontee River near Augusta, Maine. Water shut back entirely on Sundays; controlled by storage.

ANDROSCOGGIN RIVER.

This river receives the drainage from the Umbagog-Rangeley chain of lakes, near the border line between Maine and New Hampshire. It flows in a general southerly and southeasterly direction, descending with rapid fall and furnishing considerable power. The lower part of the basin is hilly and moderately wooded, while the upper two-

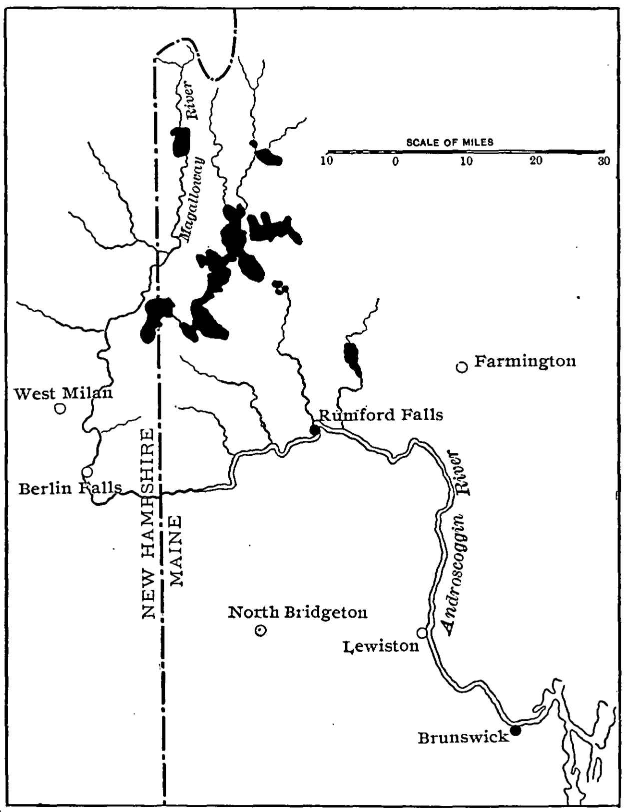
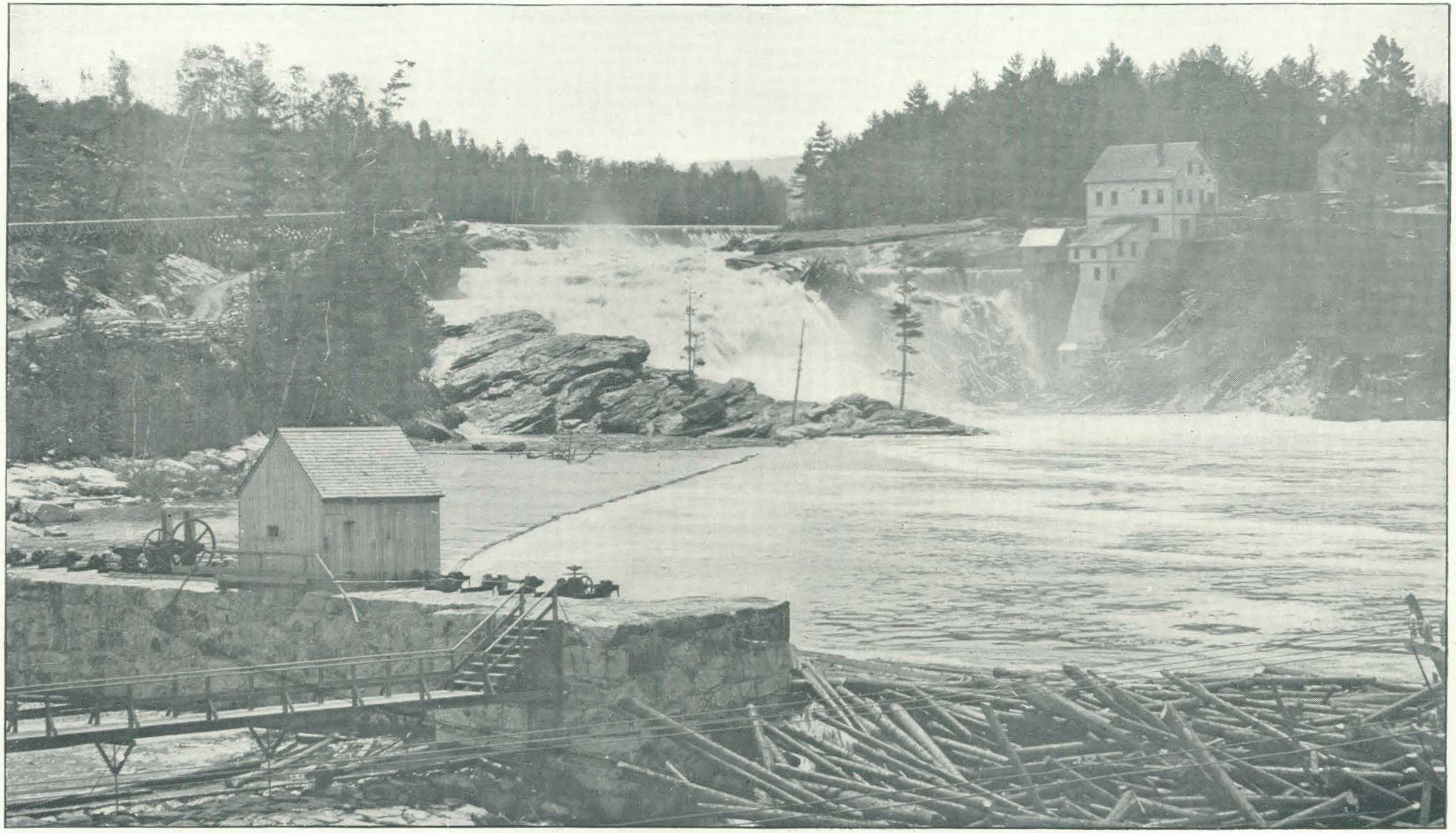


FIG. 18.—Drainage basin of Androscoggin River.

thirds is very broken and mountainous, heavily timbered, and with a gravelly and sandy soil. The entire fall of the river, from the level of Umbagog Lake to tide water at Brunswick, amounts to about 1,250 feet. At three important points there are large falls, namely, at Lewiston, at Rumford Falls, and at Berlin Falls. At Rumford Falls discharge measurements have been made since 1892 by Charles A. Mixer, resident engineer of the Rumford Falls Power Company. Pl. I shows the upper and lower dams at Rumford Falls, Maine.



UPPER AND LOWER DAMS AT RUMFORD FALLS, MAINE.

Estimated monthly discharge of Androscoggin River at Rumford Falls, Maine.

[Drainage area, 2,320 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.		Rainfall in inches.
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.	
1899.							
January	2,675	1,697	2,111	129,801	0.98	1.05	3.18
February	2,111	1,462	1,843	192,355	0.80	0.82	2.56
March	2,037	1,646	1,848	113,630	0.80	0.92	5.89
April	23,287	1,974	8,709	518,220	3.79	4.19	1.50
May	24,077	3,849	10,114	621,890	4.40	5.03	1.89
June	3,773	2,717	3,238	192,674	1.41	1.56	2.27
July	3,682	1,142	1,817	111,724	0.79	0.90	4.71
August	1,758	1,209	1,428	87,805	0.62	0.71	0.64
September	2,971	1,124	1,580	94,016	0.69	0.76	3.00
October	2,767	1,230	1,604	98,627	0.70	0.80	2.05
November	3,172	1,170	1,733	103,120	0.75	0.83	1.94
December	5,274	1,010	1,606	98,750	0.70	0.80	1.95
The year	24,077	1,010	3,135	2,272,612	1.36	18.37	31.58

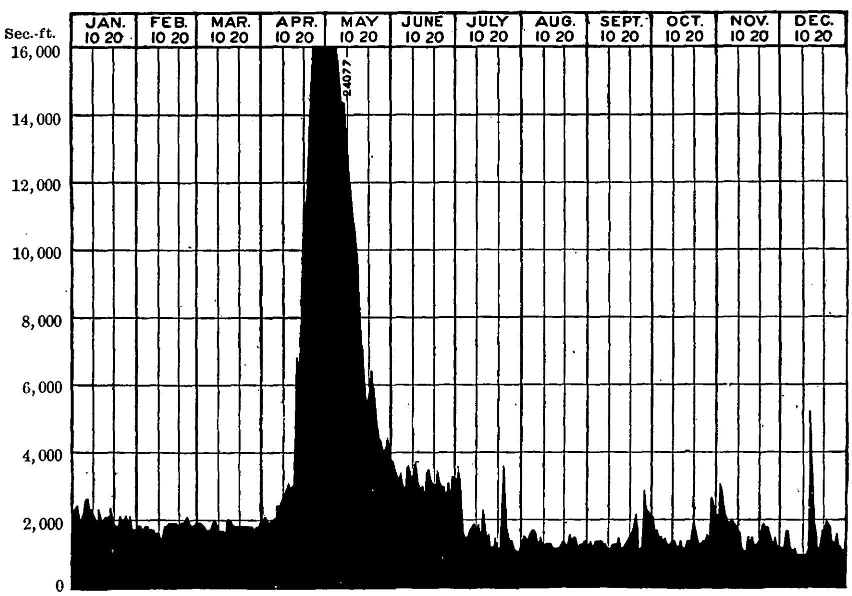


FIG. 19.—Discharge of Androscoggin River at Rumford Falls, Maine, 1899.

MERRIMAC RIVER.

The Merrimac rises in New Hampshire, among the Franconia Mountains, and runs nearly southward, through Merrimack and Hillsboro

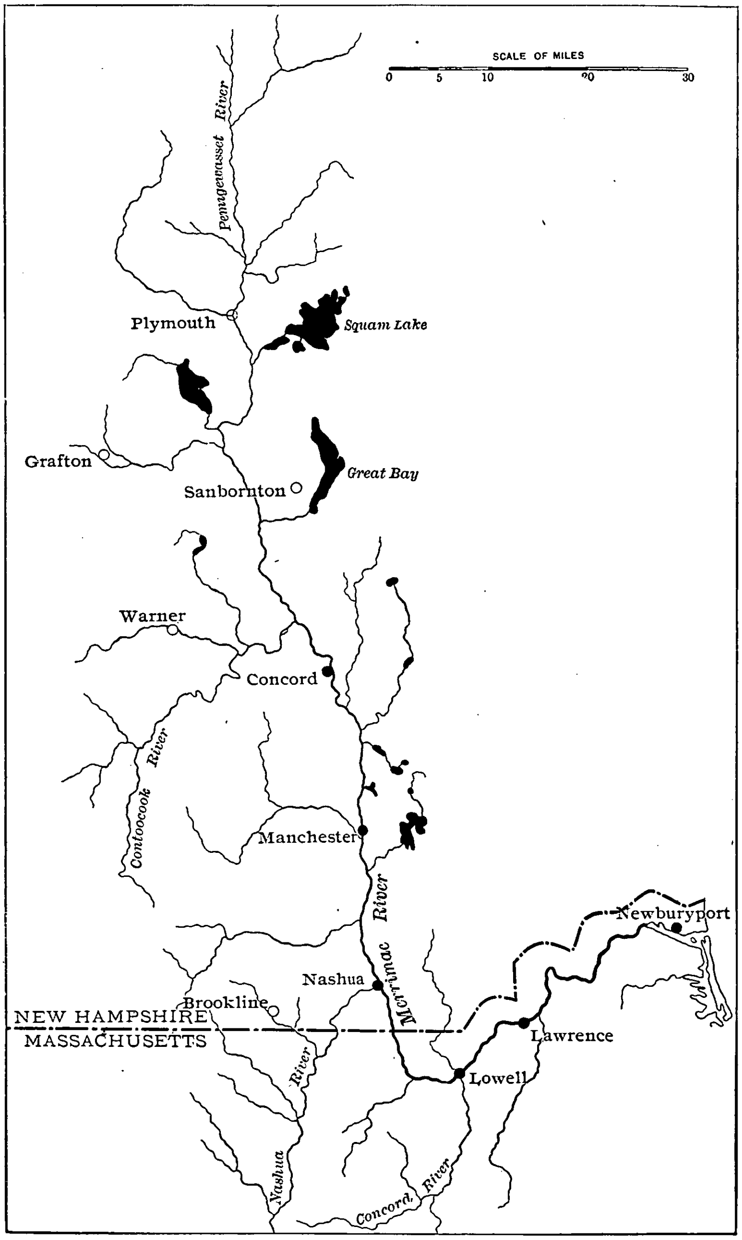


FIG. 20.—Drainage basin of Merrimac River.

counties, passing into Middlesex County, and through Essex County, Massachusetts. It enters the Atlantic Ocean about 2 miles below Newburyport. Its estimated length, exclusive of the Pemigewasset, is 150 miles. The fall of the stream is considerable, and developments of water power have taken place to an extent probably greater than in any other part of the United States. The records of river flow at Lawrence, Massachusetts, extend over a period of a half century. A daily observation of the height of Merrimac River below the Essex Company's dam at Lawrence was made by Mr. Charles S. Storrow, agent and engineer of the Essex Company, from 1848 to 1870, from which an approximate estimate of the flow can be made for those years. Uncertainties regarding the condition of the ice in the 7-mile reach below the gage render the winter observations of less value than those of the other months. From 1870 to the present time measurements of the quantity of water going over the dam and through the mills have been made by Mr. Hiram F. Mills, chief engineer of the Essex Company, from whom the results of computations of daily discharge for recent years, as shown in Water-Supply Paper No. 35, beginning on page 35, have been obtained.

In November, 1852, Mr. James B. Francis made five experiments on the flow over a dam 10 feet long, having a profile similar to that of the upper part of the Essex Company's dam. The results are given in the publication entitled Lowell Hydraulic Experiments, pages 136 and 137. These results were applied to the observations of the heights for the year 1849, taken on the crest of the Essex Company's dam, and the flow of the river for that year was found to be very nearly 50 per cent of the rainfall upon the drainage area.

After that time the mills drew water in unknown quantities until Mr. Hiram F. Mills took charge of the mills for the Essex Company and began the series of measurements above referred to.

Wachusett reservoir is located near Clinton, Massachusetts, and receives the drainage from 118.23 square miles on the headwaters of Nashua River, a tributary of the Merrimac. When completed it will flood 4,195 acres, and will contain, when full, 8,431,000 cubic feet or 63,000,000 gallons of water. Construction work upon the reservoir was begun in 1897 and it will probably be completed in 1905, at a cost, in round numbers, of $9,000,000, which includes the land and improvements taken as well as the construction of the dam and subsidiary dikes and the removal of all surface soil from the site of the reservoir.

Estimated monthly discharge of Merrimac River at Lawrence, Massachusetts.

[Drainage area, 4,553 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	11,519	5,504	7,857	483,108	1.73	1.99
February	7,098	3,075	4,882	271,133	1.07	1.11
March	18,900	6,837	11,948	734,654	2.62	3.02
April	38,200	14,590	26,438	1,573,170	5.81	6.48
May	23,647	3,543	9,528	585,854	2.09	2.41
June	4,430	1,134	2,980	177,322	0.65	0.72
July	3,984	387	2,481	152,551	0.54	0.62
August	3,604	78	2,086	128,263	0.46	0.53
September	3,359	69	1,994	118,651	0.44	0.49
October	3,156	50	1,789	110,001	0.39	0.45
November	4,645	548	2,792	166,136	0.61	0.68
December	5,051	593	2,797	171,981	0.61	0.70
The year	38,200	50	6,464	4,672,824	1.42	19.20

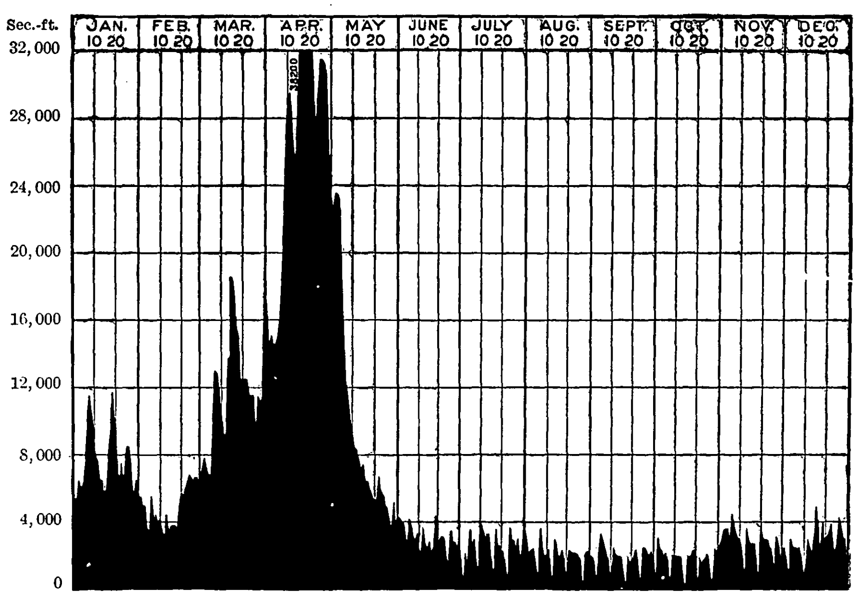


FIG. 21.—Discharge of Merrimac River at Lawrence, Massachusetts, 1899.

SUDBURY RIVER.

This small stream of eastern Massachusetts receives water from an area west of Framingham. It flows in a northerly direction, through meadows and swamps, and joins Assabet River to form Concord River, which in turn continues to the north, entering Merrimac River immediately below the city of Lowell. Storage reservoirs which have been constructed by the city of Boston control the greater part of the flow from this basin. The available water has been systematically measured by Mr. Desmond Fitzgerald, the record beginning in 1875. The run-off in cubic feet per second, by months, from 1875 to 1898, is given

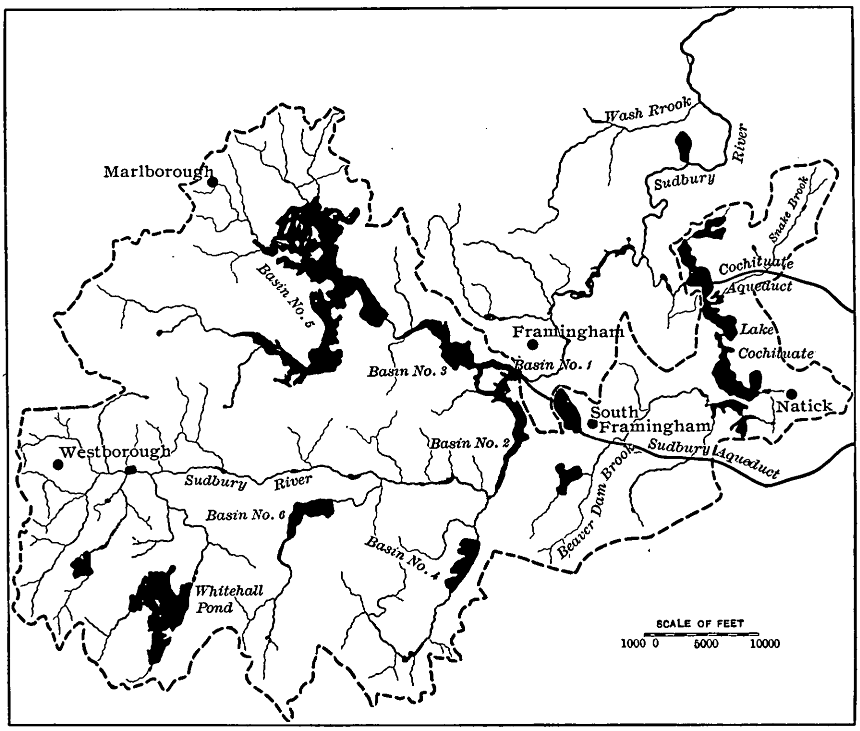


FIG. 22.—Drainage basin of Sudbury River.

in the Twentieth Annual Report, Part IV, page 75; that for 1899 in Water-Supply and Irrigation Paper No. 35, page 37. Fig. 22 is a map of the discharge basin of Sudbury River. Lake Cochituate drains into the river below the point of diversion for the water supply of the city of Boston, and has been considered as a separate watershed, with an area of 18.87 square miles, of which 7.6 per cent is water surface. Dudley Pond, which lies just north of the lake, is connected with it, and water from it is occasionally drawn into the lake. The watershed of this pond is not included in the 18.87 square miles. Figures of catchment on this area since 1863 are available, although not considered quite so accurate as those for Sudbury River.

CONNECTICUT RIVER.

This river rises in northern New Hampshire and Vermont and flows in a general southerly direction, forming the greater part of the boundary between those States. Crossing Massachusetts and Connecticut, it empties into Long Island Sound. Fig. 23 is a map of the drainage basin. Occasional measurements of flow have been made at Hanover, New Hampshire, by students acting under the direction of Dr. Robert Fletcher, professor of civil engineering of the Thayer School, connected with Dartmouth College. The object is mainly for instruction, rather than to determine the actual flow of the stream. The discharge is modified by the dam of a paper mill at Olcott Falls, Wilder, Vermont, about 2½ miles below the point of measurement. The backwater extends about 8 miles above this point, and the measurements are therefore influenced by the draft through the mill turbines, resulting in many discrepancies in the figures. The mills were put in operation in 1884, and all observations since 1883 are thus possibly affected. The measurements are made by means of weighted pine rod floats 1¼ inches square, with sheet lead attached to the sides so as to have the center of gravity relatively high. The measurements previous to 1882, when the works at Olcott Falls were put in operation, are free from errors due to draft of turbines. The record of about 1,000 cubic feet per second is for a gaging made at a time of exceptionally low water, and is believed to represent the minimum discharge.

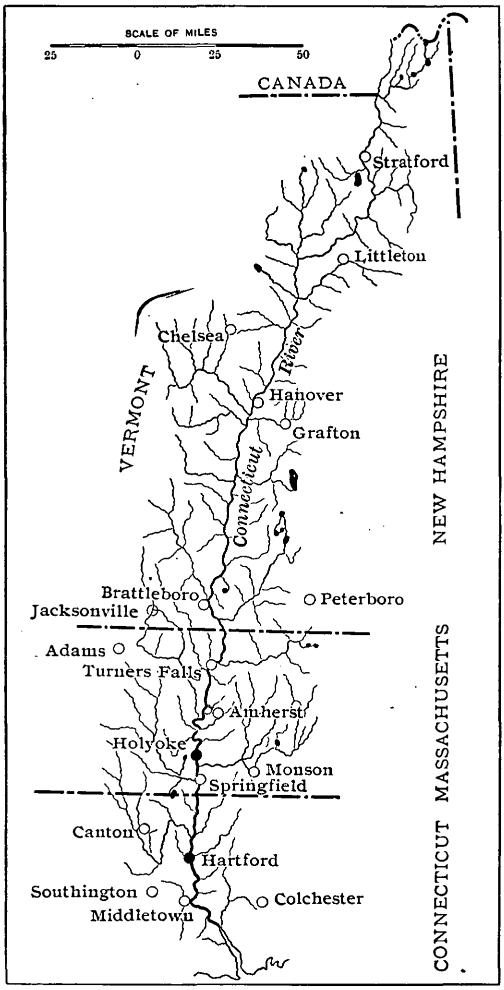
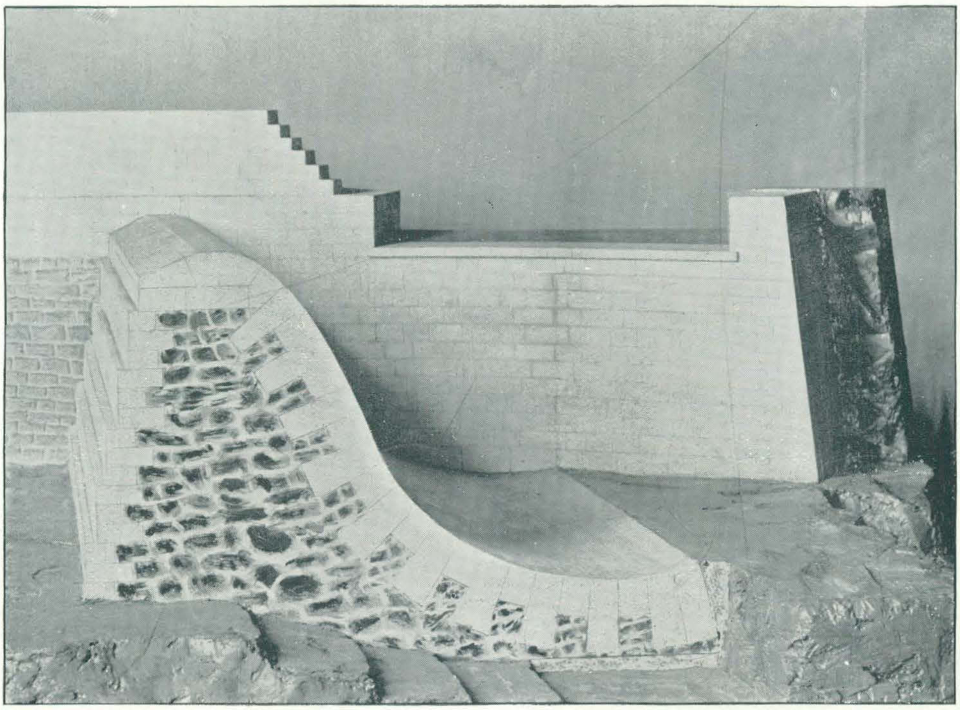


FIG. 23.—Drainage basin of Connecticut River.

A. STONE DAM AT HOLYOKE, MASSACHUSETTS, WITH 2 FEET OF WATER ON CREST.



B. SECTION OF DAM AT HOLYOKE, MASSACHUSETTS.

Discharge measurements made on Connecticut River at Hanover, New Hampshire.

Date.	Number of velocity observations.	Gage height.	Area of section.	Mean velocity.	Discharge.
1878.		*Feet.*	*Square feet.*	*Feet per sec.*	*Second-feet.*
September 20 to 21	....	....	2,244	0.573	1,287
1880.					
August 18	....	....	2,152	Discarded	....
October 9	7	....	2,453	0.416	1,020
October 26	12	....	3,401	1.48	5,033
1881.					
June 9	9	....	3,255	1.00	3,255
October 14	15	....	2,674	0.453	1,211
October 21	23	....	3,398	1.197	4,074
1883.					
October 12	22	a5.3	4,009	0.331	1,327
1884.					
September 25	13	5.7	4,025	0.500	2,000
1885.					
October 15	27	5.6	4,421	0.52	2,390
1886.					
October 12	22	5.5	4,325	0.365	1,581
1888.					
October 19	25	7.75	4,835	1.59	7,680
1889.					
October 4	17	9.65	5,150	2.77	14,296
1894.					
October 2	19	5.1	4,436	0.335	1,360
1895.					
September 25	12	6.3	4,300	0.314	1,350
1896.					
October 12	12	7.2+	4,780	0.585	2,800
1897.					
September 30	14	6.75	4,810	....	b2,680

a Mean heights during about four and one-half or five hours.
b Not reliable.

Pl. II, *A*, is a view of stone dam at Holyoke, Massachusetts, with 2 feet of water on crest. Pl. II, *B*, shows a section of the dam.

MOHAWK RIVER AND TRIBUTARY CREEKS.

The Mohawk rises in Lewis County, New York, and flows southerly through Oneida County, then turns to the east, and finally empties into Hudson River at Cohoes. Two or 3 miles from its mouth it forms a cascade 70 feet high, called Cohoes Falls. The river is nearly 175 miles long. Its valley is remarkable for its beauty and fertility. Gaging stations are maintained on the main river at Ridge Mills, at

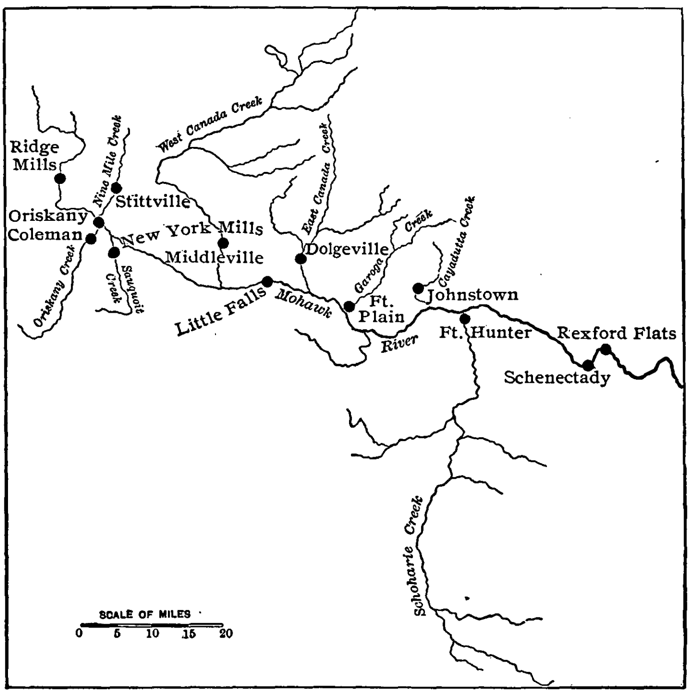
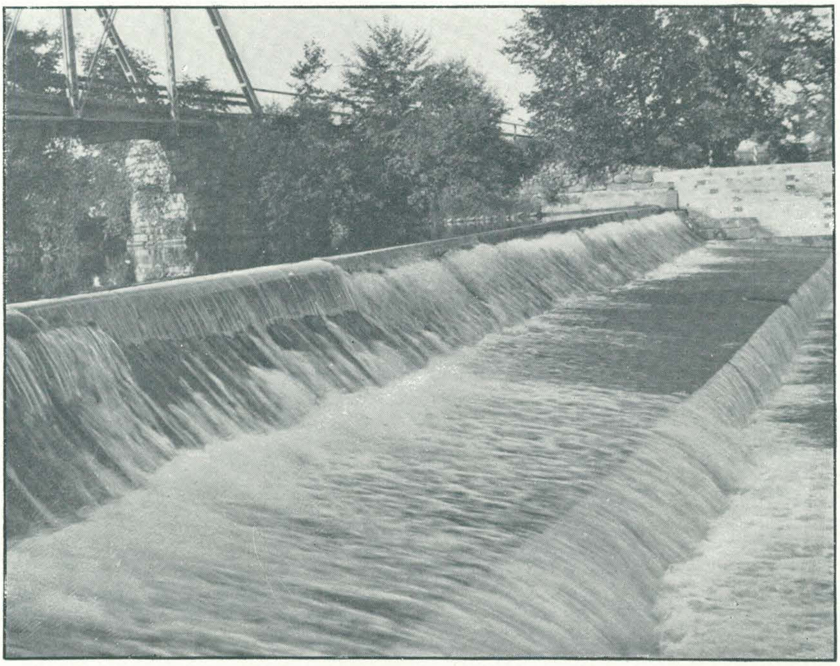
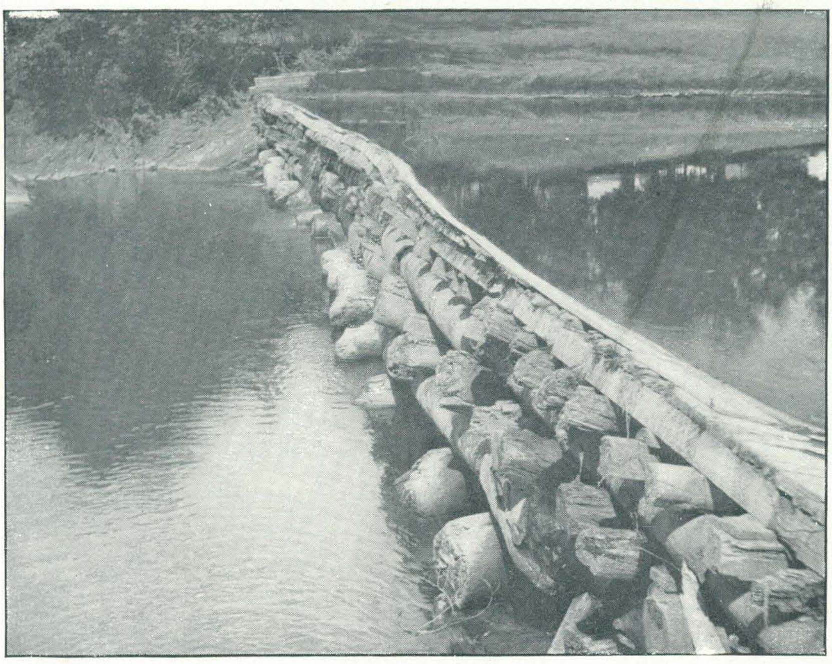


FIG. 24.—Drainage basin of Mohawk River.

Little Falls, at Schenectady, and at Rexford Flats. Of its tributary streams measurements have been made of Ninemile Creek at Stittville, of Oriskany Creek at Oriskany and Coleman, of Sauquoit Creek at New York Mills, of West Canada Creek at Middleville, of East Canada Creek at Dolgeville, of Cayadutta Creek at Johnstown, of Garoga Creek at Fort Plain, and of Schoharie Creek at Fort Hunter, all in the State of New York. The hydrographs on the following pages show the fluctuations of these tributary streams, the tables of monthly flow for some of them having been withheld for revision. Pls. III and IV and Pl. V, *A*, are views of dams on Mohawk River and its tributaries.



A. ROME WATERWORKS DAM ON MOHAWK RIVER AT RIDGE MILLS, NEW YORK.



B. DAM ON NINEMILE CREEK AT STITTVILLE, NEW YORK.

Estimated monthly discharge of Mohawk River at Ridge Mills, New York.

[Drainage area, 153 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
October	1,251	127	369	22,689	2.41	2.77
November	2,134	104	401	23,861	2.62	2.92
December	974	121	261	16,048	1.70	1.96
1899.						
January	2,373	153	377	23,180	2.46	2.83
February	697	123	244	13,551	1.59	1.65
March	1,211	176	467	28,715	3.05	3.52
April	2,226	254	997	59,325	6.52	7.27
May	1,136	94	320	19,676	2.09	2.41
June	402	214	281	16,720	1.83	2.04
July	669	127	310	19,061	2.03	2.33
August	315	121	226	13,896	1.48	1.71
September	135	53	81	4,819	0.52	0.58
October	540	93	278	17,093	1.82	2.10
November	515	205	291	17,315	1.90	2.12
December	3,625	75	532	32,711	3.48	4.01
The year	3,625	53	367	266,062	2.40	32.57

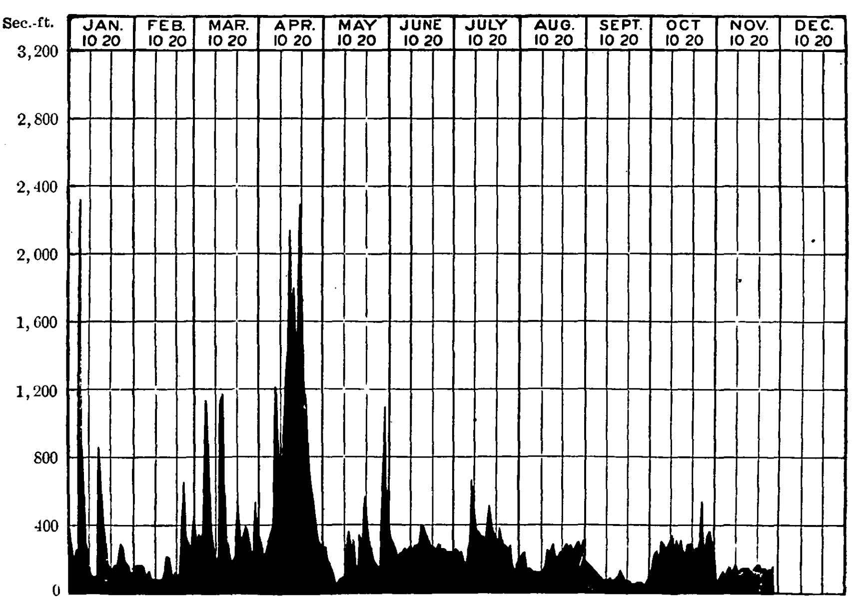


FIG. 25.—Discharge of Mohawk River at Ridge Mills, New York, 1899.

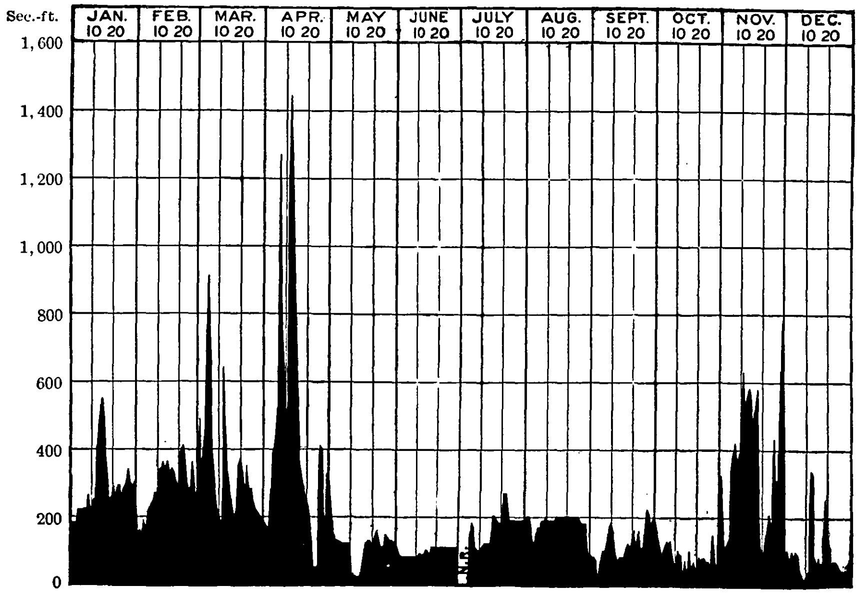


FIG. 26.—Discharge of Oriskany Creek at Oriskany, New York, 1899.

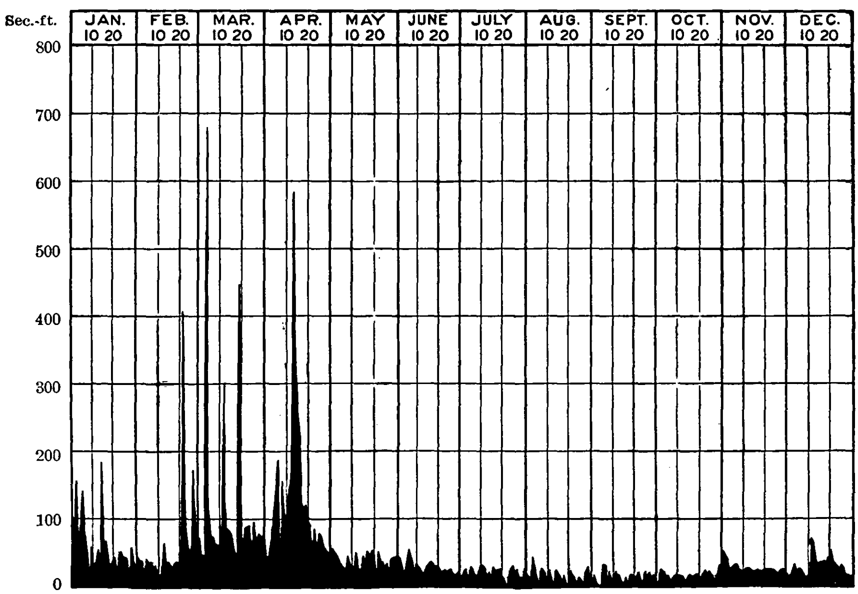
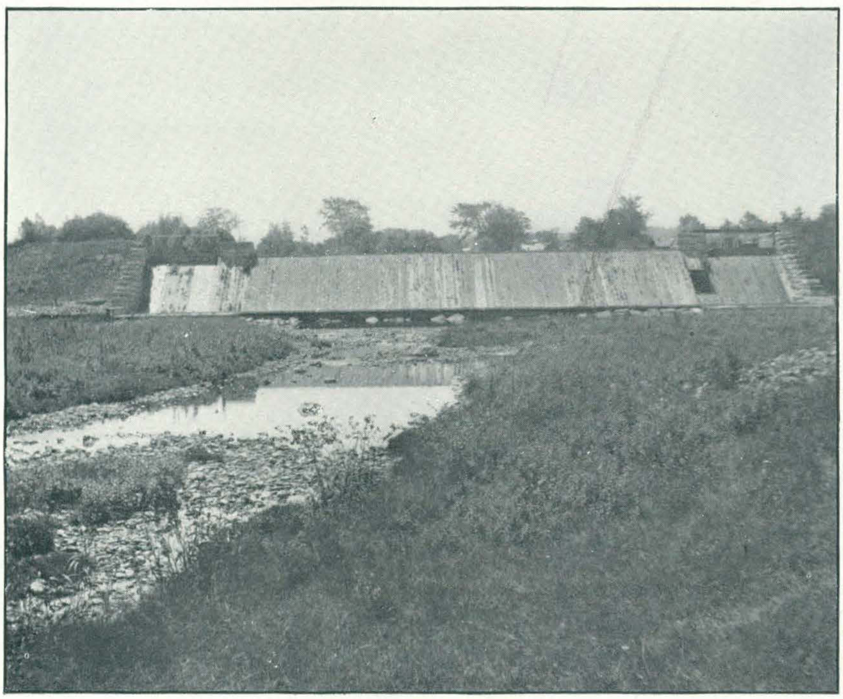


FIG. 27.—Discharge of Sauquoit Creek at New York Mills, New York, 1899.

A. DAM ON ORISKANY CREEK AT ORISKANY, NEW YORK.



B. DAM ON SAUQUOIT CREEK AT NEW YORK MILLS, NEW YORK.

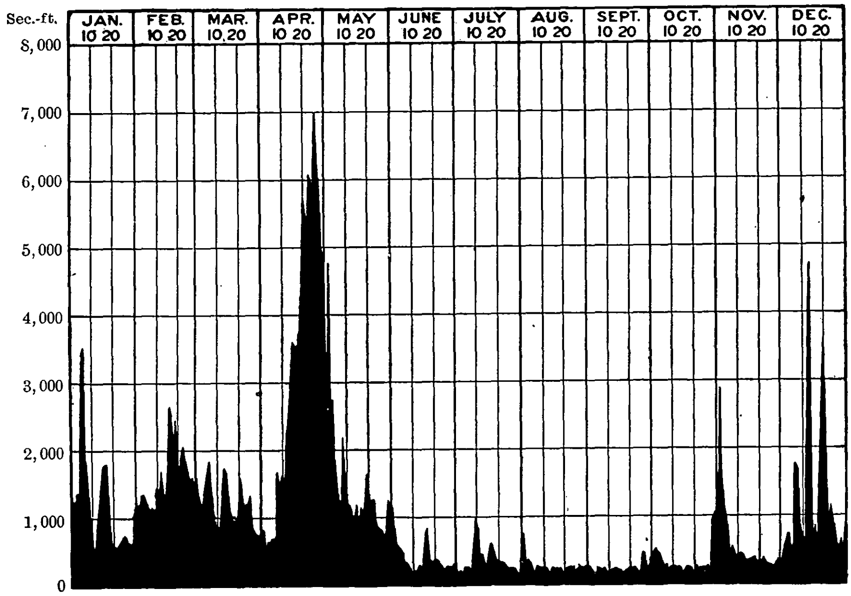


FIG. 28.—Discharge of West Canada Creek at Middleville, New York, 1899.

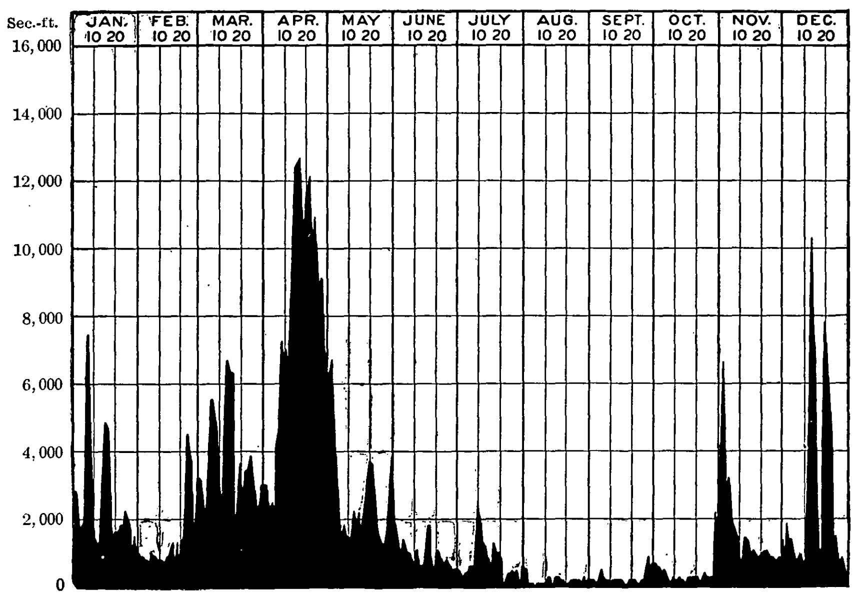


FIG. 29.—Discharge of Mohawk River at Little Falls, New York, 1899.

Estimated monthly discharge of East Canada Creek at Dolgeville, New York.

[Drainage area, 256 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
September	1,180	355	638	37,845	2.49	2.78
October	1,422	213	581	35,724	2.27	2.62
November	1,937	235	689	40,998	2.69	3.00
December	1,275	372	564	34,802	2.20	2.54
1899.						
January	1,942	342	816	50,173	3.19	3.68
February	992	348	439	24,381	1.71	1.78
March	852	372	519	31,912	2.03	2.33
April	4,472	355	1,978	117,699	7.73	8.62
May	1,701	324	633	38,921	2.47	2.84
June	384	112	196	11,663	0.76	0.85
July	394	79	166	10,207	0.65	0.75
August	210	44	97	5,964	0.38	0.44
September	192	67	92	5,474	0.36	0.40
October	372	74	112	6,887	0.44	0.51
November	1,674	134	377	22,433	1.47	1.64
December	3,029	132	706	43,410	2.76	3.18
The year	4,472	44	511	369,124	2.00	27.02

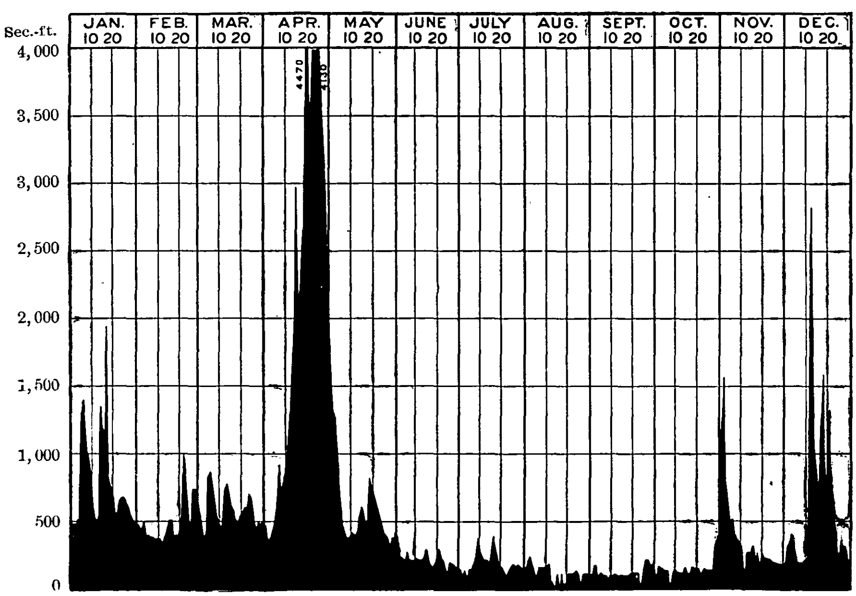


FIG. 30.—Discharge of East Canada Creek at Dolgeville, New York, 1899.

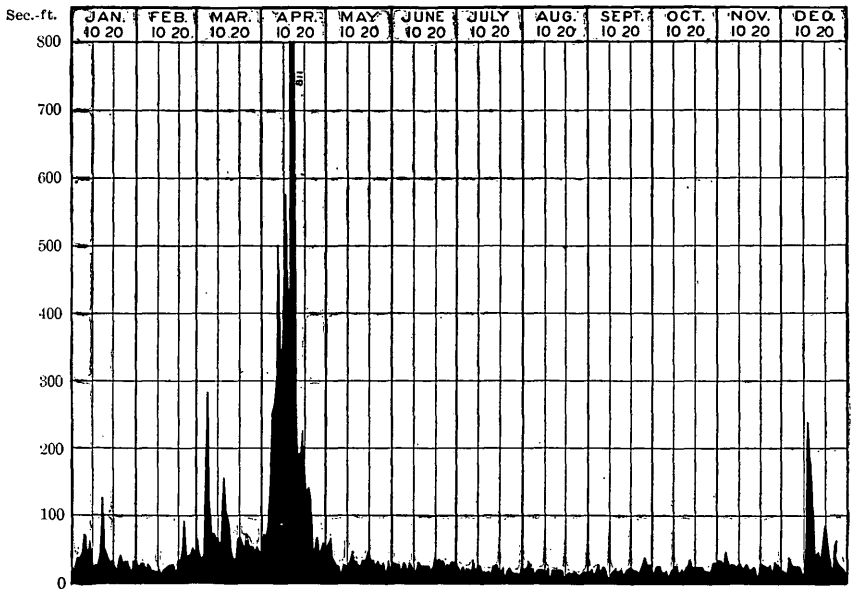


FIG. 31.—Discharge of Cayadutta Creek at Johnstown, New York, 1899.

Estimated monthly discharge of Schoharie Creek at Fort Hunter, New York.

[Drainage area, 947 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
October	3,211	161	1,142	70,219	1.20	1.38
November	9,517	667	2,148	127,815	2.27	2.53
December	3,864	689	1,573	96,720	1.66	1.91
1899.						
January	5,791	941	2,307	141,852	2.43	2.80
February	6,035	657	1,944	107,964	2.05	2.14
March	13,635	1,335	3,792	233,161	4.00	4.61
April	9,335	1,335	4,100	243,967	4.33	4.83
May	1,515	260	579	34,609	0.61	0.70
June	395	195	226	13,091	0.24	0.27
July	202	165	187	11,498	0.20	0.23
August	152	132	142	8,731	0.15	0.17
September	6,984	138	916	54,506	0.97	1.08
October	3,867	587	1,603	98,565	1.69	1.95
November	1,835	295	875	52,066	0.92	1.03

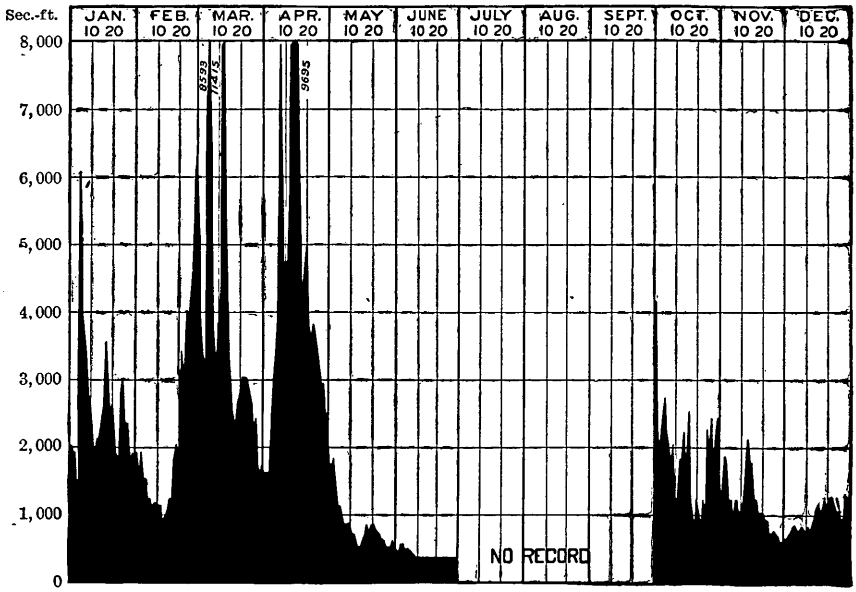


FIG. 32.—Discharge of Schoharie Creek at Fort Hunter, New York, 1899.

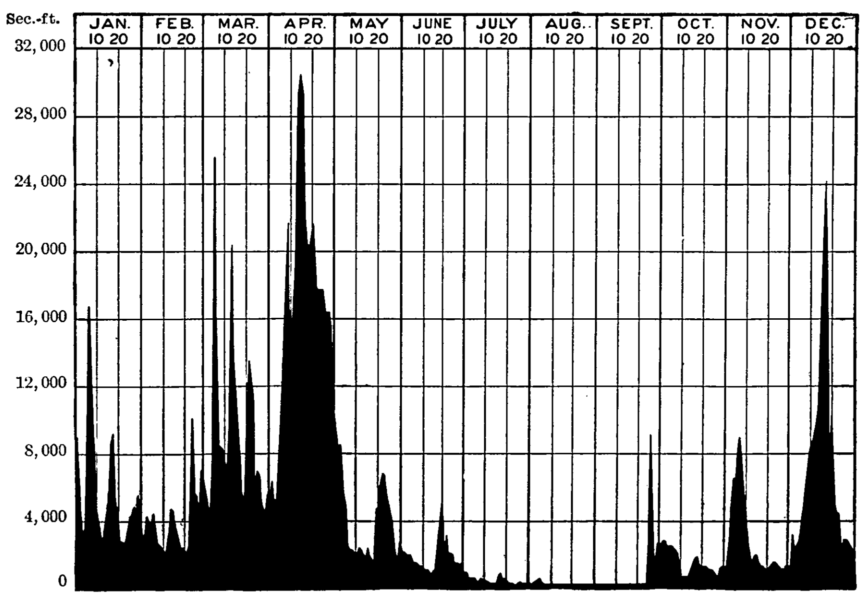


FIG. 33.—Discharge of Mohawk River at Rexford Flats, New York, 1899.

HUDSON RIVER.

This river receives the principal part of its water supply from the eastern slope of the Adirondack Mountains, in the northern part of the State of New York. It flows in a general southerly direction, and receives from the west, as its largest tributary, Mohawk River, which enters near the head of tide water. From this point south the river

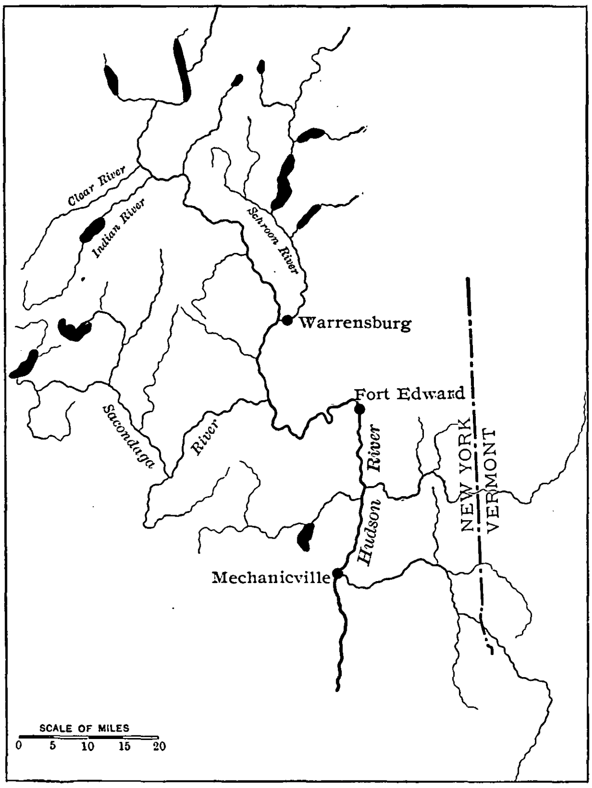


FIG. 34.—Drainage basin of upper Hudson River.

is practically a navigable estuary of the ocean. Computations of the discharge of Hudson River have been made at the dams at Fort Edward and Mechanicsville, and also of Schroon River at Warrensburg. Mohawk River and its tributaries have also been measured, as described on a preceding page. Pl. V, *B*, is a view of the dam on Hudson River at Mechanicsville, New York.

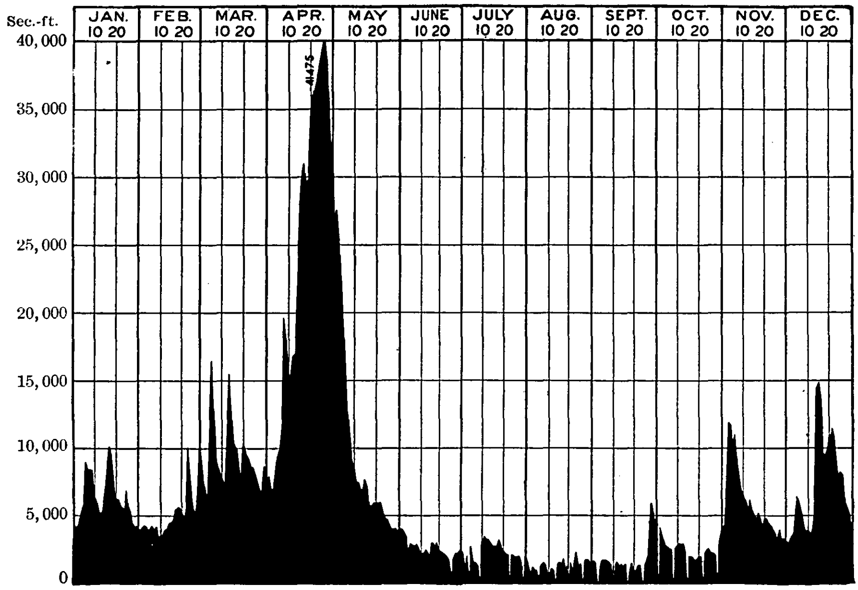
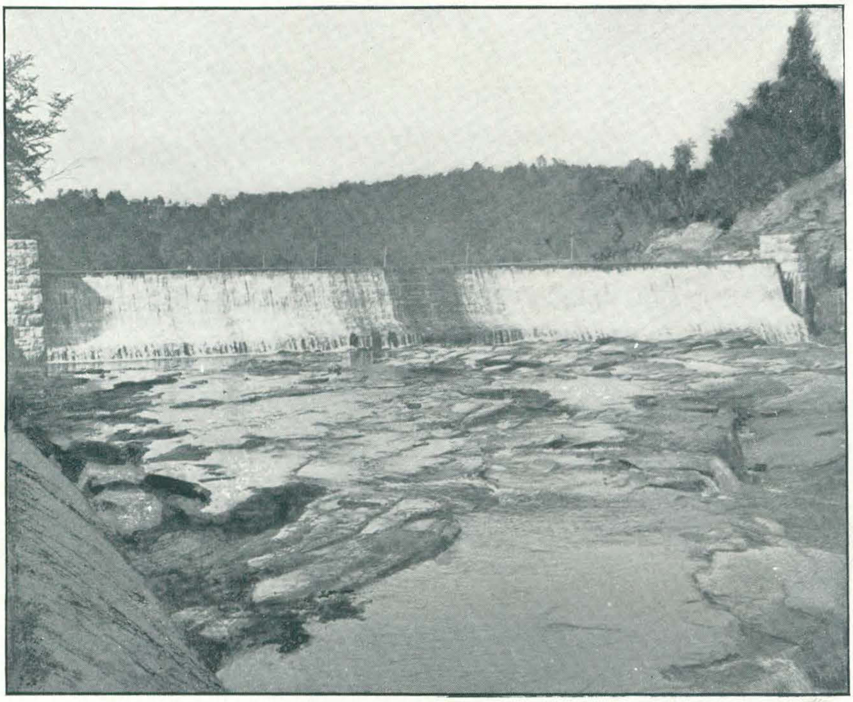


FIG. 35.—Discharge of Hudson River at Mechanicsville, New York, 1899.

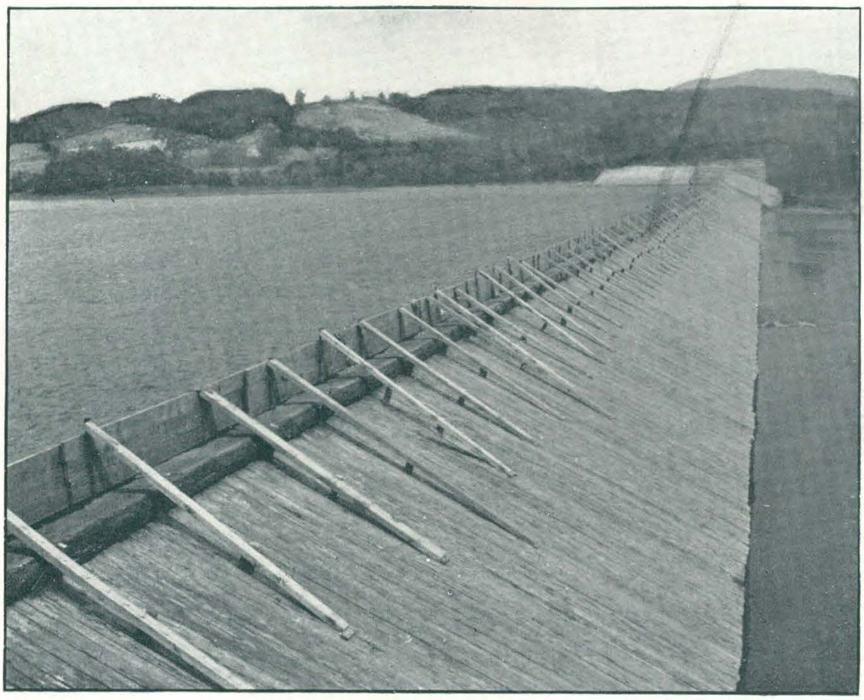
Estimated monthly discharge of Schroon River at Warrensburg, New York.

[Drainage area, 570 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1895.						
November	1,603	156	478	28,443	0.84	0.93
December	4,074	393	1,233	75,814	2.16	2.49
1896.						
January	4,176	1,061	2,779	170,874	4.88	5.62
February	1,014	371	516	28,657	0.90	0.94
March	2,410	1,424	1,664	102,315	2.91	3.35
April	7,109	1,827	3,280	195,173	5.75	6.41
May	1,827	371	728	44,763	1.28	1.47
June	1,752	371	827	49,210	1.45	1.62
July	371	215	276	16,971	0.48	0.55
August	371	156	265	16,294	0.46	0.53
September	371	156	215	12,793	0.38	0.43
October	371	261	330	20,291	0.58	0.67
November	1,976	267	1,089	64,800	1.91	2.13
December	1,009	371	243	14,941	0.43	0.49
The year	7,109	156	1,018	737,082	1.78	24.21



A. DAM ON EAST CANADA CREEK AT DOLGEVILLE, NEW YORK.



B. DAM ON HUDSON RIVER AT MECHANICSVILLE, NEW YORK.

Estimated monthly discharge of Schroon River at Warrensburg, New York—Continued.

[Drainage area, 570 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
January	371	293	337	20, 721	0. 59	0. 68
February	201	175	188	10, 441	0. 33	0. 34
March	1, 876	175	738	45, 378	1. 29	1. 49
April	3, 982	2, 327	3, 164	188, 270	5. 55	6. 19
May	2, 418	1, 423	1, 822	112, 030	3. 19	3. 68
June	4, 026	735	2, 384	141, 858	4. 18	4. 66
July	2, 480	735	1, 426	87, 681	2. 50	2. 89
August	2, 145	931	1, 377	84, 668	2. 41	2. 78
September	805	150	281	16, 720	0. 49	0. 55
October	230	127	166	9, 878	0. 29	0. 33
November	3, 357	150	2, 077	123, 590	3. 64	4. 06
December	3, 357	1, 434	2, 776	128, 078	4. 87	5. 61
The year	4, 026	127	1, 395	969, 313	2. 44	33. 26
1898.						
January	1, 724	361	852	52, 387	1. 49	1. 71
February	495	294	416	23, 103	0. 73	0. 76
March	4, 044	495	3, 194	196, 392	5. 60	6. 45
April	2, 853	2, 853	2, 853	169, 765	5. 00	5. 58
May	3, 914	770	2, 203	135, 457	3. 86	4. 45
June	1, 391	227	568	33, 798	0. 99	1. 10
July	361	148	216	13, 281	0. 38	0. 44
August	361	120	223	13, 712	0. 39	0. 45
September	220	120	166	9, 878	0. 29	0. 32
October	372	220	263	16, 171	0. 46	0. 53
November	539	339	464	27, 609	0. 81	0. 90
December	841	708	783	48, 145	1. 37	1. 58
The year	4, 044	120	1, 017	739, 698	1. 78	24. 27
1899.						
January	641	575	606	37, 262	1. 06	1. 22
February	478	478	478	26, 547	0. 83	0. 86
March	718	478	564	34, 679	0. 99	1. 14
April	5, 103	708	2, 877	171, 193	5. 04	5. 62
May	4, 854	1, 391	3, 150	193, 686	5. 52	6. 36
June	1, 506	381	1, 093	65, 038	1. 91	2. 13
July	304	150	210	12, 912	0. 37	0. 43
August	150	150	150	9, 223	0. 26	0. 30
September	381	150	234	13, 924	0. 41	0. 46
October	478	381	462	28, 407	0. 81	0. 93
November	1, 468	708	1, 047	62, 301	1. 84	2. 05
December	1, 153	708	948	58, 290	1. 66	1. 88
The year	5, 103	150	985	713, 462	1. 73	23. 38

CROTON RIVER.

Croton River receives its waters from the drainage area immediately north of the city of New York and east of Hudson River. It flows in a general southerly and westerly direction, emptying into the Hudson

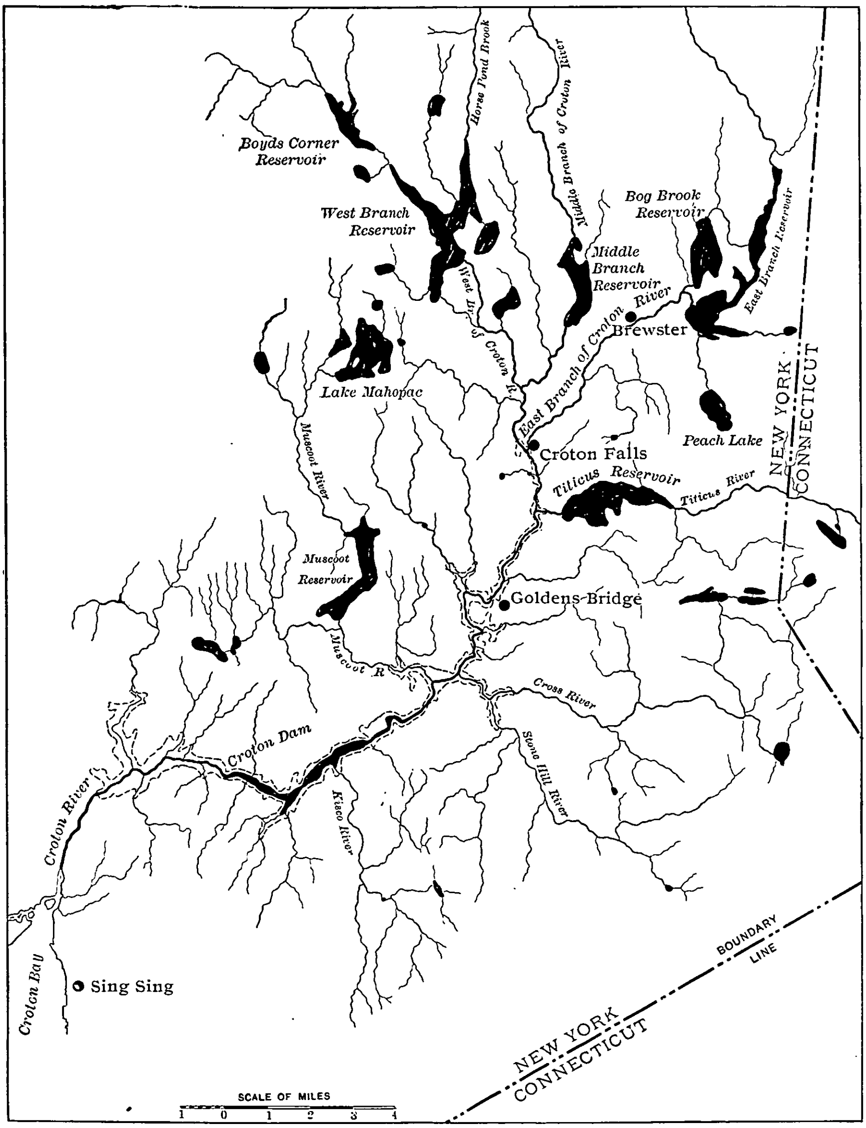


FIG. 36.—Drainage basin of Croton River.

above Sing Sing. A number of reservoirs have been completed within its basin for the water supply of the city of New York, and a new dam is being constructed about 3.2 miles above the mouth, at

A. NEW CROTON DAM, NEW YORK, LOOKING ALONG AXIS.

B. NEW CROTON DAM, SEEN FROM BELOW.

what is known as the Cornell site. Fig. 36 is a map of the drainage basin. Two views of the new Croton dam are shown in Pl. VI, *A* being a view of the dam looking along its axis, *B* a view of the dam from below. A cross section of the dam was given in the Twentieth Annual Report, Part IV, page 84. On page 46, fig. 9, is an outline of the new Croton reservoir, and in figs. 9 to 13 are given the outlines of reservoirs connected with other important storage works constructed or proposed. The new Croton dam will be of such height (elevation 196 feet) as to raise water to a depth of 30 feet above the spillway of the old dam. The total water surface will be 3,425 acres at an elevation of 200 feet, and the cubical contents, when full, 30,000,000,000 gallons. The dam was begun in October, 1892, and will probably be completed in 1903. The total cost of the reservoir, including land and improvements taken, will be, in round numbers, $6,000,000.

In the Twentieth Annual Report, Part IV, pages 82–83, are given the precipitation in the Croton River Basin and the estimated flow of the river. These figures have been revised and recomputed by Mr. John R. Freeman, the results being printed in a report upon New York's water supply made to Bird S. Coler, comptroller (1900). On page 255 of that report is a table of the rainfall, in inches, on Croton watershed from 1868 to 1899, inclusive, with the natural flow of Croton River at the old Croton dam in equivalent inches, this being the depth of run-off for the year over the entire watershed. The following table, condensed therefrom, shows the annual rainfall and run-off at the old Croton dam; also the relation which the latter bears to the former.

Estimated annual rainfall and run-off for watershed above old Croton dam, 1868 to 1899.

Year.	Rainfall.	Run-off.	Ratio.	Year.	Rainfall.	Run-off.	Ratio.
	Inches.	*Inches.*	*Per cent.*		*Inches.*	*Inches.*	*Per cent.*
1868	50.33	33.33	66.22	1886	47.74	20.10	42.10
1869	48.36	23.61	48.82	1887	57.29	26.61	46.45
1870	44.63	19.20	43.02	1888	60.69	35.27	58.12
1871	48.94	19.46	39.76	1889	55.70	31.39	56.36
1872	40.74	16.92	41.53	1890	54.05	25.95	48.01
1873	43.87	25.02	57.03	1891	47.20	23.48	49.75
1874	42.37	25.10	59.24	1892	44.28	17.68	39.93
1875	43.66	24.77	56.73	1893	54.87	29.05	52.94
1876	40.68	21.09	51.84	1894	47.33	20.56	43.44
1877	48.23	20.22	41.92	1895	40.58	15.95	39.31
1878	55.70	27.17	48.78	1896	45.85	23.26	50.73
1879	47.04	19.65	41.77	1897	53.12	25.59	48.17
1880	36.92	12.63	34.21	1898	57.40	29.72	51.77
1881	46.69	19.25	41.23	1899	44.67	22.28	49.88
1882	52.35	24.28	46.38				
1883	42.70	13.33	31.22				
1884	51.28	24.08	46.96	Average for 32 years	48.07	22.93	47.70
1885	43.67	17.71	40.55				

DELAWARE RIVER.

This river rises in Delaware County, New York, flows in a southerly direction, forming the boundary between the States of Pennsylvania

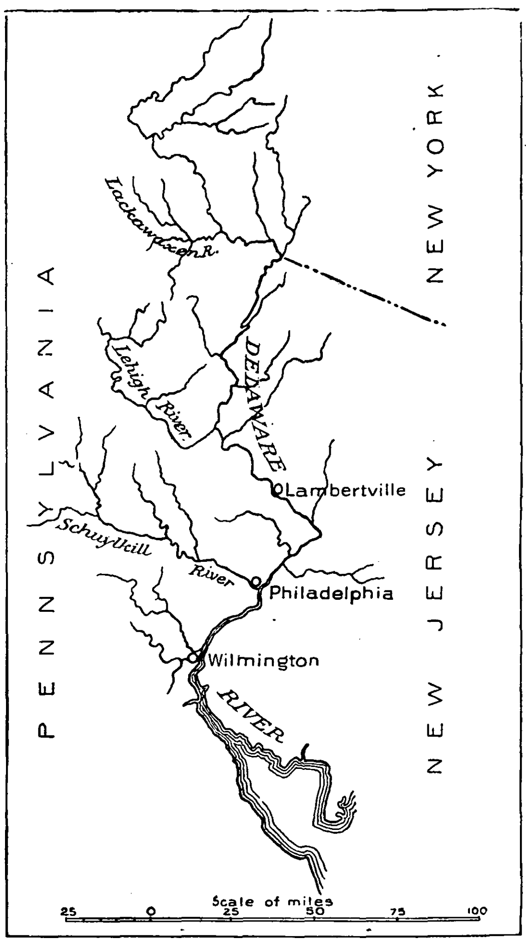


FIG. 37.—Drainage basin of Delaware River.

and New Jersey, and empties into Delaware Bay. The length of the main stream is estimated at 350 miles. The station, established July 23, 1897, is at Lambertville, New Jersey. Discharge measurements are made by E. G. Paul.

Estimated monthly discharge of Delaware River at Lambertville, New Jersey.

[Drainage area, 6,855 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth, in inches.
1899.						
January, 28 days	38, 840	14, 625	21, 476	1, 320, 508	3. 13	3. 61
February, 13 days			25, 140	1, 396, 205	3. 67	3. 82
March	63, 045	27, 850	39, 629	2, 436, 692	5. 78	6. 66
April	57, 380	15, 900	34, 819	2, 071, 874	5. 08	5. 67
May	14, 625	4, 100	8, 139	500, 448	1. 19	1. 37
June	10, 800	1, 750	3, 926	233, 613	0. 57	0. 63
July	11, 650	3, 700	6, 806	418, 485	0. 99	1. 14
August	10, 000	1, 900	5, 296	325, 638	0. 77	0. 89
September	28, 325	2, 440	9, 105	541, 785	1. 33	1. 48
October	13, 775	4, 100	6, 343	390, 016	0. 93	1. 07
November	14, 625	5, 050	10, 249	609, 858	1. 50	1. 67
December	22, 150	6, 650	12, 755	784, 274	1. 86	2. 14

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 63; rating table in Paper No. 39, page 442.

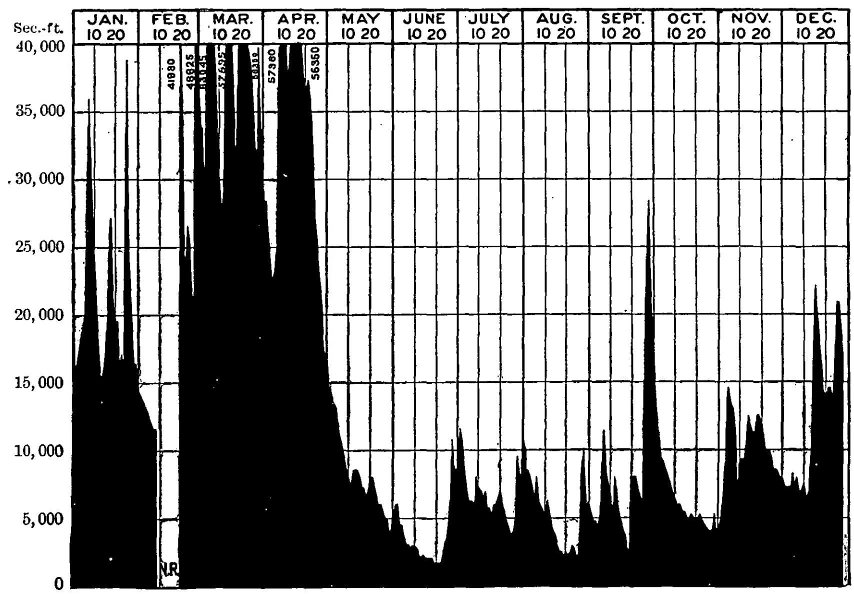


FIG. 38.—Discharge of Delaware River at Lambertville, New Jersey, 1899.

PERKIOMEN CREEK.

The drainage area of this creek is immediately west of that of Tohickon Creek. It flows in a general southerly direction, emptying into Schuylkill River about 18 miles above Philadelphia. The point of measurement is at Frederick, Pennsylvania, about 12 miles above the mouth and above two large tributaries known as West Swamp Creek and Northeast Branch.

Estimated monthly discharge of Perkiomen Creek at Frederick, Pennsylvania.

[Drainage area, 152 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,693	129	472	29,022	3.11	3.59
February	4,043	120	659	36,599	4.34	4.52
March	3,525	345	869	53,433	5.72	6.59
April	1,366	78	245	14,579	1.61	1.80
May	210	57	100	6,149	0.66	0.76
June	501	26	74	4,370	0.49	0.55
July	817	25	104	6,395	0.68	0.78
August	1,021	29	150	9,223	0.99	1.14
September	3,363	43	332	19,755	2.18	2.43
October	119	34	74	4,550	0.49	0.56
November	724	53	139	8,271	0.95	1.05
December	662	43	124	7,625	0.82	0.94
The year	3,525	25	278	200,004	1.84	24.08

The foregoing table of discharge of Perkiomen Creek is a continuation of the tables printed on page 93 of the Twentieth Annual Report, Part IV. The figures of daily flow from August 20, 1884, to December 31, 1899, are given on pages 66 to 73 of Water-Supply Paper No. 35. These measurements were begun by Mr. Rudolph Hering, and have been continued by Mr. John E. Codman, in charge of the hydrographic work of the bureau of water of the city of Philadelphia. The location of this creek and the point of measurement are shown in fig. 16 of the Twentieth Annual Report, Part IV, page 89.

The following diagrams (figs. 39 and 40) show graphically the fluctuations from 1884 to 1899, inclusive, and exhibit the rapid variations which take place in the volume of this stream.

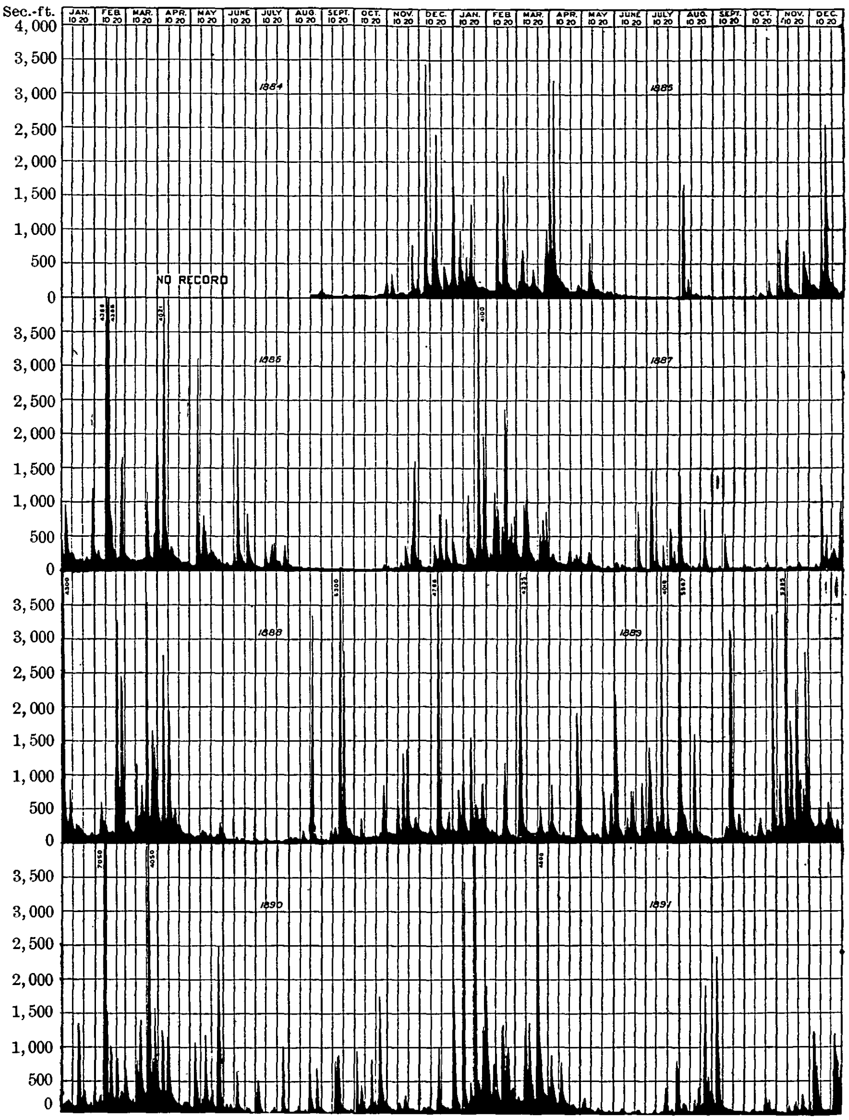


FIG. 39.—Discharge of Perkiomen Creek at Frederick, Pennsylvania, 1884-1891.

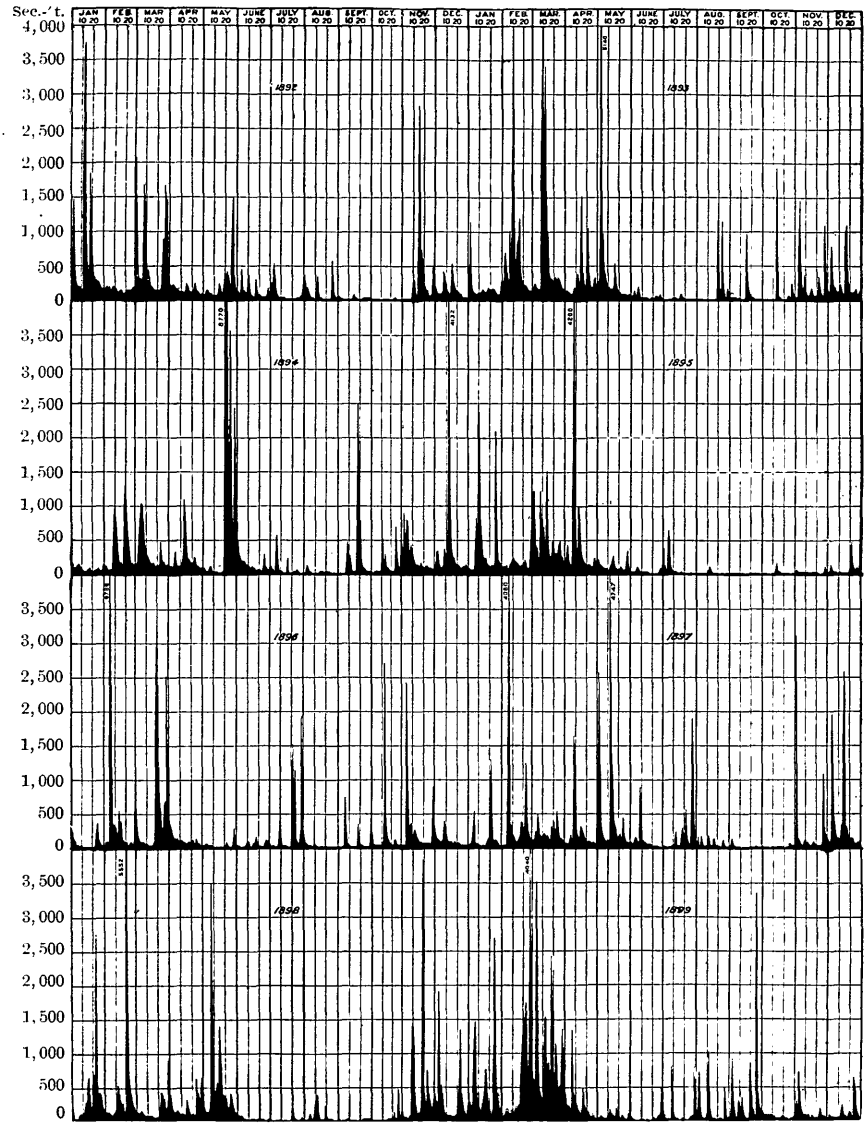


FIG. 40.—Discharge of Perkiomen Creek at Frederick, Pennsylvania, 1892-1899.

WISSAHICKON CREEK.

The drainage basin of this creek is immediately adjacent to the city of Philadelphia, and between Little Neshaminy and Perkiomen creeks. Measurements of flow were begun in April, 1897, under the direction of Mr. John E. Codman, at a point about 100 yards above the junction of the creek with Schuylkill River.

Estimated monthly discharge of Wissahickon Creek near Philadelphia, Pennsylvania.

[Drainage area, 64.6 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	925	106	207	12,728	3.20	3.69
February	1,285	106	271	15,050	4.19	4.36
March	1,059	186	326	20,045	5.05	5.82
April	451	95	146	8,688	2.26	2.52
May	108	54	81	4,980	1.25	1.44
June 1 to 5	45	21				

The foregoing table is a continuation of that on page 95 of the Twentieth Annual Report, Part IV. The figures of daily flow for 1899, to June 21, have been published on page 74 of Water-Supply Paper No. 35. At that time (June 21) measurements were discontinued by the bureau of water of Philadelphia, under whose auspices they had been made. The diagram on the next page shows graphically the fluctuations of this stream for the entire period covered by the observations. The location of the stream with reference to other tributaries of Schuylkill River is shown in fig. 16 of the Twentieth Annual Report, Part IV.

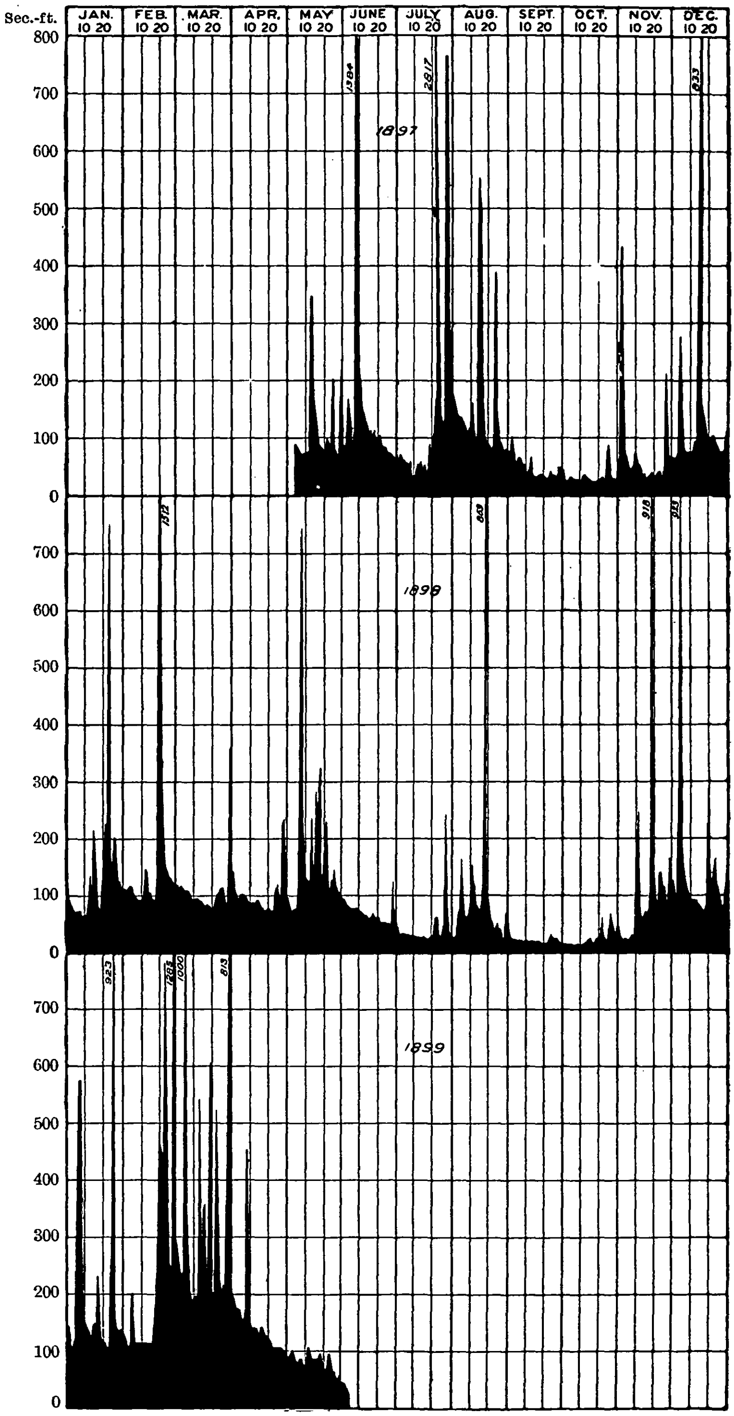


FIG. 41.—Discharge of Wissahickon Creek, Pennsylvania, at mouth, 1897–1899.

TOHICKON CREEK.

This stream rises in Bucks County, Pennsylvania, and flowing easterly discharges into Delaware River about 8 miles above Lambertville, New Jersey. Discharge measurements were begun in 1885 by Mr. Rudolph Hering, and have been continued by Mr. John E. Codman, hydrographer for the water department of the city of Philadelphia. Figs. 42 and 43 show the discharge of the creek from 1883 to 1899, inclusive.

Estimated monthly discharge of Tohickon Creek at Point Pleasant, Pennsylvania.

[Drainage area, 102.2 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,032	79	419	25,763	4.10	4.73
February	3,222	65	546	30,323	5.34	5.56
March	2,819	203	797	49,005	7.80	8.99
April	1,328	39	144	8,569	1.40	1.56
May	35	9	22	1,369	0.22	0.25
June	27	2	7	416	0.07	0.08
July	19	3	7	430	0.07	0.08
August	417	2	90	5,534	0.88	1.01
September	1,522	9	271	12,310	2.02	2.26
October	46	9	17	1,045	0.17	0.20
November	921	31	94	5,593	0.92	1.02
December	913	23	113	6,948	1.11	1.28
The year	3,222	2	190	136,542	1.86	25.05

The foregoing table is a continuation of that on page 102 of the Twentieth Annual Report, Part IV. The figures of daily flow for the year 1899 are given on page 64 of Water-Supply Paper No. 35. The following diagrams (figs. 42 and 43) show graphically the fluctuations of this stream from the beginning of observations in 1883 to the end of the year 1899. The figures for daily discharge are available, but have not yet been printed.

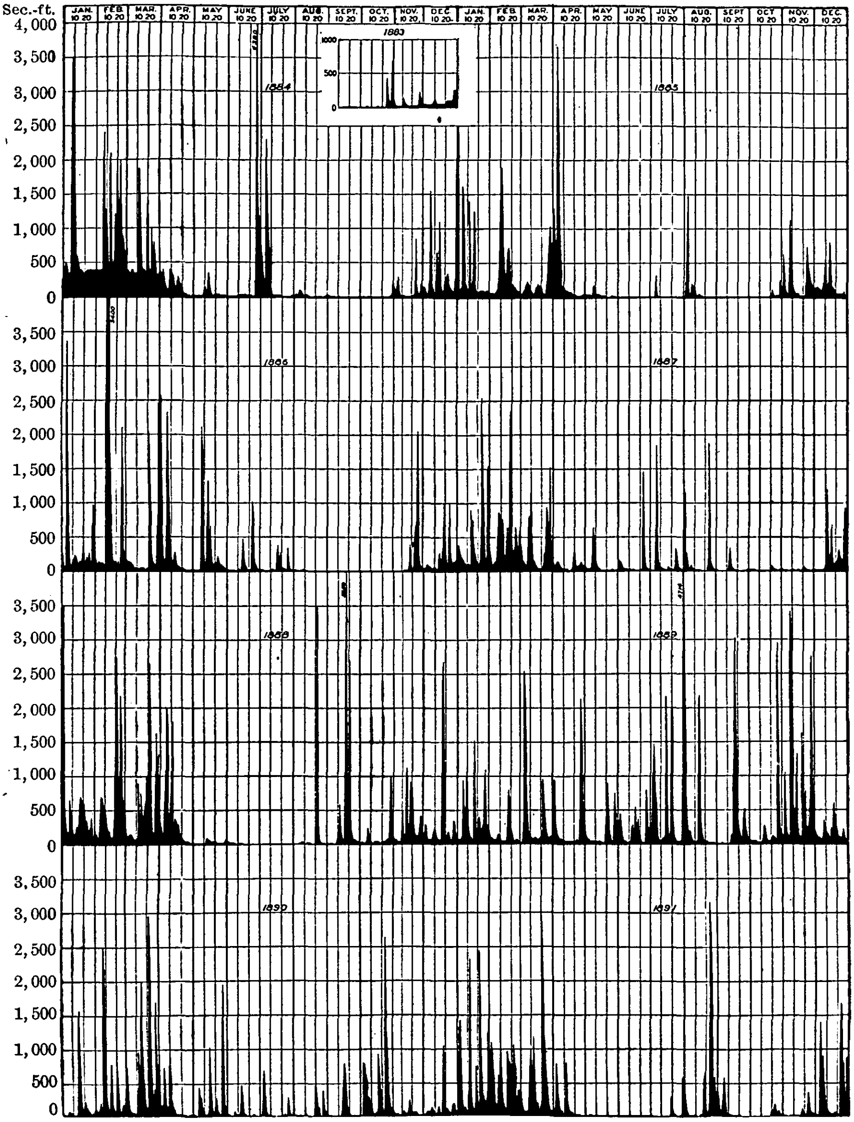


FIG. 42.—Discharge of Tohickon Creek at Point Pleasant, Pennsylvania, 1883–1891.

The foregoing diagram, showing the discharge of Tohickon Creek from 1883 to 1891, inclusive, is continued on the next page (fig. 43), where is shown the discharge from 1892 to 1899, inclusive. These hydrographs show graphically the rapid fluctuations in flow characteristic of the small rain-fed streams of the Eastern States.

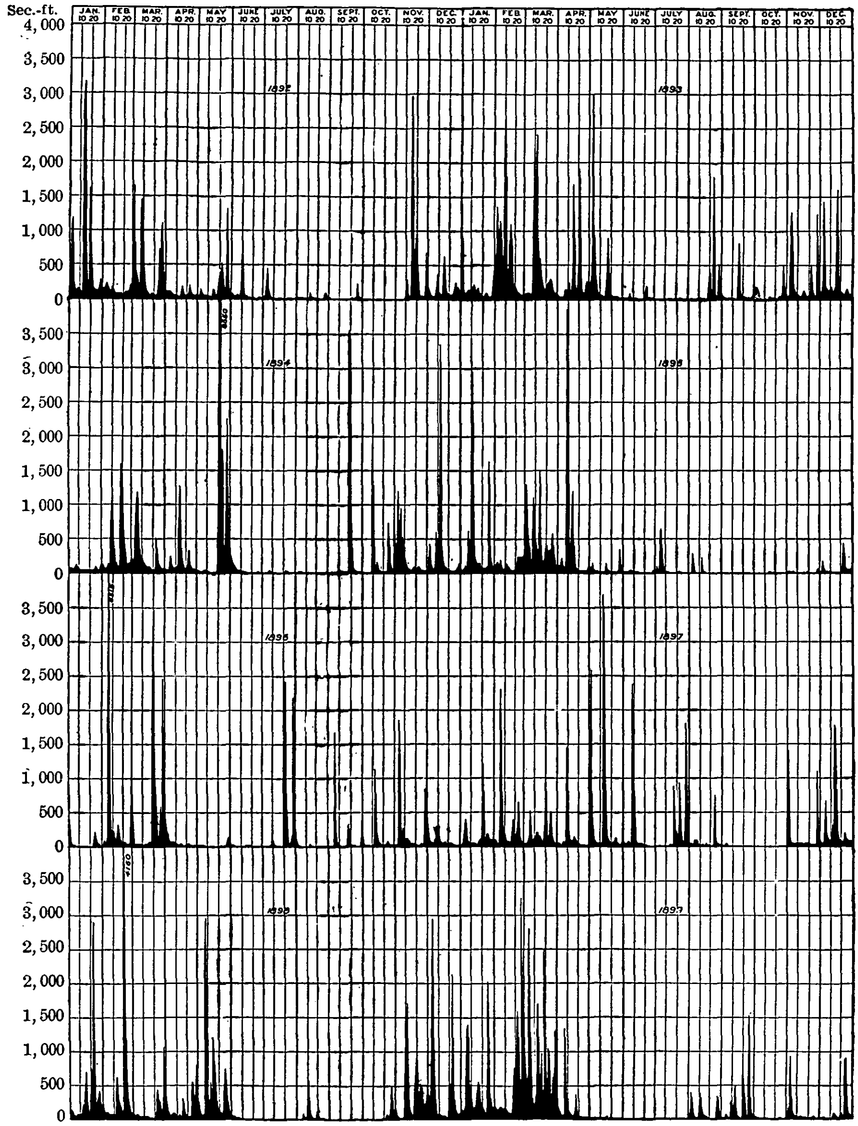


FIG. 43.—Discharge of Tohickon Creek at Point Pleasant, Pennsylvania, 1892-1899.

NESHAMINY CREEK.

The drainage basin of this creek is immediately south of that of Tohickon Creek. The waters of Big Neshaminy Creek flow in a general easterly direction, and after joining the Little Neshaminy continue southerly and empty into Delaware River about 12 miles above the city of Philadelphia. Discharge measurements are made a short distance below the forks.

Estimated monthly discharge of Neshaminy Creek, Pennsylvania, below the forks.

[Drainage area, 139.3 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,105	71	411	25,271	2.95	3.40
February	3,950	72	551	30,601	3.96	4.12
March	3,687	242	895	55,031	6.42	7.40
April	1,047	73	208	12,377	1.49	1.66
May	88	22	49	3,013	0.35	0.44
June	31	11	16	952	0.11	0.12
July	325	6	23	1,414	0.17	0.20
August	2,577	13	174	10,699	1.25	1.44
September	578	13	80	4,760	0.57	0.63
October	123	17	34	2,091	0.24	0.28
November	1,257	41	130	7,736	0.93	1.03
December	792	31	89	5,472	0.63	0.73
The year	3,950	6	222	159,417	1.59	21.41

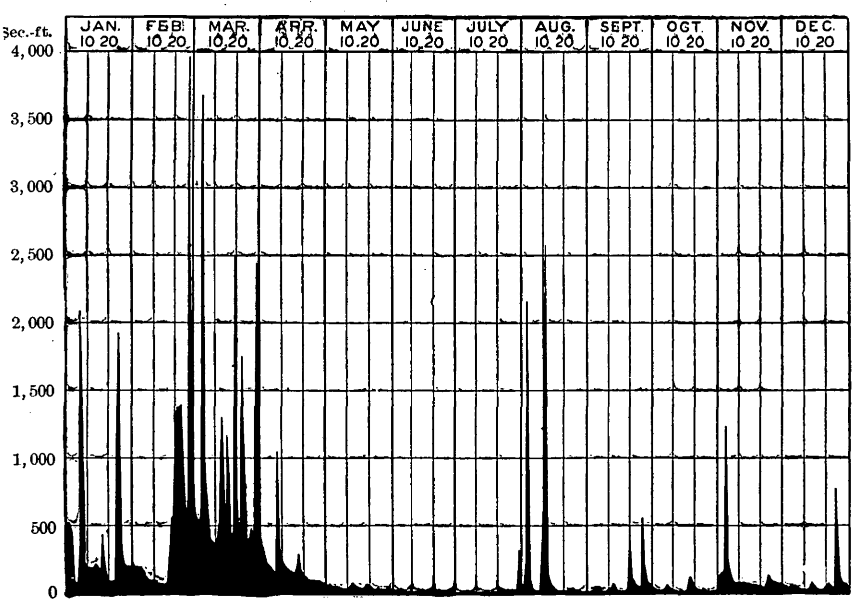


FIG. 44.—Discharge of Neshaminy Creek, Pennsylvania, below the forks, 1899.

SUSQUEHANNA RIVER.

The North Branch of this river rises in New York State and flows in a southwesterly direction until it crosses the Pennsylvania State line, when it changes its course to the southeast, turns again, near Wilkes-barre, to the southwest, and joins the West Branch, on the western border of Northumberland County, to form the Susquehanna proper.

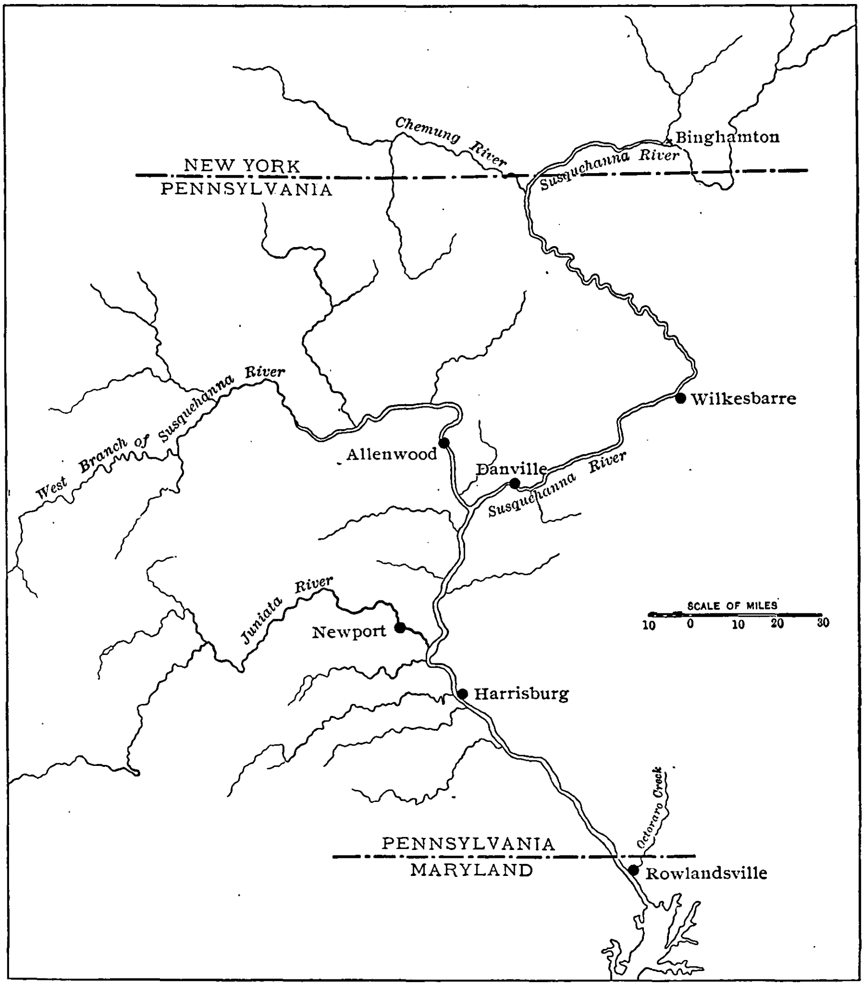


FIG. 45.—Drainage basin of Susquehanna River.

The West Branch rises in Cambria County, Pennsylvania, and flows in a general northeasterly direction until it joins the North Branch. Measurements of flow of the North Branch are made at Wilkesbarre and at Danville, Pennsylvania, and of the West Branch at Allenwood, Pennsylvania. The Wilkesbarre station was established March 30, 1899; the Danville and Allenwood stations were established March 25, 1899. Juniata River, which rises in Center County, Pennsylvania, flows into the Susquehanna about 15 miles above Harrisburg. Most of its drainage area is mountainous and covered with forest growth. The station, which was established March 21, 1899, is at Newport, about 15 miles above the junction of the river with the Susquehanna. Since March, 1897, measurements of Susquehanna River have been made at Harrisburg. The measurements at the four stations mentioned are made by E. G. Paul.

Estimated monthly discharge of North Branch of Susquehanna River at Wilkesbarre, Pennsylvania.

[Drainage area, 9,810 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	54,480	11,360	29,887	1,778,400	3.04	3.99
May	10,260	4,540	6,500	399,669	0.66	0.76
June	6,550	1,730	2,756	163,993	0.28	0.31
July	2,700	1,400	1,828	112,399	0.18	0.21
August	4,340	1,100	1,606	98,749	0.16	0.18
September	1,990	1,000	1,261	75,035	0.12	0.13
October	1,400	1,000	1,213	74,584	0.12	0.14
November	20,880	1,300	5,751	342,208	0.58	0.64
December	28,160	2,400	12,197	749,964	1.24	1.43

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 77; discharge measurements, page 76; rating table in Paper No. 39, page 442.

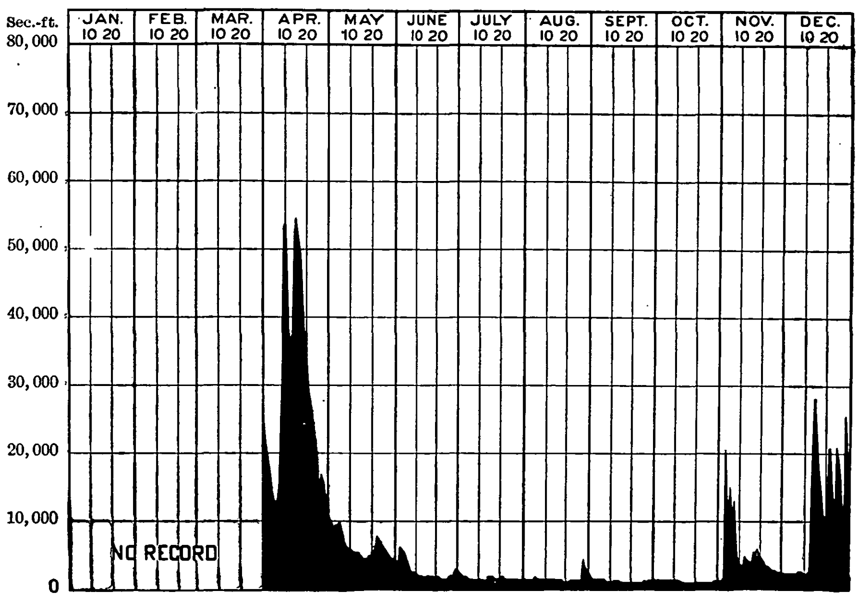


FIG. 46.—Discharge of North Branch of Susquehanna River at Wilkesbarre, Pennsylvania, 1899.

Estimated monthly discharge of North Branch of Susquehanna River at Danville, Pennsylvania.

[Drainage area, 11,070 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	59,120	13,100	32,067	1,908,119	2.89	3.22
May	11,400	4,550	7,181	441,542	0.64	0.74
June	6,400	2,500	3,587	213,441	0.32	0.36
July	4,550	2,000	2,729	167,800	0.24	0.28
August	5,600	1,350	2,085	128,202	0.18	0.21
September	3,300	970	1,563	93,005	0.14	0.16
October	1,550	970	1,272	78,212	0.11	0.13
November	28,160	1,550	8,440	502,215	0.76	0.85
December	31,760	3,600	14,247	876,014	1.29	1.49

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 78; discharge measurements, page 77; rating table in Paper No. 39, page 442.

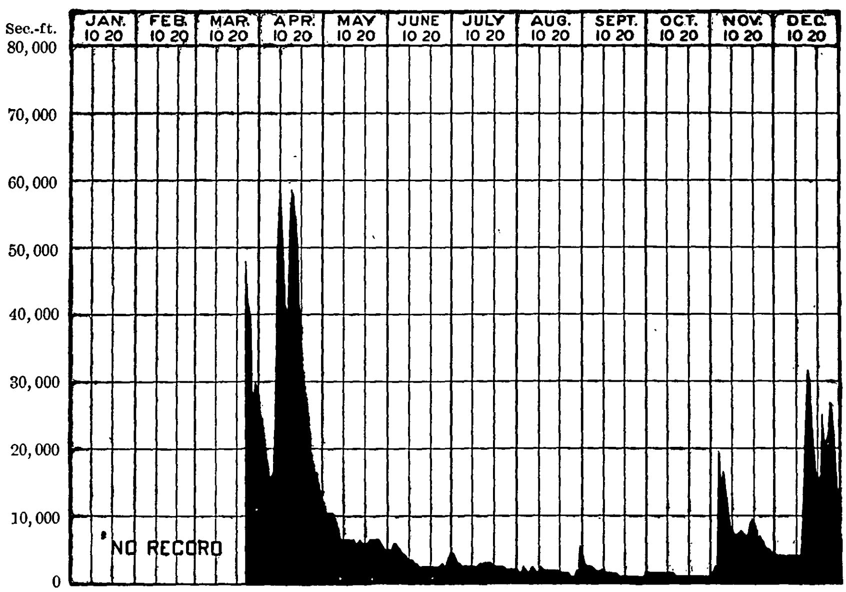


FIG. 47.—Discharge of North Branch of Susquehanna River at Danville, Pennsylvania, 1899.

Estimated monthly discharge of West Branch of Susquehanna River at Allenwood, Pennsylvania.

[Drainage area, 6,538 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 23 to 31			40, 910	2, 515, 458	6. 25	7. 21
April	79, 000	18, 875	42, 627	2, 536, 482	6. 51	7. 26
May	72, 500	5, 200	16, 961	1, 042, 892	2. 59	2. 99
June	9, 125	1, 700	3, 643	216, 774	0. 55	0. 61
July	4, 000	1, 050	2, 071	127, 341	0. 31	0. 36
August	12, 375	750	1, 580	97, 150	0. 24	0. 28
September	2, 950	1, 200	1, 515	90, 149	0. 23	0. 26
October	1, 350	750	958	58, 905	0. 14	0. 16
November	36, 750	1, 700	12, 011	714, 704	1. 83	2. 04
December	88, 750	2, 650	24, 834	1, 526, 983	3. 79	4. 37

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 79; rating table in Paper No. 39, page 442.

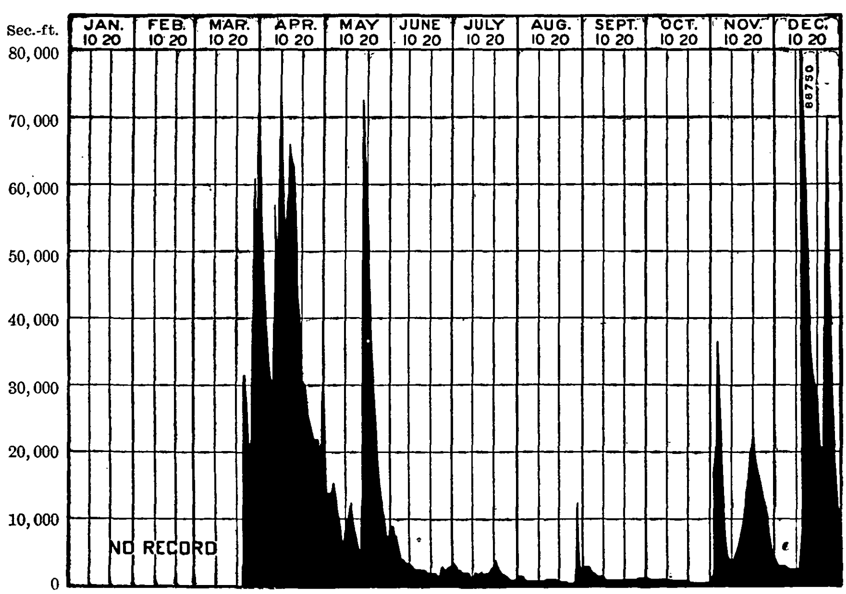


FIG. 48.—Discharge of West Branch of Susquehanna River at Allenwood, Pennsylvania, 1899.

Estimated monthly discharge of Juniata River at Newport, Pennsylvania.

[Drainage area, 3,476 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 21 to 31			13,366	821,843	3.84	4.31
April	19,000	1,820	6,072	361,309	1.74	1.94
May	20,000	1,200	4,281	263,228	1.23	1.42
June	2,270	250	790	47,008	0.22	0.24
July	1,600	250	945	58,106	0.27	0.31
August	6,200	800	1,573	96,720	0.45	0.52
September	5,500	1,200	1,818	108,178	0.52	0.58
October	1,400	450	816	50,174	0.23	0.26
November	5,850	450	2,147	127,755	0.62	0.69
December	9,350	1,200	3,684	226,520	1.05	1.21

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 80; rating table in Paper No. 39, page 442.

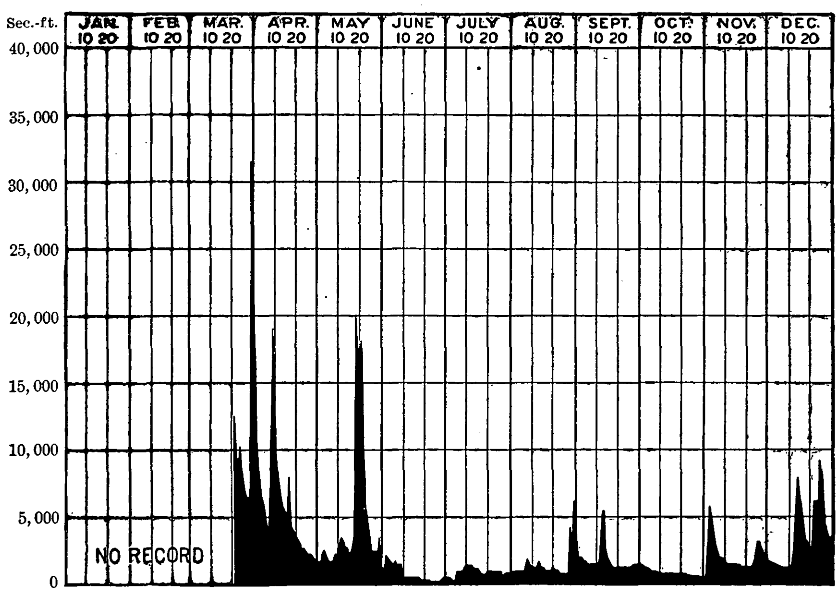


FIG. 49.—Discharge of Juniata River at Newport, Pennsylvania, 1899.

Estimated monthly discharge of Susquehanna River at Harrisburg, Pennsylvania.

[Drainage area, 24,030 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	105,450	20,800	44,350	2,726,975	1.85	2.13
February	123,350	13,100	46,351	2,574,204	1.93	2.01
March	194,950	40,300	102,511	6,303,155	4.27	4.92
April	118,875	29,100	67,479	4,015,279	2.81	3.13
May	54,435	18,300	25,263	1,553,361	1.05	1.21
June	19,300	7,000	12,033	716,013	0.50	0.56
July	11,900	5,675	8,349	513,360	0.35	0.40
August	35,400	4,350	6,719	413,135	0.28	0.32
September	12,700	5,050	6,919	411,709	0.29	0.32
October	7,600	3,475	4,729	290,775	0.20	0.23
November	42,800	11,125	19,019	1,131,709	0.79	0.88
December	83,075	10,100	32,033	1,969,632	1.33	1.53
The year	194,950	3,475	31,313	22,619,307	1.30	17.64

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 81; rating table in Paper No. 39, page 442.

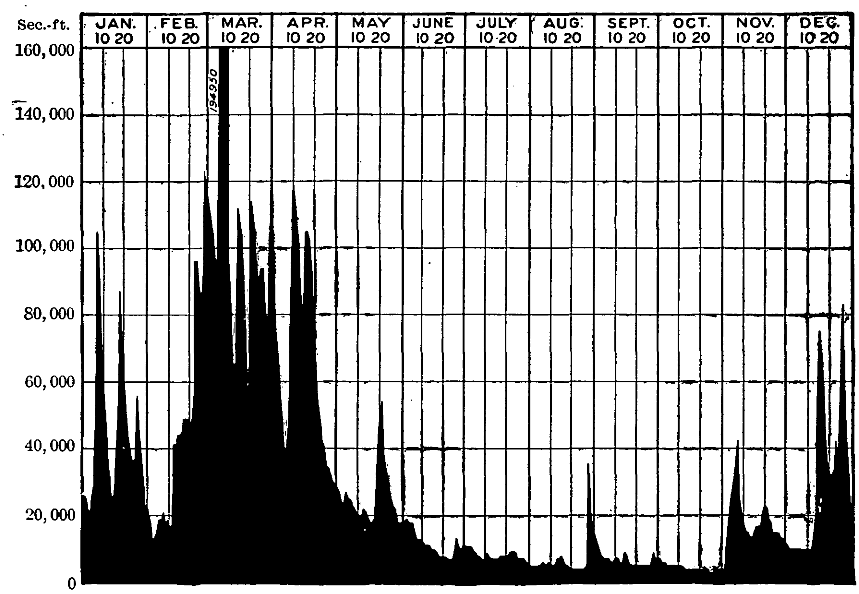


FIG. 50.—Discharge of Susquehanna River at Harrisburg, Pennsylvania, 1899.

OCTORARO CREEK.

This stream rises in Lancaster County, Pennsylvania, and flows in a southwesterly direction between Lancaster and Chester counties into Maryland, where it empties into the Susquehanna about 5 miles below the State line. The gaging station, which was established November 21, 1896, is at Rowlandsville, Maryland. Discharge measurements are made by Hugh W. Caldwell.

Estimated monthly discharge of Octoraro Creek at Rowlandsville, Maryland.

[Drainage area, 217 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,470	225	642	39,475	2.96	3.41
February	1,952	325	822	45,652	3.79	3.95
March	2,087	285	763	46,915	3.52	4.06
April	960	345	508	30,228	2.34	2.61
May	525	305	388	23,857	1.79	2.06
June	345	185	254	15,114	1.17	1.31
July	345	130	188	11,560	0.87	1.00
August	960	120	181	11,129	0.83	0.95
September	1,470	102	262	15,590	1.21	1.35

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 82; rating table in Paper No. 39, page 442.

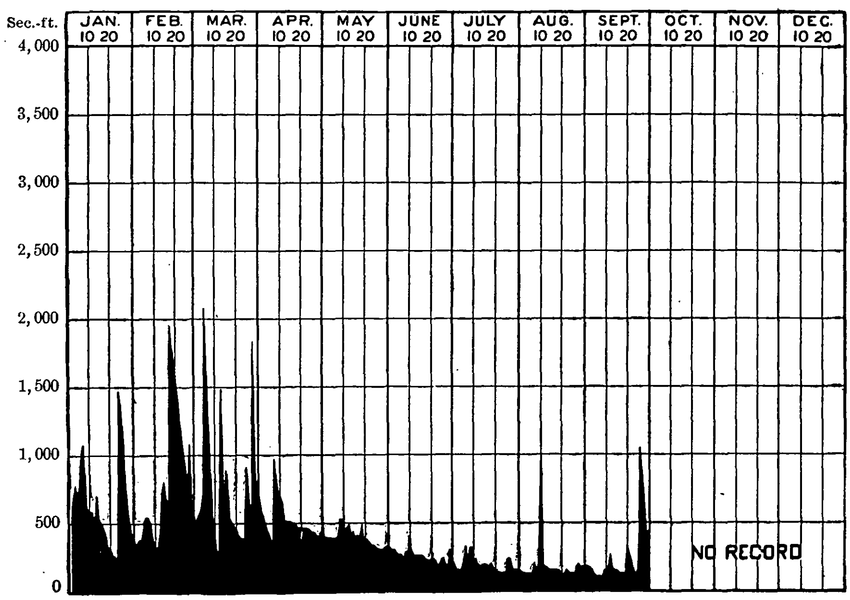


FIG. 51.—Discharge of Octoraro Creek at Rowlandsville, Maryland, 1899.

PATAPSCO RIVER.

This river rises in the north-central part of Maryland, flows in a southeasterly direction between Baltimore and Howard counties, and empties into Chesapeake Bay about 13 miles below Baltimore. It is nearly 80 miles long. Its watershed is a hilly country, largely under cultivation. The station at Woodstock, Maryland, was established August 6, 1896. Discharge measurements are made by E. G. Paul.

Estimated monthly discharge of Patapsco River at Woodstock, Maryland.

[Drainage area, 251 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
February, 15 days			1,211	67,256	4.83	5.03
March	4,562	520	997	61,303	3.97	4.58
April	1,900	400	556	33,084	2.22	2.48
May	875	310	420	25,825	1.67	1.93
June	400	217	294	17,494	1.17	1.31
July	425	148	254	15,618	1.01	1.16
August	450	148	216	13,281	0.86	0.99
September	1,900	111	246	14,638	0.98	1.09
October	235	92	170	10,453	0.68	0.78
November	235	148	195	11,603	0.78	0.87
December	670	83	237	14,573	0.94	1.08

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 83; rating table in Paper No. 39, page 442.

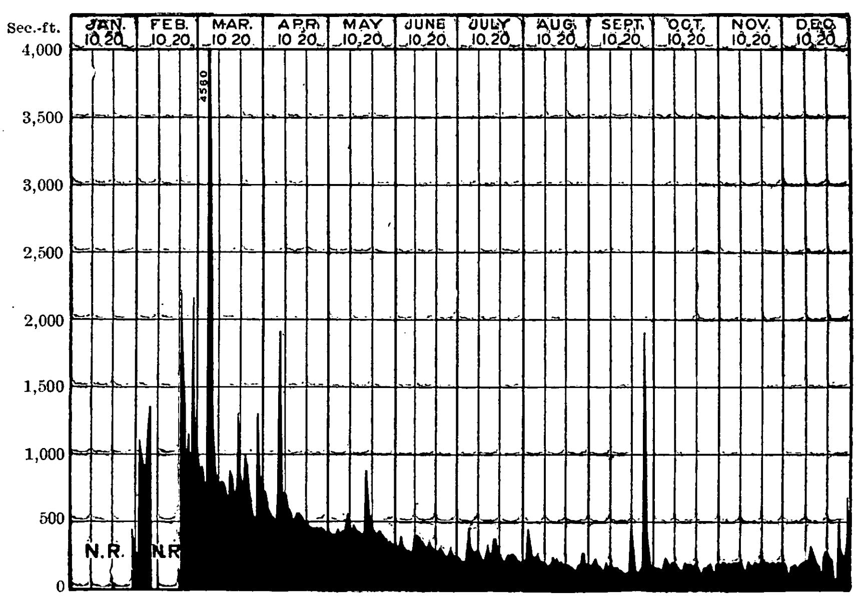


FIG. 52.—Discharge of Patapsco River at Woodstock, Maryland, 1899.

ANTIETAM CREEK.

This creek rises in the western part of Maryland and flows in a southerly direction, entering the Potomac 10 miles above Harpers Ferry. Most of its drainage basin is of a hilly character and largely under cultivation. The station is 1 mile east of Sharpsburg, Maryland. It was established June 24, 1897. Measurements are made by E. G. Paul.

Estimated monthly discharge of Antietam Creek at Sharpsburg, Maryland.

[Drainage area, 293 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	855	417	528	32,465	1.80	2.08
February	1,912	356	682	37,876	2.33	2.43
March	1,567	544	906	55,708	3.09	3.56
April	766	356	491	29,217	1.68	1.87
May	618	294	382	23,488	1.30	1.50
June	972	233	347	20,648	1.18	1.32
July	279	105	189	11,621	0.65	0.75
August	798	105	216	13,281	0.74	0.85
September	325	105	177	10,532	0.60	0.67
October	171	60	105	6,456	0.36	0.41
November	356	80	152	9,045	0.52	0.58
December	432	80	135	8,301	0.46	0.53
The year	1,912	60	359	258,638	1.23	16.55

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 86; rating table in Paper No. 39, page 442.

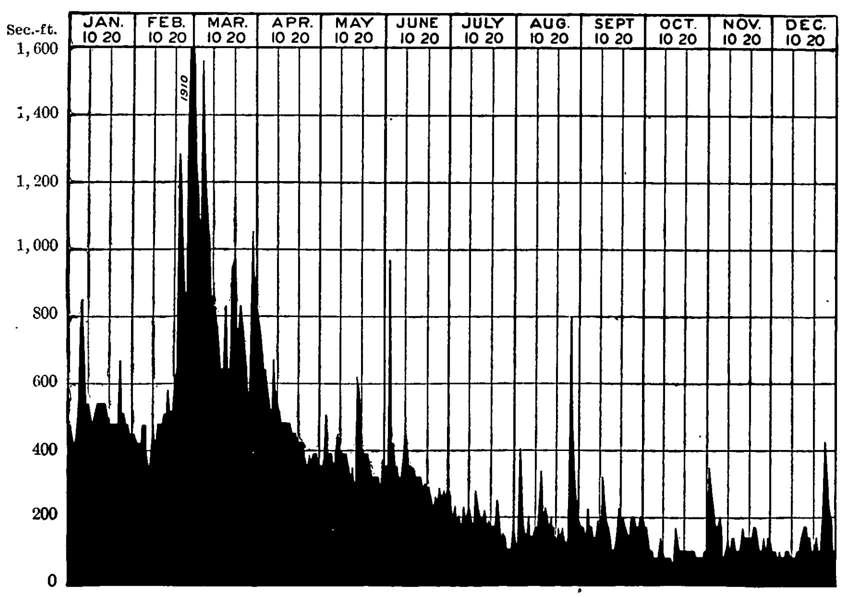


FIG. 53.—Discharge of Antietam Creek at Sharpsburg, Maryland, 1899.

SHENANDOAH RIVER.

This river is formed by the junction of the North and South forks at Riverton, Virginia. The South Fork is formed by the junction of North and South rivers at Port Republic, Virginia. Shenandoah River empties into the Potomac at Harpers Ferry. Its length is estimated at 200 miles. The two stations at Port Republic, one on North River and the other on South River, established in August, 1895, have been discontinued. There is a station on the North Fork of the Shenandoah at Riverton, Virginia, and one on the South Fork of the Shenandoah at Front Royal, Virginia. Both of these stations were established June 26, 1899. The station on the main river is at Millville, West Virginia. Measurements at these stations are made by E. G. Paul.

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

[Drainage area, 2,995 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	15,760	2,780	4,973	305,778	1.66	1.91
February, 19 days			3,692	205,043	1.23	1.28
March 10 to 31			6,853	421,375	2.29	2.64
April	4,830	2,100	3,308	196,840	1.10	1.23
May	4,830	1,500	2,546	156,547	0.85	0.98
June	4,600	1,040	1,634	97,230	0.55	0.61
July	1,800	740	929	57,122	0.31	0.36
August	1,950	640	1,013	62,287	0.36	0.41
September	1,800	740	1,014	60,337	0.34	0.38
October	940	640	801	49,252	0.27	0.31
November	5,060	940	1,523	90,625	0.51	0.57
December	4,380	840	1,419	87,251	0.47	0.54

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 91; rating table in Paper No. 39, page 442.

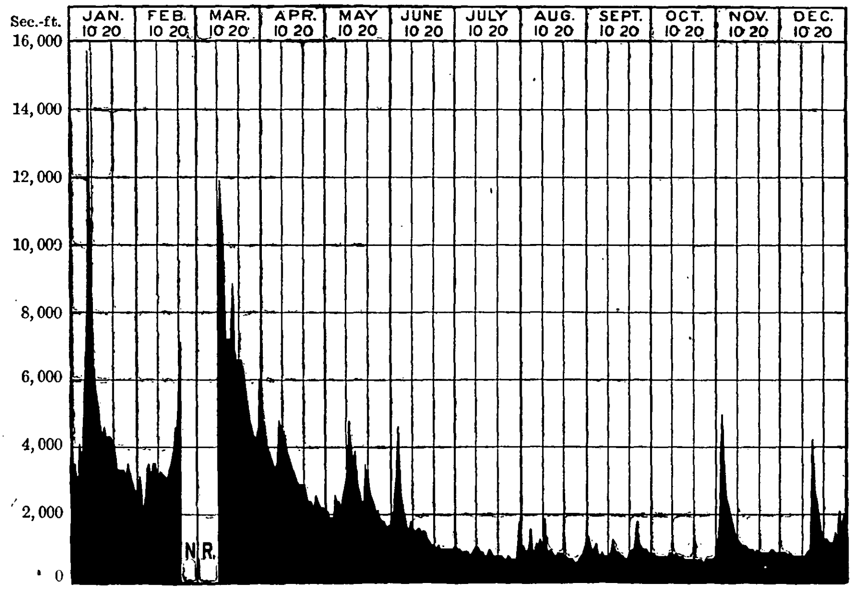


FIG. 54.—Discharge of Shenandoah River at Millville, West Virginia, 1899.

MONOCACY RIVER.

This river rises in the south-central part of Pennsylvania, and flows in a southerly direction through Frederick County, entering the Potomac near the Montgomery County line. The station, which was established August 4, 1896, is 4 miles northeast of Frederick, on the road leading from Frederick to Mount Pleasant, Maryland, about 2,000 feet above the mouth of Israel Creek and about 3,000 feet below the mouth of Tuscarora Creek. Discharge measurements are made by E. G. Paul.

Estimated monthly discharge of Monocacy River at Frederick, Maryland.

[Drainage area, 665 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	8,631	500	1,924	118,302	2.89	3.33
February	11,168	600	2,781	154,449	4.18	4.35
March	10,609	1,450	3,371	207,275	5.07	5.84
April	6,696	420	1,218	72,476	1.83	2.04
May	2,482	340	718	44,148	1.08	1.25
June	5,406	210	780	46,413	1.17	1.31
July	305	120	205	12,605	0.31	0.36
August	550	90	211	12,974	0.32	0.37
September	1,020	65	314	18,684	0.47	0.53
October	500	90	128	7,870	0.19	0.22
November	2,138	180	420	24,992	0.63	0.70
December	1,966	120	467	28,715	0.70	0.81
The year	11,168	65	545	748,903	1.57	21.11

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 94; rating table in Paper No. 39, page 442.

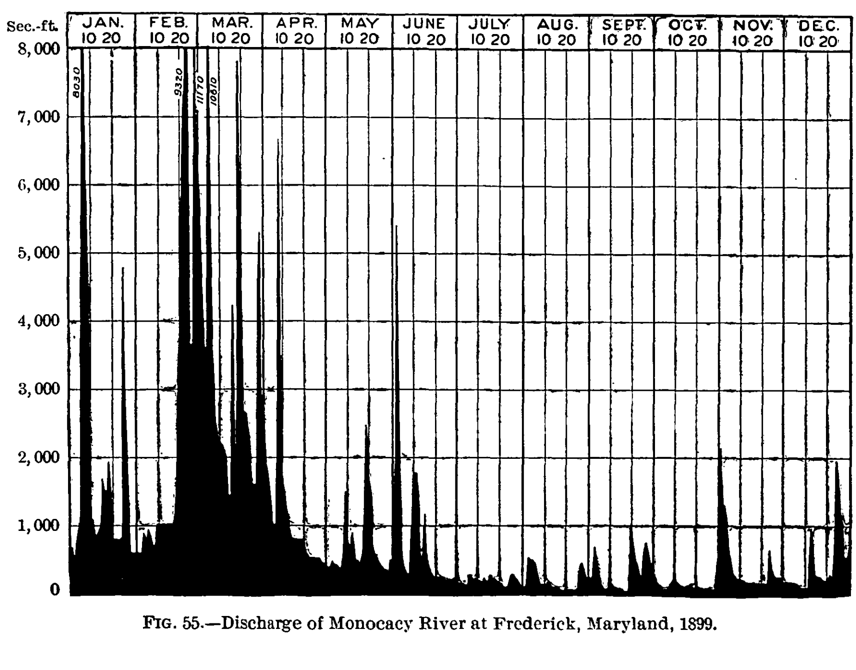


FIG. 55.—Discharge of Monocacy River at Frederick, Maryland, 1899.

POTOMAC RIVER.

The Potomac is formed by the junction of North and South branches about 15 miles below Cumberland, Maryland. The North Branch rises in the western part of West Virginia and flows in a northeasterly direction, forming the boundary between Maryland and West Virginia. The South Branch rises in Highland County, Virginia, and flows in a northeasterly direction until it joins the North Branch. There is a station on the North Branch at Piedmont, West Virginia, and one on the South Branch at Springfield, West Virginia. The former station was established June 27, 1899, the latter in April, 1894. Discharge measurements at both stations are made by E. G. Paul. The main Potomac River is measured at Point of Rocks, Maryland, about 6 miles above the mouth of Monocacy River and also above a number of smaller streams, so that the discharge measurements do not represent the entire flow of the Potomac. The drainage area at Point of Rocks is estimated to be 9,654 square miles. Rock Creek, another tributary of the Potomac, which rises in Montgomery County, Maryland, is measured at the Zoological Park, District of Columbia. Measurements at these stations also are made by Mr. Paul.

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

[Drainage area, 9,654 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	45,750	8,800	19,048	1,171,215	1.97	2.27
February	106,630	7,300	29,061	1,613,965	3.01	3.13
March	122,555	14,550	35,980	2,212,324	3.73	4.30
April	25,800	5,950	12,072	718,334	1.25	1.39
May	49,755	5,500	11,508	707,599	1.19	1.37
June	16,800	3,100	5,525	328,760	0.57	0.63
July	7,300	1,600	2,640	162,327	0.27	0.31
August	3,900	1,600	2,448	150,522	0.25	0.29
September	3,900	1,800	2,465	146,678	0.25	0.28
October	2,100	1,600	1,729	106,312	0.18	0.21
November	9,800	2,100	3,320	197,554	0.34	0.38
December	12,350	2,100	4,232	260,216	0.44	0.51
The year	122,555	1,600	10,836	7,775,806	1.12	15.07

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 93; discharge measurements, page 92; rating table in Paper No. 39, page 442.

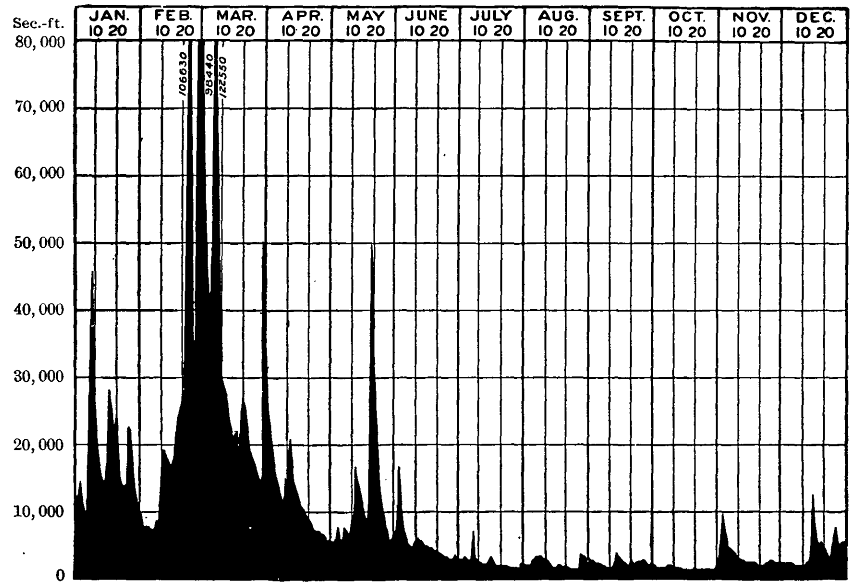


FIG. 56.—Discharge of Potomac River at Point of Rocks, Maryland, 1899.

WATER POWER ON POTOMAC RIVER.[1]

Along the upper part of the North Branch of Potomac River, as far down as Piedmont, West Virginia, the river flows through a narrow and tortuous valley, the steep and wooded hillsides of which afford little opportunity for settlement. The roads are few and bad, and the West Virginia Central and Pittsburg Railway affords the only means of transportation. There are several small towns along the river which owe their existence to the lumber trade.

In this part of its course the river assumes much of the nature of a mountain torrent, presenting a continuous series of riffles and falls, the latter in some instances having a drop of 5 feet and more. The average fall is 46 feet per mile, but in some portions it exceeds 60 feet per mile. There seems to be little opportunity for developing the water powers of this stream, however, on account of the frequent and heavy freshets, which would inflict serious damage upon the cheaper forms of milldams. Stone and brush dams, crib dams, and loose rock dams would either be swept away or would require incessant repairs and rebuilding. On account of the narrowness of the valley, wasteweirs would be impracticable, and dams would have to be built to withstand the heaviest floods passing over them, which would render their construction elaborate and expensive. It is also difficult to find good mill sites. The North Branch above Savage River discharges probably 100 second-feet in the driest season. This flow, with the

[1] From report of H. A. Pressey and earlier reports by Dwight Porter and Gerard H. Matthes.

large available head and the fact that the river does not freeze over in winter, seems to indicate that there would be power at all times for average mill purposes. The fact that no attempt has been made by any of the sawmills and tanneries along the river to use the water power has, however, several explanations besides the high waters. The sawmill owners prefer to use steam, because the mills are primarily of a temporary character, likely to be shifted whenever it may be found advantageous to shorten the distance which the raw materials have to be hauled, and also because they are supplied with an abundance of fuel at no cost in the form of sawdust. The tanneries, although of a more permanent character, invariably use steam power, the owners preferring it because, besides being able to utilize tan bark as fuel, they require the use of the steam in their processes.

South Branch of the Potomac has its headwaters in Pendleton County, West Virginia, and in Highland County, Virginia. The main river and its numerous forks pursue northeasterly courses through the narrow, sparsely settled valleys, separated by steep and wooded ridges. The highest point is Spruce Knob, in the western part of the basin, with an altitude of 4,680 feet. The total area drained comprises 1,487 square miles. At a point 12 miles below Petersburg, Moorefield River, or South Fork, enters South Branch. The low-water flow of South Branch above the mouth of North Fork is about 100 second-feet, of North Fork at its mouth 17 second-feet, and of South Fork at its mouth 34 second-feet. From Moorefield to its mouth the river has a total fall of about 280 feet in 54 miles. Above Moorefield the stream has more fall, averaging over 8 feet per mile. Owing to the gradual slope of the bed, and the few riffles and falls, there are few good dam sites along the river, and consequently little power is developed. There is no railroad in the valley above Romney, and the consequent lack of good means of transportation will account in a great measure for the scarcity of industrial enterprises.

Results of gagings at several points on the North and South branches may be found in the Nineteenth Annual Report, Part IV, page 132 and on following pages. A gaging station was maintained by the United States Geological Survey on North Branch at Cumberland, Maryland, from June, 1894, to November, 1897, and on South Branch at Springfield, West Virginia, from June, 1894, to February, 1896, the results of which may be found in the annual reports of the Survey. In June, 1899, stations were established at Piedmont, West Virginia, on North Branch, and at Springfield, West Virginia, on South Branch. Results of measurements at these stations may be found in Water-Supply and Irrigation Paper No. 35, pages 84 and 85.

From the junction of its two main branches the river flows at almost right angles to the Blue Ridge mountain ranges, cutting through the mountains at Harpers Ferry, West Virginia. Its valley is for the most part narrow, with high banks and frequently precipitous rock walls. The river bed is gravel and sand, with frequent rock projections near the surface. The fall is rapid, averaging 3.3 feet per mile from Cumberland to tide water at Georgetown. At Harpers Ferry it receives the Shenandoah, then cuts through the Blue Ridge and reaches the Atlantic Coastal Plain, crossing the fall line about 3 miles above Washington.

The tributaries of Potomac River above the Shenandoah drain a series of narrow valleys between the parallel ranges of the Allegheny Mountains. The falls of these tributaries are not great, though fairly numerous. The narrowness of the valleys and the steepness of the slopes of the Potomac and its upper tributaries cause the rainfall to run off quickly. The entire absence of lakes, marshes, and low-lying lands subject to overflow makes the tributaries and the main stream subject to heavy freshets, while their low-water flows are very small. This large fluctuation in the quantity of water is the most serious disadvantage in the development of water power on the Potomac. As an example, the low-water flow at Great Falls, 16 miles above Washington, may be taken as about 1,000 second-feet, whereas the maximum flow recorded in June, 1889, was estimated at 471,000 second-feet, and a common yearly maximum is about 200,000 second-feet. The facilities for storage on the Potomac are poor, though small reservoirs might be built to advantage on some of its tributaries. In other respects the conditions are favorable to the development of water power. In several places large falls might be rendered available. Good rock foundations can be found near the surface, and the banks are high and rocky, suitable for the construction of high dams. The local rock, which abounds, makes an excellent material for dams; and this rock and other materials could be easily transported on the Chesapeake and Ohio Canal, which follows close to the river, on the Maryland side, from Washington to Cumberland.

The Potomac crosses the Blue Ridge Range at an elevation of 245 feet and reaches sea level at Georgetown, a distance of 61½ miles. Of this fall about 90 feet occurs in a distance of 1 mile—at the Great Falls of the Potomac, located about 16 miles above Washington. This fall occurs in a series of rapids and in two or three main leaps, the largest of which is between 35 and 40 feet. No water-power development has ever been undertaken, nor the fall in any way utilized, except to furnish water for the Chesapeake and Ohio Canal Company, which in turn leases certain quantities of water to mill owners in Georgetown. The water supply for the city of Washington is also taken from the river at this point. The city now uses approximately 90 second-feet. Colonel Elliott, Corps of Engineers, United States Army, puts the possible population of Washington at 1,000,000 and the consumption at 200 gallons per head, making a total consumption of 200,000,000 gallons, which is equal to 309 second-feet. The amount used by the canal is variable and very uncertain.

For a number of years companies have contemplated development at Great Falls, but very little has actually been done beyond making detailed studies and surveys. The plans in each case provide for a dam running from the Maryland shore, at a point about 300 feet below the present Government dam across Falls and Conns Islands, to the Virginia shore, at almost right angles to the current. By this means a fall of 60 feet could easily be obtained.

As has been stated, a serious difficulty met with in developing the water power of this river is the great fluctuation in the flow. The low-water flow is very small for a stream with so large a drainage area. The following table shows the number of days in each year when the flow was less than 2,000 second-feet:

Table of flow of Potomac River, showing the number of days on which the flow at Chain Bridge was less than 2,000 second-feet.

Year.	Number of days.	Average flow.	Point of measurement.
		Cubic feet.	
1886	0	....	Great Falls.
1887	0	....	Do.
1888	0	....	Do.
1889	0	....	Do.
1890	0	....	Do.
1891	0	....	Do.
1892	1	1,900	Chain Bridge.
1893	0	....	Do.
1894	No record.	....	Do.
1895	16	1,830	Do.
1896	14	1,973	Point of Rocks.
1897	56	1,249	Do.
1898	6	1,614	Do.
1899	6	1,620	Do.

The drainage areas at these stations are as follows:

	Square miles.
Chain Bridge	11,545
Great Falls	11,427
Point of Rocks	9,654

This flow, with a head of 60 feet, gives 13,600 as the gross horsepower, which amount could have been developed practically all of the time since 1886, without the use of an auxiliary steam plant, except in the driest year, 1897.

With a flow of 7,500 second-feet something over 50,000 horsepower could be developed. The engineer officer in charge of the Washington Aqueduct keeps a systematic record of the flow over the dam at Great Falls. According to records published in reports of the Chief of Engineers, the quantity of water flowing in the river has been less than 7,500 second-feet, as follows:

	Days.
1886	94
1887	175
1888	127
1889	24
1890	40
1891	118
1892	166
Average	106

Mr. J. P. Frizell, member of the American Society of Civil Engineers, who has investigated the power at Great Falls for an improvement company, states:

If the Great Falls water power were developed with water wheels and engines to the extent of 50,000 horsepower, no part of the steam power would be required to run on an average more than 106 days in the year. Of the water power, some 10,000 horsepower might be considered as permanent; it would have suffered no interruption during the above period of 7 years. The second 10,000 horsepower would have had to be furnished by steam an average of perhaps 30 days in the year; the third 10,000 horsepower 50 days; the fourth 10,000 horsepower 80 days; the fifth 10,000 horsepower, say, 100 days—the aggregate quantity of steam power required being equivalent to about 20,000 horsepower for 106 days in the year. Of the 50,000 horsepower, about 12 per cent would be furnished by steam and 88 per cent by water. If 15,000 second-feet were flowing in the river it would be equivalent to nearly 100,000 horsepower with the reduced fall that would exist in that condition of the stream. According to the above record the water was below this amount in—

	Days.
1886	127
1887	295
1888	282
1889	191
1890	239
1891	240
1892	299
Average for 7 years	239

That is to say, nearly 100,000 horsepower could be furnished at Great Falls wholly by water about four months in the average year. The use of water to this extent is wholly within the limit of modern practice. Of this power, about five-sixteenths would come from steam and eleven-sixteenths from water. The use of water would be equivalent to something over 10,000 second-feet the whole year round.

The records of the United States Geological Survey show that the flow of the river during 1897, 1898, and 1899 was less than 7,500 second-feet on an average of 190 days each year. This means that 50,000 horsepower might be developed for 175 days each year without the use of an auxiliary steam plant; during the remaining 190 days, in order to maintain the 50,000 horsepower, the same plant would be required to develop not over 20,000 horsepower. In this estimate no account is taken of storage, though storage would increase to some extent the available water power. The facilities for storage, however, at this point are not good.

The only fall on the Potomac below Great Falls, of sufficient size for development, is at Little Falls, 4 miles above Washington. A riprap dam 7 feet high and 1,750 feet long has been built by the Chesapeake and Ohio Canal Company at the head of the rapids, the elevation of the crest of the dam being 37 feet above tide water. The last feeder of the canal draws its water from this point. There are several small mills in Georgetown taking power from this canal, under an available head of about 34 feet. From the riprap dam, for a distance of about a half mile, there is a series of rapids, with occasional falls of from 5 to 10 feet. There have been several projects for development of power at this point. The plans contemplate the building of a 60-foot dam directly across the river, utilizing the fall on either the Virginia or Maryland side for development of electric power to be conducted to the city of Washington. The facilities for storage are somewhat better than at Great Falls, the water being backed up as far as Cabin John Bridge. One scheme of development contemplated the building of a 60-foot dam and a tunnel through the hills on the Virginia side to Pimmit Run, the water then to be conducted down the run and a power plant located near its mouth. About the same power would be developed as by the former plans. There are also possibilities of partial development at much less cost.

About 20 miles above Little Falls, at the mouth of Seneca Creek, is located Dam No. 2. It is an old rubble structure from 2 to 10 feet high above the rock foundation and 2,500 feet long. The location is not a favorable one, the fall being small and the facilities for building not very good.

For a distance of 1 mile above and 3 miles below Harpers Ferry there is a series of riffles and rapids. In the 3 miles below the city the river falls about 25 feet, and the site seems to be favorable for development, with good locations for dams and power plants and good building materials in the immediate vicinity. This power was partially developed some years ago, a dam being built and a cotton mill and other factories erected, but for some reason these have been abandoned and the site is now entirely unimproved.

At Harpers Ferry 1,400 horsepower have been developed by the Shenandoah Pulp Company. The fall there is 22 feet. The dam impounding the water for this power was formerly known as Dam No. 3, and was originally built to supply power to the Government works at Harpers Ferry. The works were destroyed, however, during the

Civil war, and the dam being used only as a feeder to the canal was not in good order until repaired by the Shenandoah Pulp Company. The opportunities for further development near Harpers Ferry are perhaps as favorable as anywhere on the river, the aggregate fall above and below the city being about 50 feet, with good facilities for building and transportation. Freshets, however, are felt at this point quite severely, the river rising, in extreme cases, as much as 25 feet above low water.

Above Harpers Ferry there are several dams, built to supply water to the Chesapeake and Ohio Canal, and also used to some extent for water power. About 10 miles above that city there is a wooden dam about 8 feet high which furnishes power to a cement mill; 15 miles farther up the river is Dam No. 4, a masonry structure 800 feet long and 15½ feet high above low water. On the Virginia side there are good sites for dams. Dam No. 5 is located 7 miles above Williamsport. Years ago the Honeywood Flour Mill utilized this power, but it is now entirely unused. The dam is of masonry, 720 feet long and 16½ feet high above low water.

There are several points on the Maryland shore favorable for dams. Ten miles above Hancock there is a crib dam, rock filled, 470 feet long and 16½ feet high above low water. The crest is about 428 feet above tide. This is known as Dam No. 6. The canal might be utilized to advantage at this point, on the Maryland side, and a suitable site might be selected on the Virginia side.

Estimates of power at these various sites may be found in the Tenth Census of the United States, Volume XVI, Part I.

NORTH (OF JAMES) RIVER.

This river rises on the western slope of the Shenandoah Mountains and flows in a southeasterly direction across the valley between the Shenandoah and Blue Ridge ranges, emptying into James River about 17 miles south of Lexington, Virginia. Most of its watershed is under cultivation, except in the upper part, where it is mountainous and covered with forest growth. The station is about 1 mile above the mouth of North River. It was established August 21, 1895. Measurements are made by D. C. Humphreys.

Estimated monthly discharge of North (of James) River at Glasgow, Virginia.

[Drainage area, 831 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	8,540	600	1,477	90,817	1.78	2.05
February, 26 days	8,170	480	2,257	125,347	2.72	2.83
April	1,570	340	771	45,878	0.93	1.03
May	2,820	220	577	35,478	0.69	0.77
June	340	190	223	13,269	0.27	0.30
July	195	170	178	10,945	0.21	0.24
August	640	155	202	12,420	0.24	0.28
September	1,340	170	231	13,745	0.28	0.31
October	200	160	178	10,945	0.21	0.24
November	1,230	160	229	13,626	0.28	0.31
December	820	175	240	14,757	0.29	0.33

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 96; rating table in Paper No. 39, page 443.

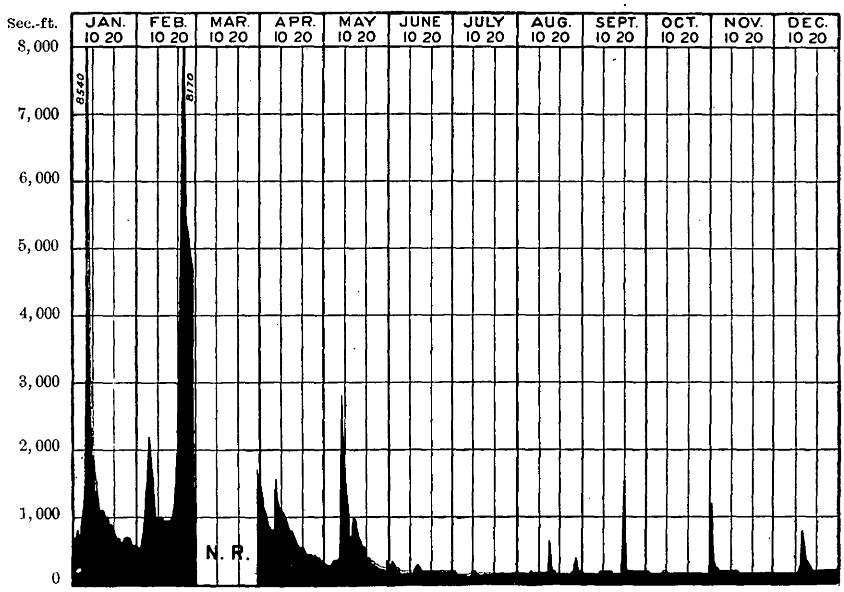


FIG. 57.—Discharge of North (of James) River at Glasgow, Virginia, 1899.

JAMES RIVER.

This river rises in the Allegheny Mountains, on the western border of Virginia, and flows in an easterly direction across the State, emptying into Chesapeake Bay. The upper part of its drainage area is mountainous and largely covered with forests, while in the eastern part of the State the river flows through a flat and cultivated area. Measurements of flow are made at Buchanan and at Cartersville. The station at Buchanan was established August 18, 1895. It is a half mile above the mouth of Purgatory Creek. Measurements are made by D. C. Humphreys. The station at Cartersville was established January 1, 1899; measurements are made by D. C. Humphreys and F. H. Anschutz.

Estimated monthly discharge of James River at Buchanan, Virginia.

[Drainage area, 2,058 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	17,020	1,480	3,277	201,495	1.59	1.83
February	16,860	1,380	5,994	332,890	2.91	3.03
March	52,565	2,620	8,090	497,435	3.93	4.53
April	5,520	2,200	3,099	184,403	1.51	1.68
May	9,820	1,940	3,560	218,896	1.73	1.99
June	3,370	1,380	1,950	116,033	0.95	1.05
July	1,380	370	537	33,019	0.26	0.30
August	1,010	370	467	28,715	0.23	0.26
September	2,070	370	660	39,273	0.32	0.36
October	450	310	362	22,259	0.18	0.21
November	770	370	463	27,550	0.22	0.24
December	1,940	370	674	41,443	0.33	0.38
The year	52,565	310	2,428	1,743,411	1.18	15.85

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 35, page 98; discharge measurements, page 97; rating table in Paper No. 39, page 443.

A. DAM OF ROANOKE RAPIDS WATER POWER COMPANY, NEAR WELDON, NORTH CAROLINA.

B. LOWER DAM OF COTTON MILL AT LENOIR, TENNESSEE.

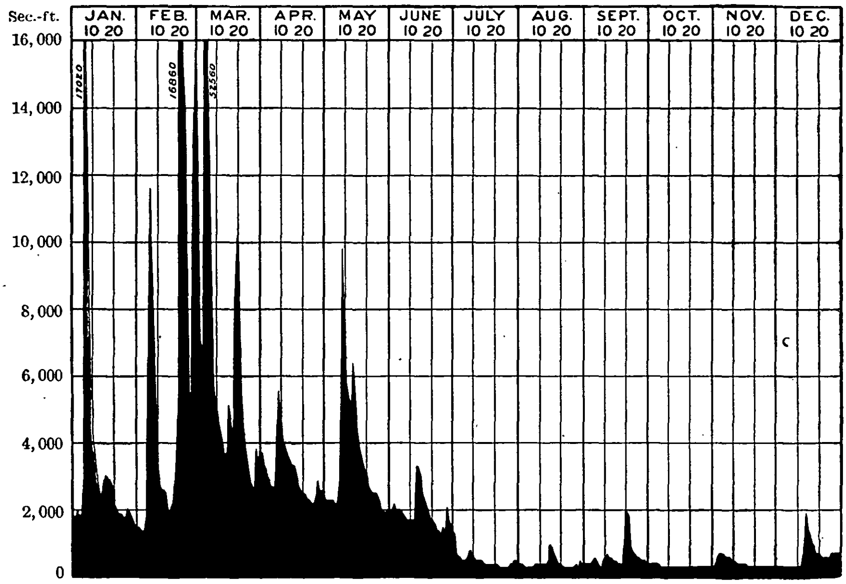


FIG. 58.—Discharge of James River at Buchanan, Virginia, 1899.

SOUTHERN ATLANTIC COAST DRAINAGE.

ROANOKE RIVER.

The Roanoke rises in Montgomery County, Virginia. A portion of its headwaters is known as Staunton River, which joins Dan River at Clarksville, Virginia, to form the main Roanoke River. There are a number of fine water powers along the stream, as described in the Nineteenth Annual Report, Part IV, page 176. The river flows in a southerly direction and enters Albemarle Sound. Gaging stations are maintained by the United States Weather Bureau on Dan River at Danville, Virginia, and on Roanoke River at Clarksville, Virginia, also at Weldon, North Carolina. Two stations, established in July, 1896, are maintained by the Survey, one at Roanoke, Virginia, and the other at Neal, North Carolina. Measurements at the Roanoke station are made by D. C. Humphreys, those at the Neal station by E. W. Myers.

Pl. VII, *A*, is a view of the dam of the Roanoke Rapids Water Power Company, located about 5 miles above Weldon, North Carolina. In the distance is the bulkhead, a view of which is shown in Pl. XXVI of the Nineteenth Annual Report, Part IV. A description of the plant of this company is given in the same report, page 175. The Great Falls of Roanoke River begin about 9 miles above Weldon and terminate immediately below that place. This portion of the river has a fall of 85 feet, 58 feet of which are in the upper half and 27 feet in the lower half.

Estimated monthly discharge of Roanoke River at Roanoke, Virginia.

[Drainage area, 388 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	7,757	510	1,229	75,568	3.17	3.66
February	6,015	705	2,616	145,285	6.74	7.02
March	12,472	740	3,306	203,278	8.52	9.82
April	740	302	446	26,539	1.15	1.28
May	705	205	357	21,951	0.92	1.06
June	865	140	280	16,661	0.72	0.80
July	222	100	146	8,977	0.38	0.44
August	170	70	115	7,071	0.30	0.35
September	705	65	134	7,974	0.35	0.39
October	140	70	94	5,780	0.24	0.28
November	280	90	139	8,271	0.36	0.40
December	420	100	179	11,006	0.46	0.53
The year	12,472	65	753	538,361	1.94	26.03

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 108; discharge measurements, page 107; rating table in Paper No. 39, page 443.

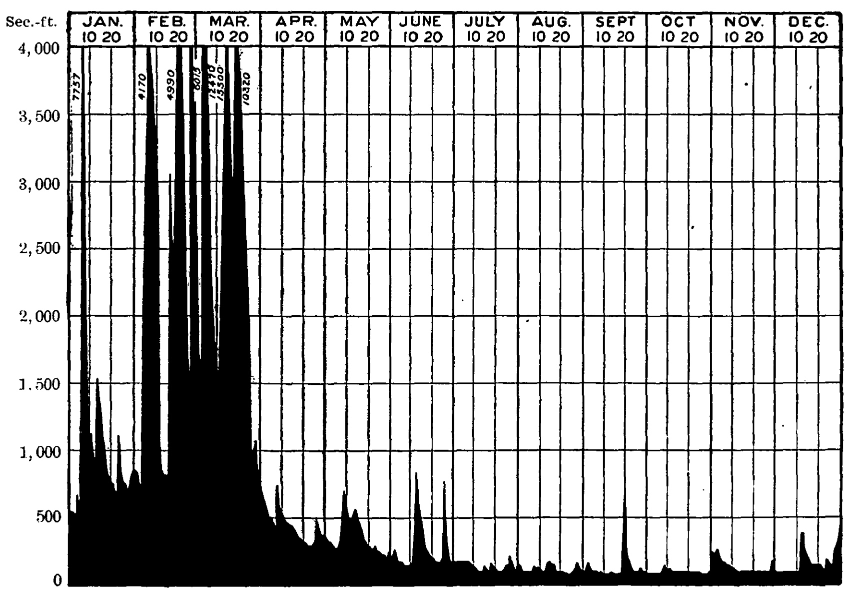


FIG. 59.—Discharge of Roanoke River at Roanoke, Virginia, 1899.

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

[Drainage area, 8,717 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	62,750	6,880	18,585	1,142,747	2.13	2.46
February	58,300	8,440	29,967	1,664,283	3.44	3.58
March	83,000	18,030	37,777	2,322,817	4.33	4.99
April	31,500	8,440	15,863	943,914	1.82	2.03
May	12,340	5,490	8,106	498,419	0.93	1.07
June	27,640	4,580	10,759	640,205	1.23	1.37
July	11,240	3,740	6,095	374,767	0.70	0.81
August	13,110	2,690	5,626	345,929	0.65	0.75
September	13,440	2,970	5,564	331,081	0.63	0.70
October	9,240	3,180	4,563	280,568	0.52	0.60
November	13,620	3,915	6,132	364,879	0.70	0.78
December	10,840	3,740	5,566	342,240	0.63	0.72
The year	83,000	2,690	12,884	9,251,849	1.48	19.86

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 109; rating table in Paper No. 39, page 443.

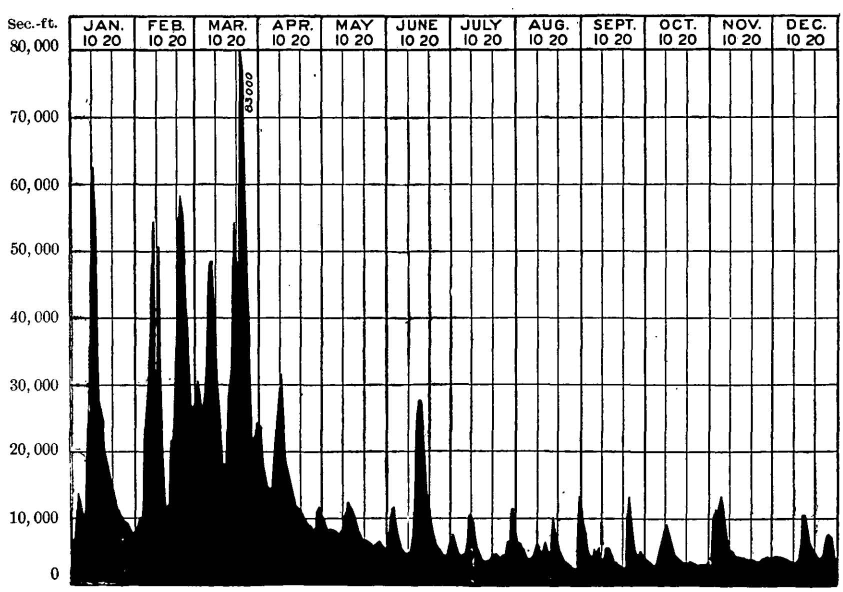


FIG. 60.—Discharge of Roanoke River at Neal, North Carolina, 1899.

TAR RIVER.

Tar River rises in the north-central part of North Carolina and flows in a southeasterly direction into Pamlico River. It crosses the fall line at Rocky Mount, North Carolina, where is located the principal power on the river. Below this point the fall is from 1 to 1½ feet per mile; above this point about 2 feet per mile. The drainage basin is largely covered with forests. The stream is subject to violent freshets and to periods of very low flow. The station, which was established July 24, 1896, is at Tarboro, North Carolina. Measurements are made by E. W. Myers.

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

[Drainage area, 2,290 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	6,247	1,250	2,440	150,030	1.07	1.23
February	19,850	3,060	11,874	659,449	5.19	5.40
March	15,850	3,835	9,537	586,407	4.16	4.80
April	13,240	1,755	5,060	301,091	2.21	2.47
May	2,030	705	1,354	83,254	0.59	0.68
June	6,413	500	1,907	113,474	0.83	0.92
July	5,459	430	1,250	76,860	0.55	0.63
August	6,413	453	2,028	124,697	0.89	1.02
September	2,250	350	711	42,307	0.31	0.35
October	4,845	453	1,325	81,471	0.58	0.67
November	5,666	735	1,598	95,088	0.70	0.78
December	4,685	800	1,524	93,707	0.66	0.76
The year	19,850	350	3,384	2,407,825	1.48	19.71

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 110; rating table in Paper No. 39, page 443.

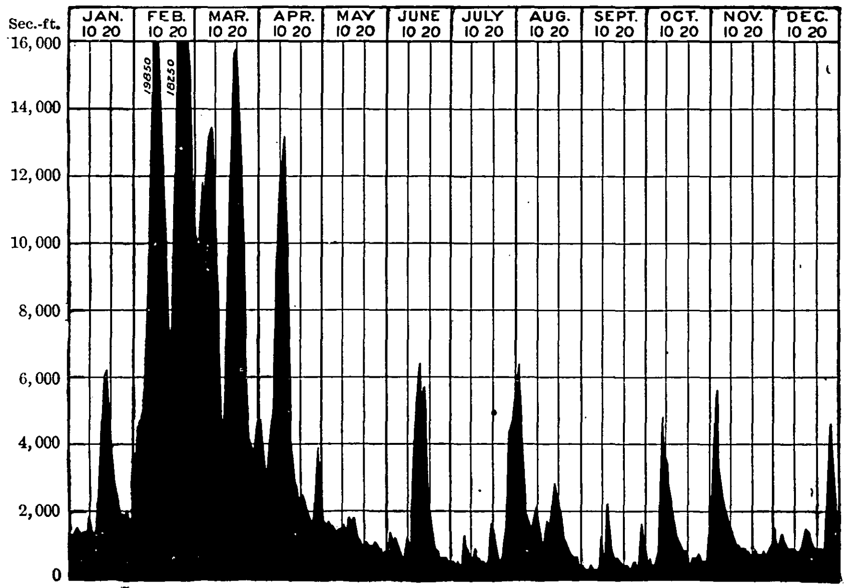


FIG. 61.—Discharge of Tar River at Tarboro, North Carolina, 1899.

NEUSE RIVER.

This river rises in the north-central part of North Carolina and flows in a southeasterly direction, emptying into Pamlico Sound. The river is subject to violent freshets and to periods of low flow. There is no power on the river below Smithfield, where it crosses the fall line. The station is at Selma, North Carolina. It was established July 29, 1896. Discharge measurements are made by E. W. Myers.

There are a number of localities along the river where power can probably be developed. The elevation of the river at Smithfield is about 106 feet above sea level. At the crossing of the Seaboard Air Line railway, some 35 miles above, the elevation is about 175 feet, making the fall in that part of the river about 2 feet to the mile. Above the railroad crossing the fall is much greater. A considerable portion of the area drained is forest covered, and the minimum flow per square mile undoubtedly decreases in the upper portion of the catchment basin.

Additional details concerning this river may be found in the Nineteenth Annual Report, Part IV, page 185, and in the Twentieth Annual Report, Part IV, page 144.

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

[Drainage area, 1,175 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	3,200	356	1,107	68,067	0.94	1.08
February	12,050	1,625	6,754	375,098	5.74	5.98
March	9,890	1,425	5,386	331,172	4.58	5.28
April	8,570	495	2,078	123,650	1.76	1.96
May	1,760	440	948	58,290	0.81	0.93
June	3,625	335	868	51,650	0.73	0.81
July	3,850	295	948	58,290	0.81	0.93
August	4,100	265	843	51,834	0.72	0.83
September	712	185	289	17,197	0.25	0.28
October	4,100	195	721	44,333	0.61	0.68
November	4,540	235	964	57,362	0.82	0.91
December	980	295	436	26,809	0.37	0.43
The year	12,050	185	1,778	1,263,752	1.51	20.10

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 112; discharge measurements, page 111; rating table in Paper No. 39, page 443.

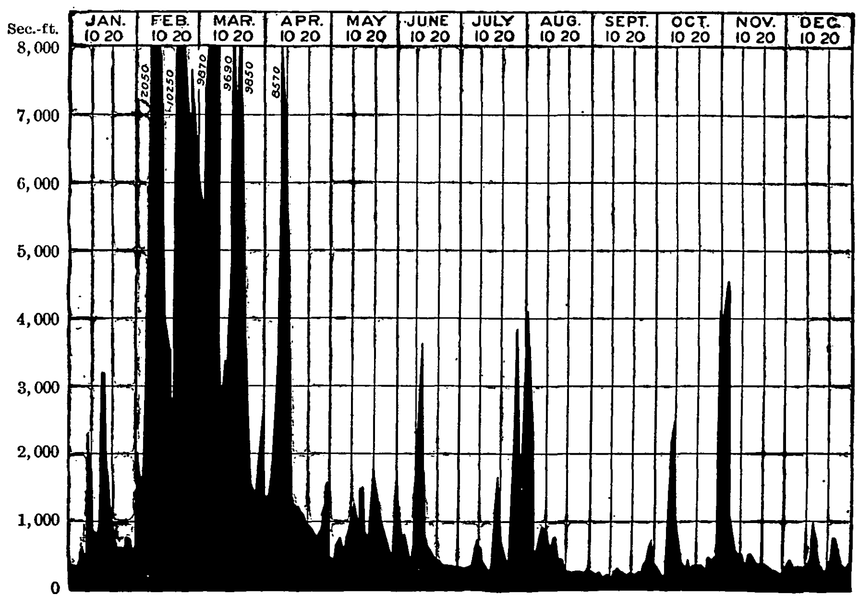


FIG. 62.—Discharge of Neuse River at Selma, North Carolina, 1899.

HAW RIVER.

This river is formed by two forks which rise in the counties of Guilford and Rockingham, North Carolina, and unite in Alamance County. It flows in a southeasterly direction through Alamance and Chatham counties, and unites with Deep River at Moncure, North Carolina, to form Cape Fear River. Including one branch, the river is nearly 130 miles long. The station, which is 1¾ miles north of Moncure, was established May 6, 1898. Discharge measurements are made by E. W. Myers.

Estimated monthly discharge of Haw River at Moncure, North Carolina.

[Drainage area, 1,800 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
May, 26 days	5,795	380	1,453	89,341	0.81	0.93
June	1,570	320	613	36,476	0.34	0.38
July	4,585	320	955	58,720	0.53	0.61
August	13,250	290	2,545	156,486	1.41	1.63
September	9,250	345	2,077	123,590	1.15	1.28
October	7,300	290	1,097	67,452	0.61	0.70
November	3,998	575	1,496	89,018	0.83	0.92
December	4,895	600	1,255	77,167	0.70	0.81
1899.						
January	9,700	730	2,840	174,625	1.58	1.82
February	24,200	2,425	9,860	547,597	5.48	5.71
March	21,000	2,213	7,816	480,587	4.34	5.00
April	11,000	950	2,790	166,017	1.55	1.73
May	6,200	625	1,881	115,658	1.05	1.21
June	3,190	320	944	56,172	0.52	0.58
July	5,570	305	1,019	62,656	0.57	0.66
August	2,935	270	856	52,633	0.48	0.55
September	1,690	270	465	27,669	0.26	0.29
October	5,390	280	1,028	63,209	0.57	0.66
November	8,100	320	1,116	66,407	0.62	0.69
December	1,450	305	464	28,530	0.26	0.30
The year	24,200	270	2,590	1,841,760	1.44	19.20

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 27, page 35; discharge measurements, page 44. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 36, page 113; rating table in Paper No. 39, page 443.

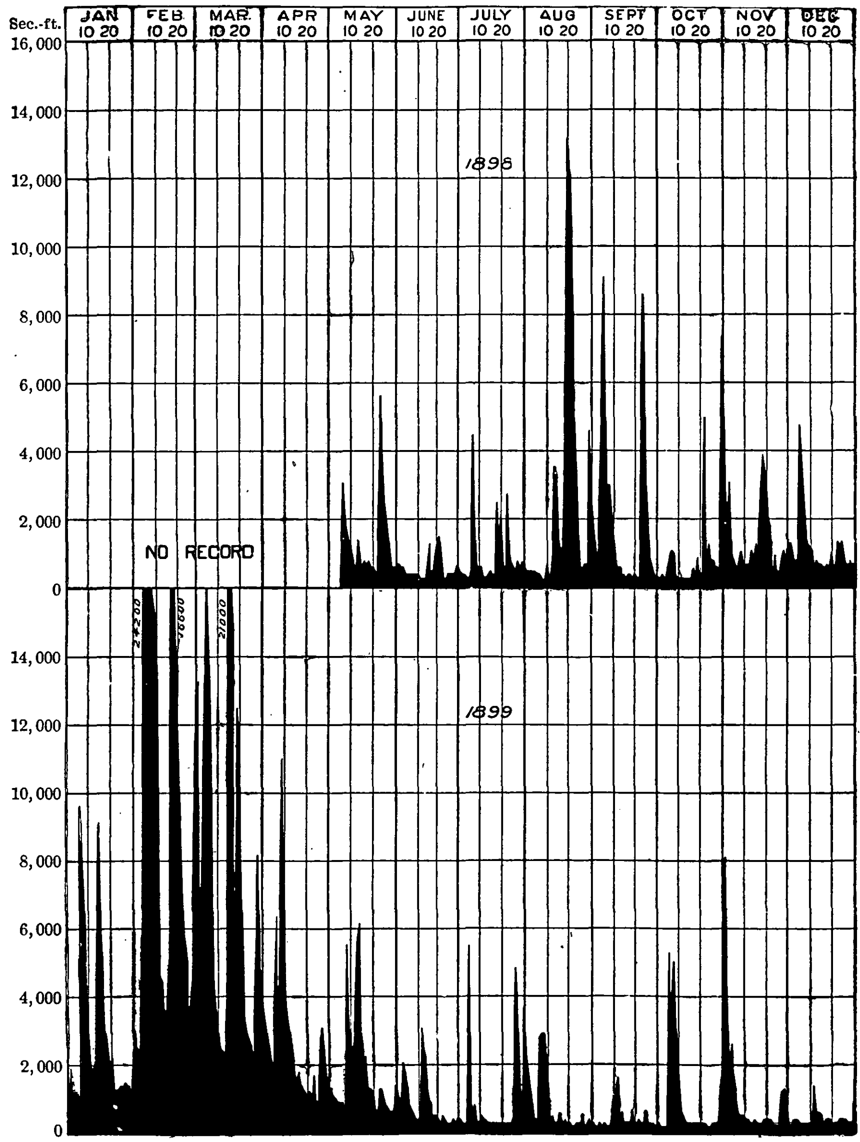


FIG. 63.—Discharge of Haw River at Moncure, North Carolina, 1898 and 1899.

DEEP RIVER.

This river rises in Guilford County, North Carolina, flows in a southeasterly direction through Randolph County, and subsequently flows eastward, uniting with Haw River at Moncure, Chatham County, forming the Cape Fear. The estimated length of Deep River is 130 miles. The station is about a quarter of a mile south of Moncure, and about 2 miles above the junction of the river with the Haw. The station was established May 5, 1898. Discharge measurements are made by E. W. Myers.

Estimated monthly discharge of Deep River at Moncure, North Carolina.

[Drainage area, 1,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
May, 27 days *a*	4,125	340	951	50,929	0.68	0.78
June	850	270	378	22,493	0.27	0.30
July	5,300	260	818	50,297	0.58	0.67
August	16,980	250	3,181	195,592	2.27	2.62
September	10,100	260	1,811	107,762	1.29	1.44
October	6,200	280	1,001	61,549	0.72	0.83
November			1,138	67,716	0.81	0.90
December			1,281	78,766	0.92	1.06
1899.						
January	10,650	515	2,876	176,838	2.05	2.37
February	24,570	2,320	10,109	561,425	7.22	7.52
March	21,930	1,665	7,413	455,808	5.30	6.11
April	15,605	875	3,278	195,055	2.34	2.61
May	6,850	470	1,759	108,157	1.26	1.45
June	2,415	325	673	40,046	0.48	0.54
July	3,935	240	701	43,103	0.50	0.58
August	2,273	225	651	40,028	0.47	0.54
September	2,558	220	408	24,278	0.29	0.32
October	4,800	230	888	54,601	0.63	0.72
November	10,350	235	940	55,934	0.67	0.74
December	3,603	245	601	36,954	0.43	0.49
The year	24,570	220	2,525	1,792,227	1.80	23.99

a Approximate.

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 27, page 35; discharge measurements, page 44. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 36, page 114; rating table in Paper No. 39, page 443.

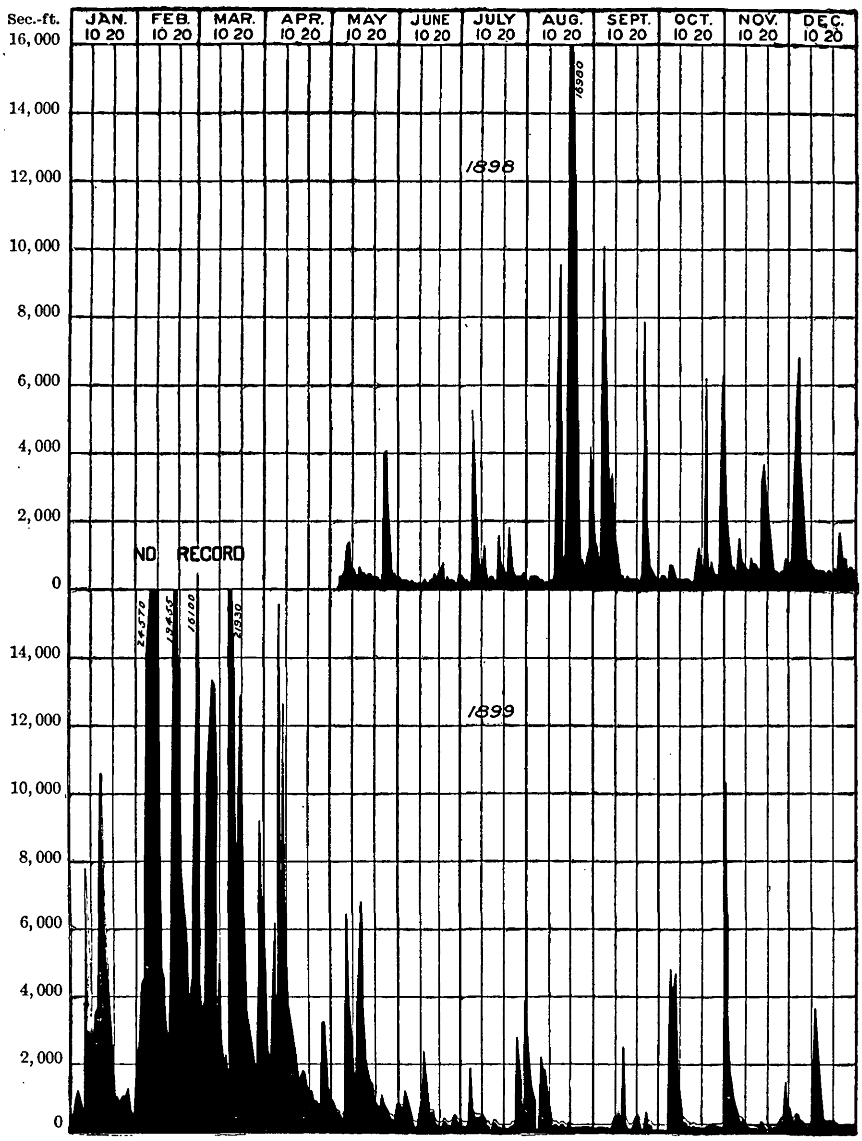


FIG. 64.—Discharge of Deep River at Moncure, North Carolina, 1898 and 1899.

CAPE FEAR RIVER.

This river is formed by the junction of Haw and Deep rivers at Moncure, Chatham County, North Carolina. It flows in a southerly direction and empties into the Atlantic Ocean near Wilmington, North Carolina. Most of its watershed is flat and well covered with forests. Measurements of Cape Fear River are made at Fayetteville. The station is located about a mile east of the city. Measurements are also made of Haw and Deep rivers. The measurements, which are of value in the study of the valuable water powers of the Cape Fear and its tributaries, are made by E. W. Myers.

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

[Drainage area, 4,493 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	16,462	1,940	5,116	314,570	1.14	1.31
February	69,200	4,955	25,842	1,435,187	5.75	5.98
March	48,200	4,214	17,042	1,047,788	3.79	4.31
April	34,600	3,064	8,408	500,311	1.87	2.09
May	9,347	1,782	3,706	227,873	0.82	0.85
June	5,593	984	2,280	135,669	0.51	0.57
July	6,613	910	2,481	152,551	0.55	0.63
August	5,833	645	1,947	119,716	0.43	0.44
September	2,578	612	1,133	67,418	0.25	0.28
October	9,161	612	2,132	131,092	0.47	0.54
November	13,482	1,319	3,151	187,498	0.70	0.78
December	7,333	1,674	2,992	183,971	0.67	0.77
The year	69,200	612	6,352	4,503,644	1.41	18.65

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 116; discharge measurements, page 115; rating table in Paper No. 39, page 443.

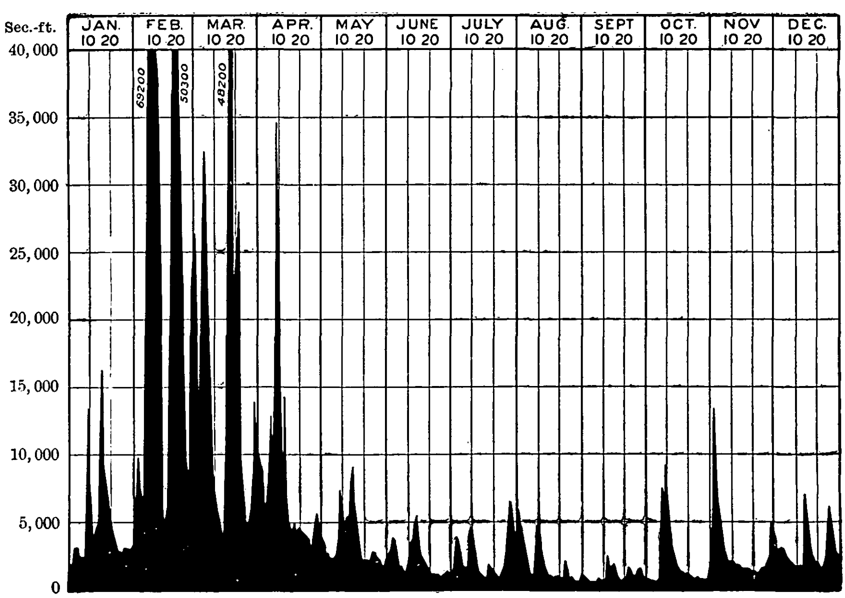


FIG. 65.—Discharge of Cape Fear River at Fayetteville, North Carolina, 1899.

YADKIN RIVER.

This river rises in the west-central part of North Carolina, flows first easterly, then turns abruptly south and continues across the central part of North Carolina and through the northeastern part of South Carolina. It empties into the Atlantic Ocean. After passing into South Carolina the river is known as the Pedee. Throughout the upper part of its course its watershed, which is well timbered, is rough and mountainous. As the ocean is approached the land becomes flat and marshy. There are a number of places where water powers can be developed, and measurements have been made to determine the amount of power available. Two stations have been established on the river, one near Salisbury, North Carolina, established September 24, 1895, and the other at Norwood, North Carolina, established September 1, 1896. Discharge measurements at both stations are made by E. W. Myers.

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

[Drainage area, 3,399 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	46,600	2,500	8,548	525,596	2.51	2.90
February	45,800	3,100	13,443	746,586	3.95	4.11
March	107,400	6,900	23,899	1,469,492	7.03	8.10
April	27,700	6,500	9,825	584,628	2.89	3.22
May	11,300	4,000	6,211	381,899	1.83	2.11
June	12,900	3,100	4,823	286,988	1.42	1.58
July	10,900	2,250	3,703	227,689	1.09	1.26
August	5,000	1,450	2,356	144,865	0.69	0.79
September	10,500	1,450	2,495	148,463	0.73	0.81
October	5,700	1,600	2,226	136,871	0.65	0.75
November	3,700	1,800	2,120	126,149	0.62	0.69
December	8,900	1,800	2,716	167,000	0.80	0.92
The year	107,400	1,450	6,864	4,946,226	2.02	27.24

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 117; rating table in Paper No. 39, page 443.

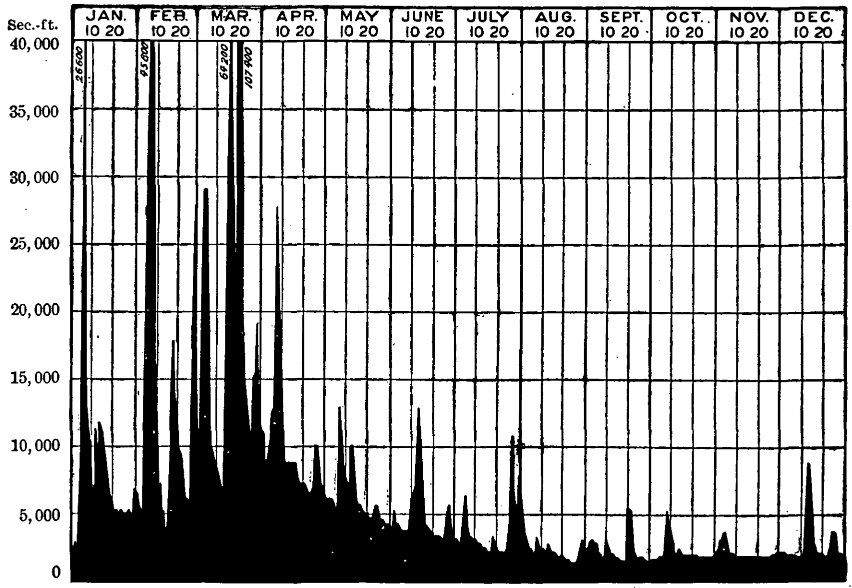


FIG. 66.—Discharge of Yadkin River at Salisbury, North Carolina, 1899.

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

[Drainage area, 4,614 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	51,000	5,400	12,026	739,450	2.61	3.00
February	66,750	5,820	22,070	1,225,706	4.78	4.97
March 1 to 18*a*	....	4,600	24,572	1,510,873	5.33	6.14
April 9 to 30*a*	....	5,820	8,219	489,064	1.78	1.99
May	17,200	5,000	7,523	462,571	1.63	1.88
June	12,980	3,570	5,865	348,992	1.27	1.42
July	14,180	2,670	4,489	276,018	0.97	1.12
August	7,500	2,080	3,321	204,200	0.72	0.83
September	8,760	2,080	3,355	199,636	0.73	0.81
October	6,240	1,790	2,840	174,625	0.62	0.71
November	4,250	2,080	2,999	178,453	0.65	0.72
December	9,180	2,080	3,739	229,902	0.81	0.93

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 119; discharge measurements, page 118; rating table in Paper No. 39, page 443.

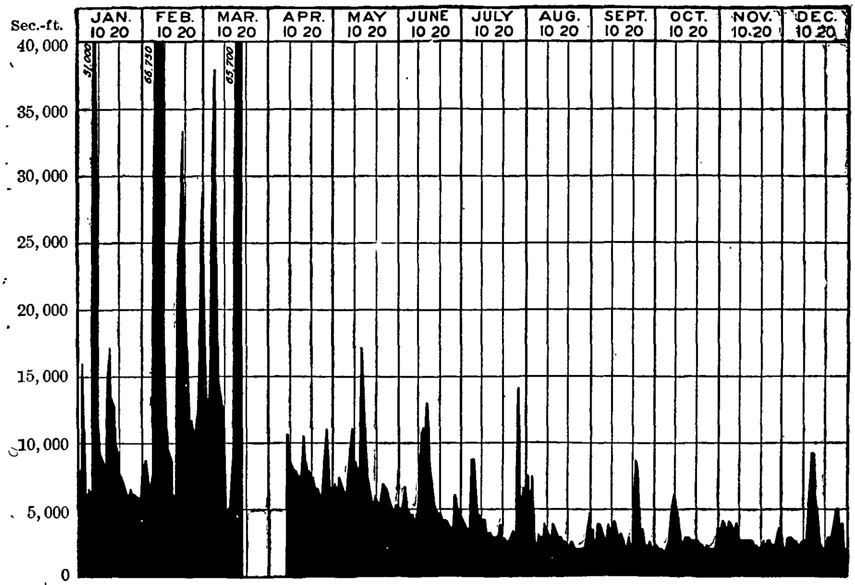


FIG. 67.—Discharge of Yadkin River at Norwood, North Carolina, 1899.

CATAWBA RIVER.

This river rises in the west-central part of North Carolina and flows in a general southerly direction into South Carolina; where it unites with Congaree River to form the Santee. In South Carolina the Catawba is known as Wateree River. Near its source the river flows through a mountainous country, which becomes more level as the South Carolina line is approached. The greater portion of its watershed is covered with woodland or forest. At a number of places there are water powers which can be developed. Two stations are maintained, one at Catawba, North Carolina, established July 4, 1896, and the other, known as the Rockhill station, 3 miles south of Fort Mill, South Carolina, established September 7, 1895. Measurements of discharge are made by E. W. Myers.

Additional details concerning this stream have been published in Water-Supply Paper No. 36, beginning on page 121. In that discussion is given a comparison of the minimum flows for Catawba River at Catawba and Rockhill, the latter place being the farther downstream, which shows that the minimum flow per square mile is less for the lower station, although the drainage area is greater.

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

[Drainage area, 1,514 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	17,075	2,400	4,175	256,711	2.76	3.18
February	32,710	2,400	8,776	487,394	5.80	6.04
March	61,050	4,135	13,127	807,148	8.67	9.99
April	19,730	3,900	6,172	367,259	4.08	4.55
May	8,520	2,600	3,933	241,831	2.59	2.99
June	3,787	1,270	2,492	148,284	1.65	1.84
July	4,625	1,470	1,873	115,166	1.24	1.43
August	5,400	1,270	1,645	101,147	1.09	1.26
September	2,800	1,210	1,588	94,493	1.05	1.17
October	1,760	1,150	1,386	85,222	0.92	1.06
November	1,540	1,270	1,384	82,354	0.91	1.01
December	12,650	1,400	2,921	179,605	1.93	2.22
The year	61,050	1,150	4,123	2,966,614	2.72	36.74

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 121; rating table in Paper No. 39, page 443.

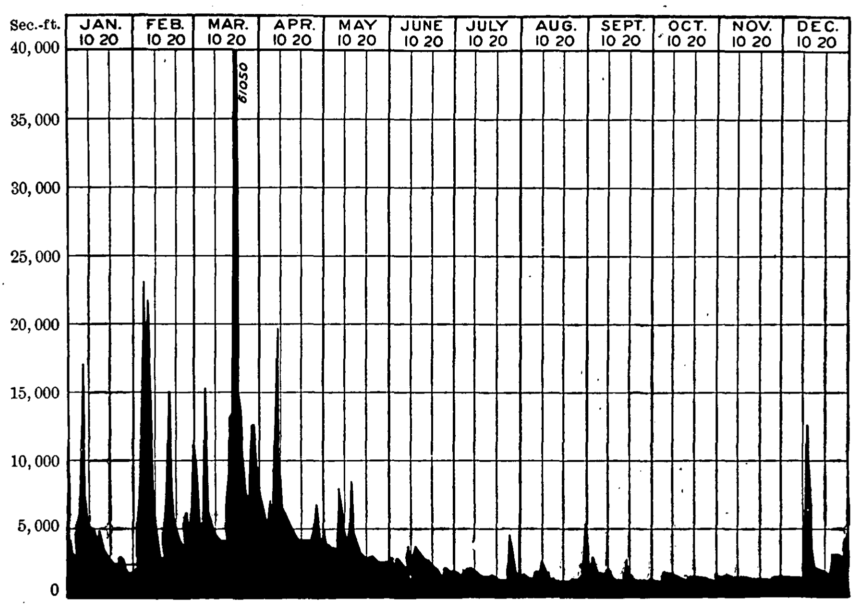


FIG. 68.—Discharge of Catawba River at Catawba, North Carolina, 1899.

Estimated monthly discharge of Catawba River at Rockhill, South Carolina.

[Drainage area, 2,987 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	29,174	2,830	6,144	377,780	2.06	2.37
February	43,202	3,090	13,670	659,193	4.58	4.76
March	66,965	4,060	17,486	1,075,172	5.85	6.74
April	22,986	4,880	8,505	506,083	2.85	3.17
May	11,494	3,090	4,702	289,115	1.57	1.81
June	5,310	2,390	2,916	173,514	0.98	1.09
July	4,460	1,880	2,317	142,467	0.78	0.90
August	3,380	1,640	2,152	132,321	0.72	0.83
September	7,958	1,640	2,479	147,511	0.83	0.92
October	3,380	1,640	1,914	117,687	0.64	0.74
November	2,600	1,640	1,853	110,261	0.62	0.69
December	8,400	1,750	2,963	182,188	0.99	1.14
The year	66,965	1,640	5,592	4,013,292	1.87	25.16

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 123; discharge measurements, page 122; rating table in Paper No. 39, page 444.

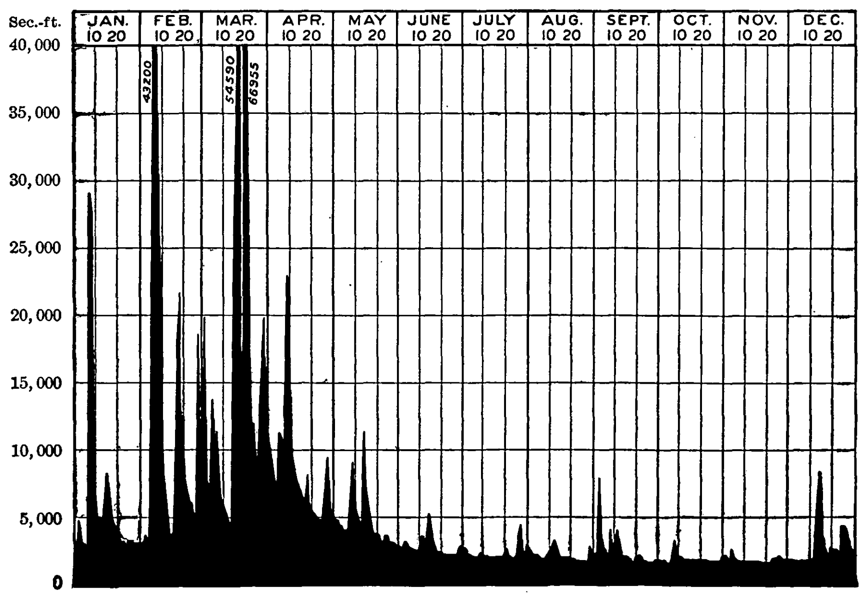


FIG. 69.—Discharge of Catawba River at Rockhill, South Carolina, 1899.

BROAD RIVER (OF THE CAROLINAS).

This river rises on the eastern slope of the Blue Ridge Mountains, near Hickorynut Gap, in the west-central part of North Carolina. It flows in a general southeasterly direction and unites with Saluda River above Columbia, South Carolina, to form the Congaree. The latter river unites with the Wateree to form the Santee. The drainage area covers about 4,950 square miles, of which 3,550 are in South Carolina and 1,400 in North Carolina. The upper part of the basin is a rough,

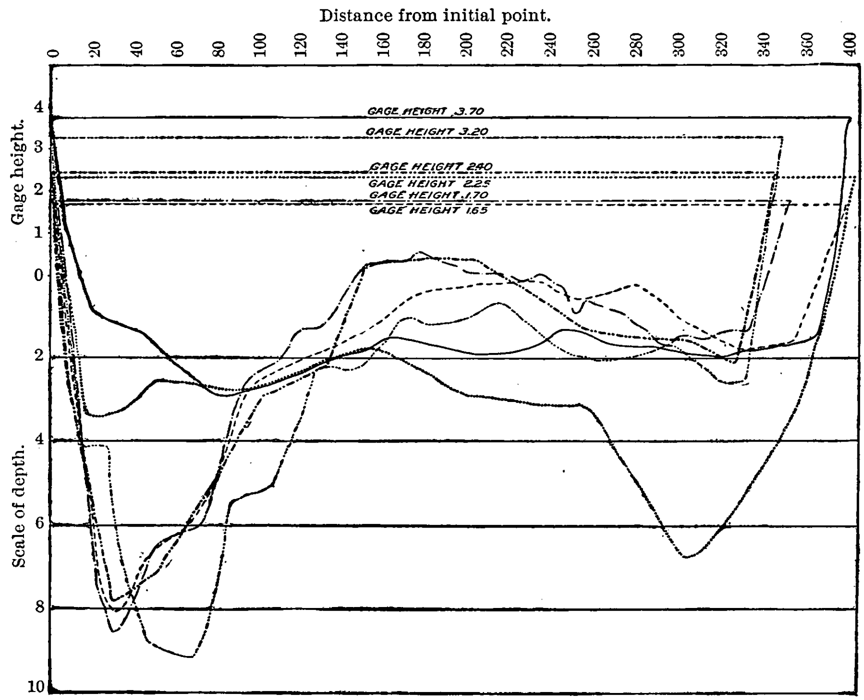


FIG. 70.—Cross sections of Broad River (of the Carolinas) at Gaffney, South Carolina.

broken country, largely covered with forests. In South Carolina the topography is flatter and the greater part of the land within the basin is under cultivation. Broad River receives a number of important tributaries, but there are no towns of importance along it. There are a number of sites for the possible development of water power, which are described in the Nineteenth Annual Report, Part IV, page 215. Two stations are maintained on the river—one near Gaffney, South Carolina, and the other at Alston, South Carolina, the latter established July 3, 1896. Discharge measurements at both stations are made by E. W. Myers. Fig. 70 (cross sections of the river at Gaffney) shows the changes that have taken place in the cross section corresponding to the various heights of water.

Estimated monthly discharge of Broad River (of the Carolinas) at Gaffney, South Carolina.

[Drainage area, 1,435 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January	7,840	3,400	4,503	276,879	3.14	3.62
February	7,240	3,500	4,739	263,191	3.30	3.44
March	9,760	3,500	4,425	272,083	3.08	3.55
April	7,840	4,040	5,161	307,101	3.60	4.02
May	4,605	3,500	4,045	248,717	2.82	3.25
June	4,840	2,660	3,378	201,005	2.35	2.62
July	8,200	2,750	4,414	271,406	3.08	3.55
August	10,000	3,600	4,951	304,425	3.45	3.98
September	23,200	3,820	7,066	420,456	4.92	5.48
October 26 to 31			1,738	106,865	1.21	1.39
November	2,120	1,650	1,727	102,764	1.20	1.34
December	6,400	1,200	2,391	147,017	1.67	1.93
1899.						
January	16,240	1,650	3,349	205,922	2.33	2.69
February, 25 days	20,560	2,120	6,857	380,818	4.78	4.98
March	25,360	3,210	8,157	501,554	5.68	6.54
April	11,440	2,660	4,595	273,421	3.20	3.57
May	6,880	1,500	2,541	156,240	1.77	2.04
June	3,820	1,050	1,689	100,502	1.18	1.32
July	2,660	900	1,257	77,290	0.88	1.01
August	2,660	680	1,276	78,458	0.89	1.02
September	2,480	600	1,050	62,479	0.73	0.81
October	1,350	600	872	53,617	0.61	0.70
November	1,350	680	913	54,327	0.64	0.71
December	4,490	680	1,336	82,147	0.93	1.07
The year	25,360	600	2,824	2,026,775	1.97	26.46

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 27, page 38; discharge measurement, page 44. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 36, page 124; rating table in Paper No. 39, page 444.

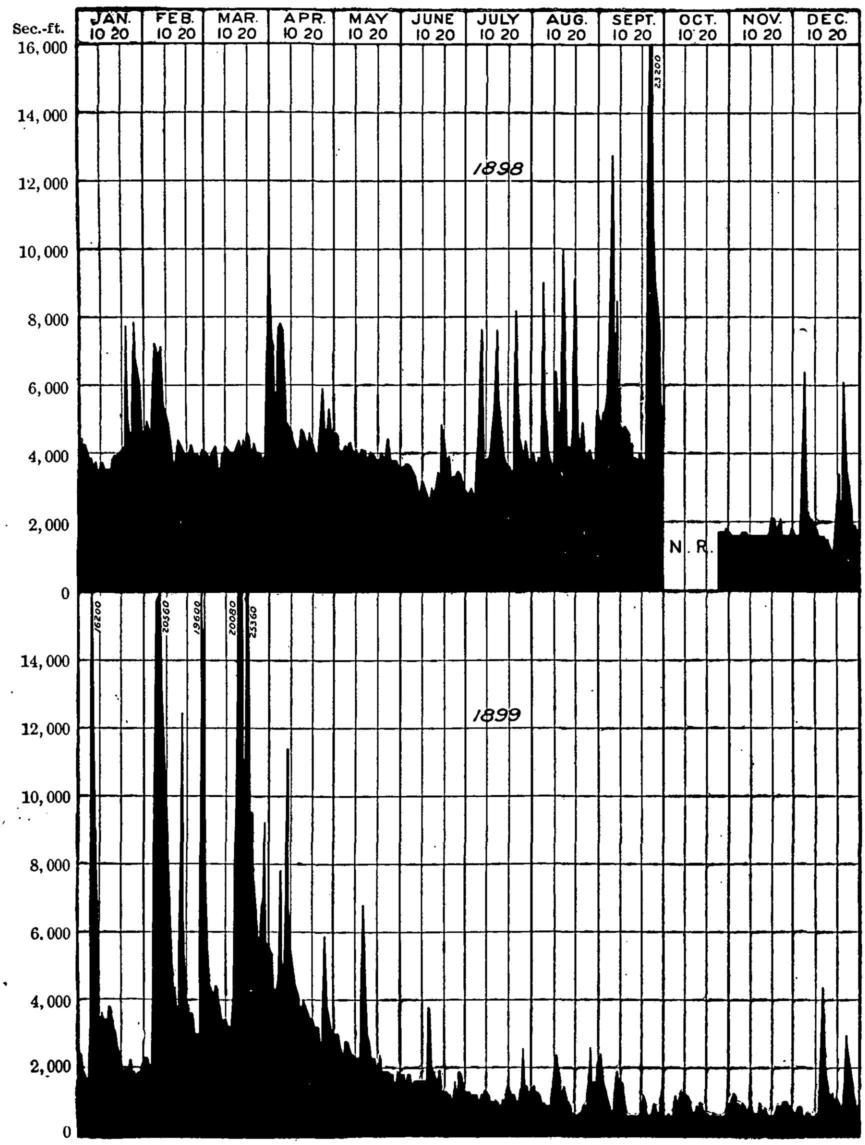


FIG. 71.—Discharge of Broad River (of the Carolinas) at Gaffney, South Carolina, 1898 and 1899.

Estimated monthly discharge of Broad River (of the Carolinas) at Alston, South Carolina.

[Drainage area, 4,609 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	46,200	4,000	10,271	631,539	2.23	2.57
February	66,450	6,050	23,167	1,286,630	5.03	5.24
March	52,500	6,300	19,574	1,203,558	4.25	4.90
April	23,700	5,675	10,361	616,522	2.25	2.51
May	7,080	3,500	4,767	293,111	1.03	1.19
June	6,050	2,340	3,480	207,074	0.76	0.85
July	11,875	1,650	2,923	179,728	0.63	0.72
August	9,550	1,520	3,373	207,398	0.73	0.84
September	25,050	1,650	3,952	235,160	0.86	0.95
October	12,050	1,460	2,897	178,130	0.63	0.72
November	9,550	1,890	3,447	205,111	0.75	0.83
December	20,100	2,430	5,673	348,819	1.23	1.42
The year	66,450	1,460	7,824	5,592,780	1.70	22.74

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 125; rating table in Paper No. 39, page 444.

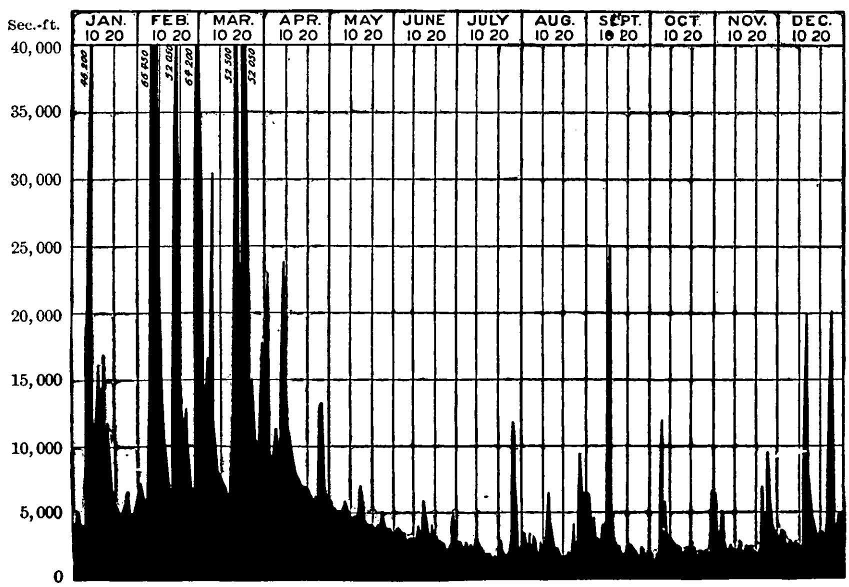


FIG. 72.—Discharge of Broad River (of the Carolinas) at Alston, South Carolina, 1899.

SALUDA RIVER.

This river rises in the mountains between North and South Carolina, flows in a southeasterly direction, and near Columbia, South Carolina, unites with the Broad to form the Congaree. Measurements have been made to determine the horsepower available on the Saluda. The station was established August 30, 1896. It is near Waterloo, being at the Charleston and Western Carolina Railway bridge about 3 miles from Coronaca, South Carolina. Measurements of discharge are made by E. W. Myers.

Estimated monthly discharge of Saluda River at Waterloo, South Carolina.

[Drainage area, 1,056 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	9,845	1,103	2,683	164,971	2.54	2.93
February	15,850	1,805	5,417	300,845	5.13	5.34
March	11,070	2,375	4,448	273,497	4.21	4.85
April	4,287	1,902	2,858	170,063	2.71	3.02
May	2,585	925	1,666	102,438	1.58	1.82
June	2,098	850	1,256	74,737	1.19	1.33
July	1,837	505	1,145	70,403	1.08	1.25
August	1,870	430	1,096	67,390	1.04	1.20
September	2,620	485	1,137	67,656	1.08	1.20
October	1,967	485	1,135	69,788	1.07	1.23
November	2,515	505	1,204	71,643	1.14	1.27
December	3,012	550	1,375	84,545	1.30	1.50
The year	15,850	430	2,118	1,517,976	2.01	26.94

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 127; discharge measurement, page 126; rating table in Paper No. 39, page 444.

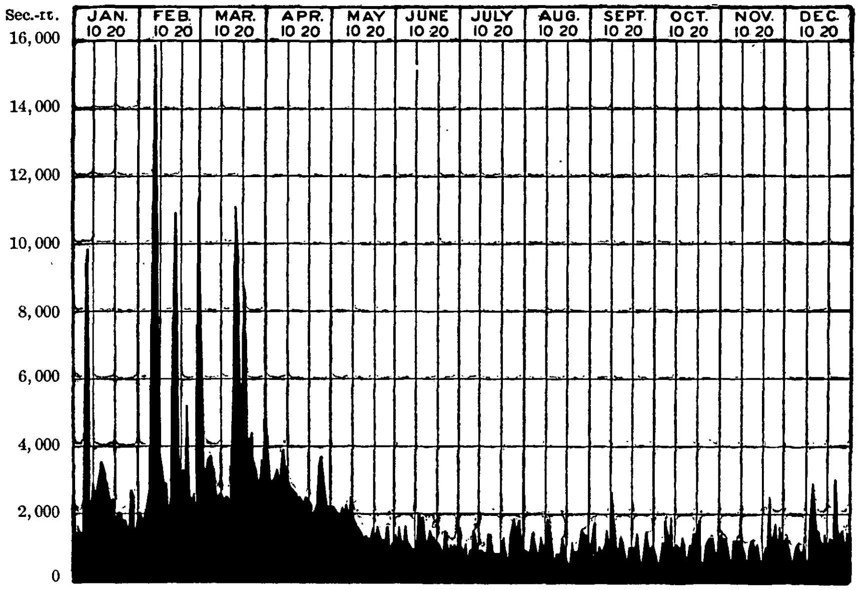


FIG. 73.—Discharge of Saluda River at Waterloo, South Carolina, 1899.

TUGALOO RIVER.

This river is formed by the junction of the Tallulah and Chattooga rivers, which have their sources in the Blue Ridge Mountains. The basin is largely covered with an original growth of oak and is extremely wild and picturesque. There are many beautiful falls in its watershed, the most important being the Tallulah—which make a descent of 335 feet in four successive leaps, the total fall in $2\frac{2}{3}$ miles being 525 feet—and the Toccoa, on Toccoa Creek, with a vertical fall of 190 feet. The station is at Cooks Ferry, about a half mile from Madison, South Carolina. It was established July 19, 1898. Measurements are made by Max Hall and others. A number of discharge measurements have also been made of various tributaries of Tugaloo River, the results of which are given in Water-Supply Paper No. 36, page 129.

Estimated monthly discharge of Tugaloo River at Madison, South Carolina.

[Drainage area, 593 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	4,020	1,634	2,099	129,062	3.54	4.08
February	9,020	1,889	3,790	210,486	6.37	6.63
March	11,780	2,310	4,771	293,357	8.05	9.28
April	5,820	2,310	3,276	194,936	5.52	6.16
May	2,710	1,430	1,881	115,658	3.17	3.66
June	3,100	1,073	1,448	86,163	2.44	2.72
July	2,310	716	1,027	63,148	1.73	1.99
August	4,060	563	801	49,252	1.35	1.56
September	1,838	512	765	45,521	1.29	1.44
October	1,838	512	662	40,705	1.12	1.29
November	1,481	512	619	36,834	1.04	1.16
December	8,700	563	1,411	86,759	2.38	2.74
The year	11,780	512	1,879	1,351,881	3.17	42.71

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 128; rating table in Paper No. 39, page 444.

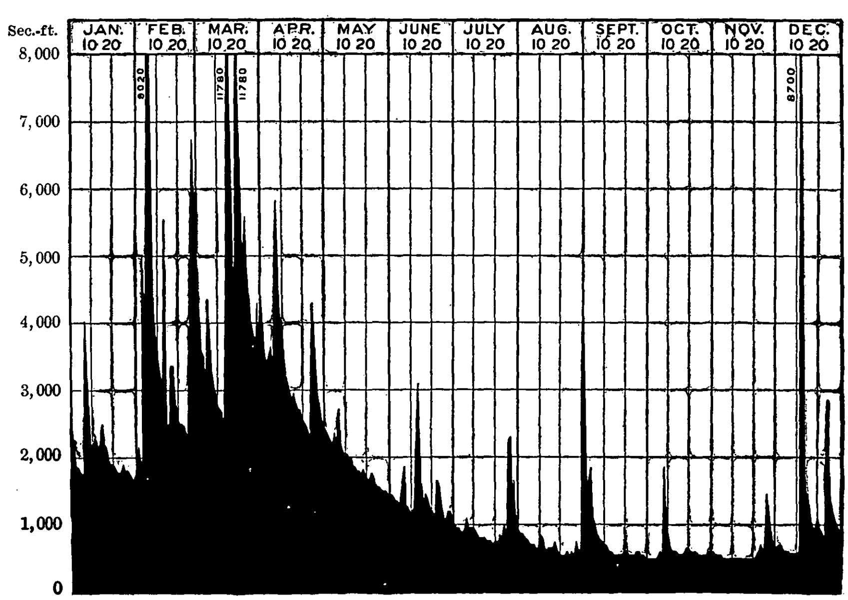


FIG. 74.—Discharge of Tugaloo River at Madison, South Carolina, 1899.

BROAD RIVER (OF GEORGIA).

This river rises in the northeastern part of Georgia and flows in a southeasterly direction between Elbert and Wilkes counties, emptying into Savannah River. The watershed is a rolling country, largely covered with timber. The station is at Carlton, Georgia. It was established May 27, 1897. Measurements are made by Max Hall.

Estimated monthly discharge of Broad River (of Georgia) at Carlton, Georgia.

[Drainage area, 762 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	4,757	975	1,599	98,319	2.10	2.42
February	17,380	1,220	3,602	200,045	4.73	4.93
March	14,815	1,407	2,870	176,469	3.77	4.35
April	3,900	1,257	1,622	96,516	2.13	2.38
May	1,370	870	1,072	65,915	1.41	1.63
June	1,760	730	957	56,945	1.26	1.41
July	4,825	570	943	57,983	1.24	1.43
August	2,090	490	721	44,333	0.95	1.09
September	1,840	490	654	38,916	0.86	0.95
October	2,270	490	684	42,058	0.90	1.04
November	1,760	570	771	45,878	1.01	1.13
December	2,360	660	940	57,798	1.23	1.42
The year	17,380	490	1,370	981,175	1.80	24.18

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 132; rating table in Paper No. 39, page 444.

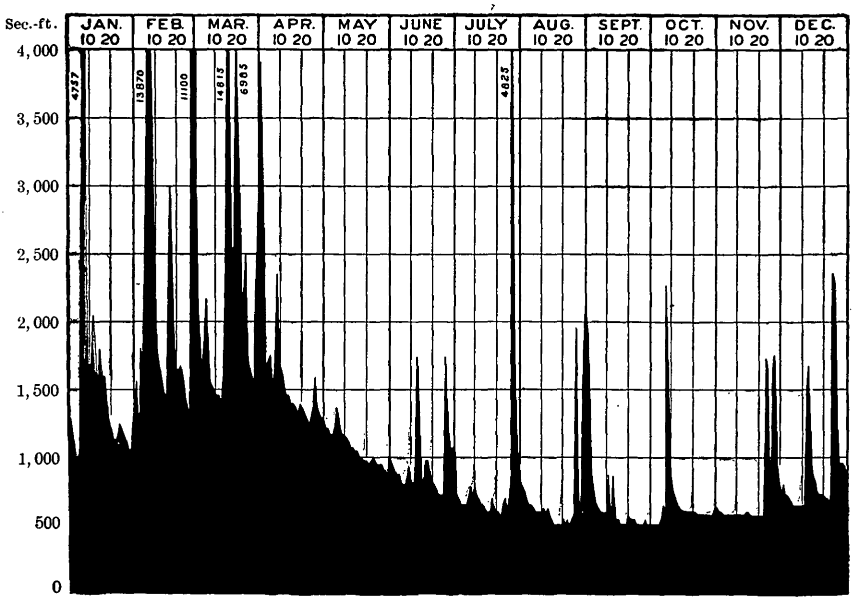


FIG. 75.—Discharge of Broad River (of Georgia) at Carlton, Georgia, 1899.

SAVANNAH RIVER.

This river is formed by the junction of Seneca and Tugaloo rivers, about 100 miles above Augusta, Georgia. The headwater tributaries have their sources in the Blue Ridge Mountains, in North and South Carolina and Georgia, where more than one-fifth of the territory is in original oak forest. There are a large number of fine water powers along the main river and its tributaries, the most important being at Tallulah Falls, on Tallulah River, which are 335 feet high, there being a total fall of 525 feet in a distance of $2\frac{5}{8}$ miles. In order to determine the value of these water powers, systematic measurements were begun August 4, 1896, at the Seaboard Air Line railway bridge about 3 miles west of the town of Calhoun Falls, South Carolina. Another station is maintained at Augusta, Georgia, where records have been kept by the city of Augusta since 1875. Measurements at both stations are made by B. M. Hall and Max Hall.

Estimated monthly discharge of Savannah River near Calhoun Falls, South Carolina.

[Drainage area, 2,712 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 4 to 31	50,324	7,256	15,185	933,689	5.60	6.46
April	19,244	3,120	9,632	573,144	3.55	3.96
May	7,700	3,770	5,798	356,505	2.14	2.47
June	12,140	3,120	4,922	292,879	1.81	2.02
July	12,140	1,990	3,184	195,777	1.17	1.35
August	5,480	2,330	3,031	186,369	1.12	1.29
September	4,160	1,990	2,870	170,777	1.06	1.18
October	7,256	1,910	2,549	156,732	0.94	1.08
November	7,700	1,830	2,474	147,213	0.91	1.01
December	12,140	2,190	4,434	272,636	1.63	1.88

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 130; discharge measurements, page 129; rating table in Paper No. 39, page 444.

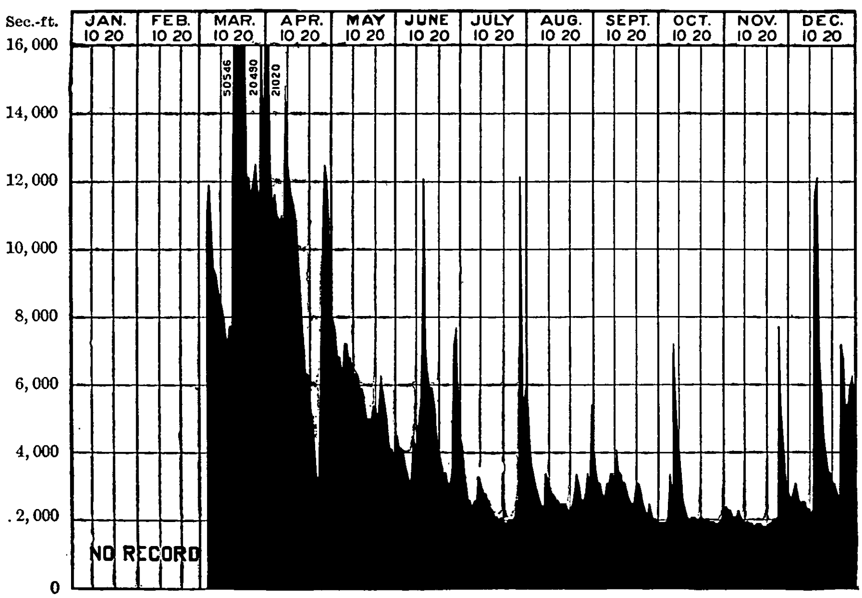


FIG. 76.—Discharge of Savannah River near Calhoun Falls, South Carolina, 1899.

Estimated monthly discharge of Savannah River at Augusta, Georgia.

[Drainage area, 7,294 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	45,320	7,600	16,034	985,893	2.20	2.54
February	112,800	12,850	34,891	1,937,748	4.78	4.98
March	93,440	11,900	24,804	1,525,138	3.41	3.93
April	31,700	9,420	14,386	856,027	1.97	2.20
May	10,820	5,750	7,640	469,765	1.05	1.21
June	9,590	4,360	6,090	362,380	0.83	0.92
July	13,230	3,250	5,148	316,538	0.71	0.82
August	16,430	2,350	5,126	315,185	0.70	0.81
September	17,690	3,160	5,554	330,486	0.76	0.85
October	18,120	3,000	5,611	345,007	0.77	0.89
November	12,470	3,340	4,807	286,036	0.66	0.73
December	19,000	3,000	7,043	433,057	0.97	1.12
The year	112,800	2,350	11,428	8,163,260	1.57	21.00

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 131; rating table in Paper No. 39, page 444.

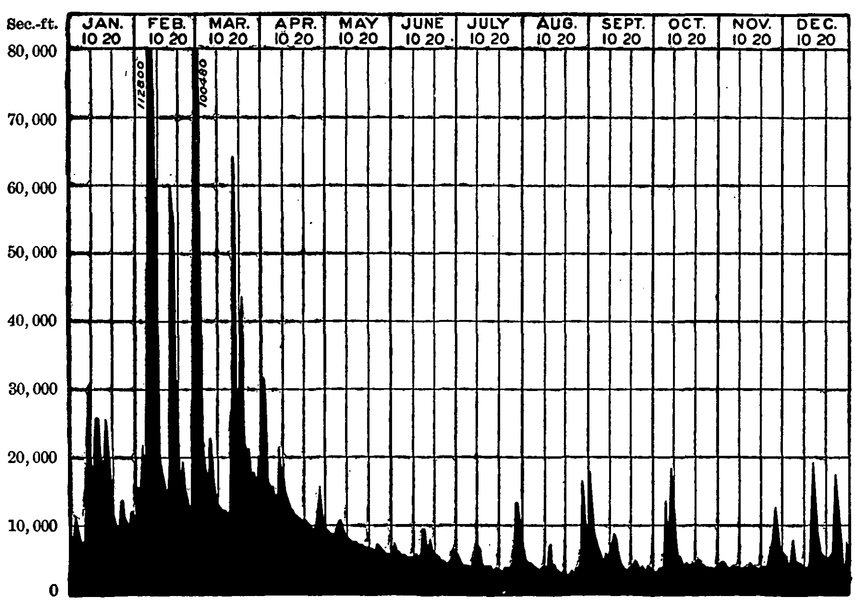


FIG. 77.—Discharge of Savannah River at Augusta, Georgia, 1899.

OCONEE RIVER.

This river rises in the northern part of Georgia, near Gainesville, on the southern slope of Chattahoochee Ridge, which separates the headwaters of the Oconee from the tributaries of Chattahoochee River. It flows in a southerly direction and joins the Ocmulgee, at the southern border of Montgomery County, to form the Altamaha. Most of its watershed is hilly and is made up of cultivated ground broken by extensive tracts of forest. For a time a station was maintained at Cary, Georgia, just below the mouth of Apalachee River, but as the ratings were affected by the dam several miles below, the station was abandoned March 31, 1898. Since that time measurements have been made at Dublin, Georgia, by B. M. Hall and his assistants.

Estimated monthly discharge of Oconee River at Dublin, Georgia.

[Drainage area, 4,182 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	17,302	4,070	10,736	660,131	2.57	2.96
February	25,510	8,638	14,954	830,503	3.58	3.73
March	19,240	7,498	12,183	749,103	2.91	3.36
April	11,032	5,332	7,639	454,552	1.83	2.04
May	6,016	2,429	3,420	210,288	0.82	0.94
June	2,644	1,300	1,862	110,797	0.45	0.50
July	5,560	1,015	1,669	102,623	0.40	0.46
August	5,674	982	2,097	128,939	0.50	0.58
September	3,480	890	1,630	96,992	0.39	0.44
October	9,664	865	2,628	161,589	0.63	0.72
November	4,888	1,015	1,666	99,134	0.40	0.45
December	6,244	1,746	3,047	187,353	0.73	0.84
The year	25,510	865	5,294	3,792,004	1.27	17.02

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 134; discharge measurements, page 133; rating table in Paper No. 39, page 444.

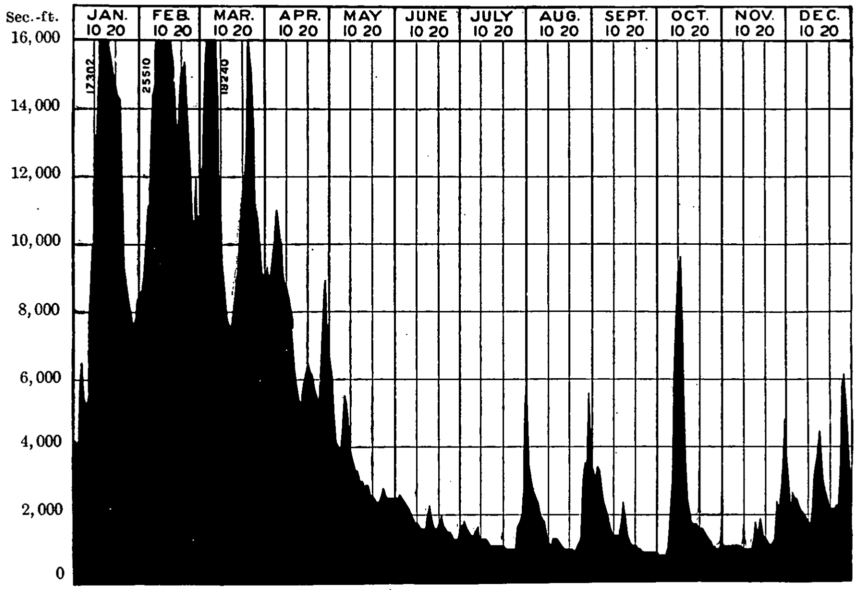


FIG. 78.—Discharge of Oconee River at Dublin, Georgia, 1899.

YELLOW RIVER.

This river is an important tributary of the Ocmulgee. Its headwaters are in Gwinnett County, Georgia, a short distance from Chattahoochee River. About a third of the watershed is under cultivation, the ground being well terraced on the hillsides. There are a number of falls along the river capable of development for water power. The station, which is at Almon, Georgia, was established September 12, 1897. Measurements are made by B. M. Hall and his assistants.

Estimated monthly discharge of Yellow River at Almon, Georgia.

[Drainage area, 379 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
May 9 to 31	570	255	391	24,042	1.03	1.19
June	570	175	276	16,423	0.73	0.81
July	1,155	147	284	17,462	0.75	0.86
August	660	120	223	13,712	0.59	0.68
September	412	147	197	11,722	0.52	0.58
October	750	147	256	15,741	0.68	0.78
November	862	193	272	16,185	0.72	0.80
December	1,087	277	405	24,902	1.07	1.23

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 135; rating table in Paper No. 39, page 444.

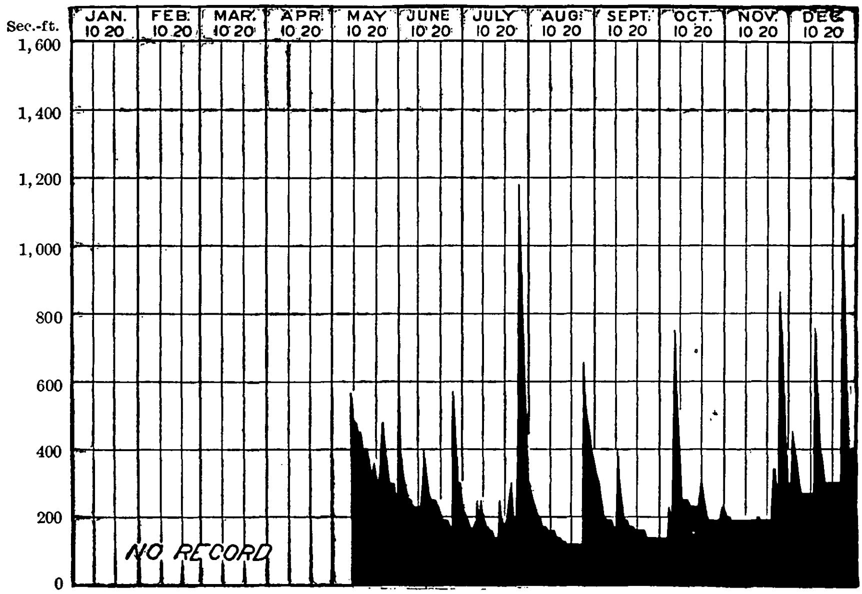


FIG. 79.—Discharge of Yellow River at Almon, Georgia, 1899.

OCMULGEE RIVER.

This river rises in the north-central part of Georgia and flows in a southeasterly direction, joining the Oconee, south of Mount Vernon, to form Altamaha River, which empties into the Atlantic Ocean. The drainage area has the same general features as that of the Oconee. The station at Macon was established by the United States Weather Bureau January 21, 1893; measurements were begun by the Survey in 1895, and are made by B. M. Hall and his assistants.

The details of measurements and observations on this river, as well of other streams in this vicinity, are given in Water-Supply Paper No. 36, and other facts are noted in the Twentieth Annual Report, Part IV, notably on pages 171 and 172. On the latter page is a diagram showing the fluctuations of the stream from 1893 to 1898, inclusive. The illustration on the next page (fig. 80) is a continuation of that graphic presentation.

Estimated monthly discharge of Ocmulgee River at Macon, Georgia.

[Drainage area, 2,425 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	19,840	2,380	5,570	342,486	2.30	2.66
February	21,920	3,820	8,140	452,073	3.36	3.50
March	18,292	3,460	5,495	337,874	2.27	2.62
April	11,060	2,770	4,481	266,638	1.85	2.06
May	5,090	1,390	2,112	129,862	0.87	1.00
June	2,800	810	1,331	79,200	0.55	0.61
July	3,220	650	1,196	73,539	0.49	0.56
August	2,140	620	1,071	65,853	0.44	0.51
September	1,720	580	880	52,364	0.36	0.40
October	6,820	600	1,339	82,332	0.55	0.63
November	3,340	620	987	58,731	0.41	0.46
December	4,000	850	1,581	97,212	0.65	0.75
The year	21,920	580	2,849	2,038,164	1.17	15.76

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 137; rating table in Paper No. 39, page 444.

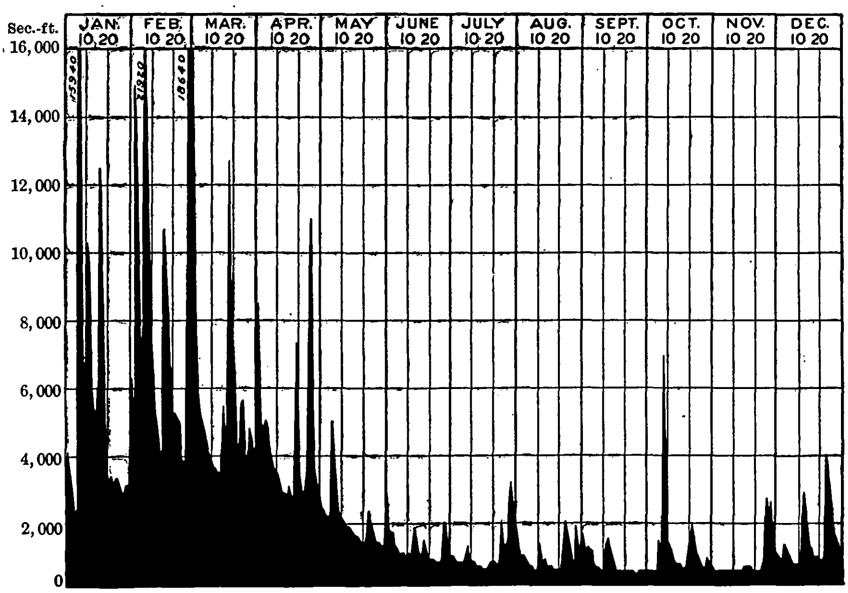


FIG. 80.—Discharge of Ocmulgee River at Macon, Georgia, 1899.

EASTERN GULF DRAINAGE.

CHATTAHOOCHEE RIVER.

The Chattahoochee rises in the northeastern part of Georgia and flows in a southwesterly direction to the boundary line between Georgia and Alabama, when it turns southward and forms the dividing line between those States to the southern border of Georgia, where it joins Flint River to form the Apalachicola. Its watershed above the mouth of Chestatee River is mountainous, and over 80 per cent of it is in oak forests; from that point to West Point, Georgia, it is narrow and hilly, about 50 per cent being under cultivation. From West Point to Columbus, Georgia, the river flows through a rocky, mountainous, well-wooded country. Below Columbus the river is navigable, but the country is hilly, consisting of extensive high plains traversed by narrow, deep valleys. There are a large number of important water powers on the main river and its tributaries. The most important fall is near Columbus, where the river descends 120 feet in 4 miles. From West Point to Columbus, a distance of 34 miles, there is a fall of 362 feet. Two stations are maintained on the river, one at Oakdale, Georgia, established October 17, 1895, and the other at West Point, Georgia, established July 30, 1896. Measurements are made by B. M. Hall and his assistants. A station has also been maintained by the United States Weather Bureau at Eufaula, Alabama, 80 miles below West Point.

Estimated monthly discharge of Chattahoochee River at Oakdale, Georgia.

[Drainage area, 1,560 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	6,675	2,385	3,712	228,242	2.38	2.75
February	26,695	3,350	8,511	472,677	5.46	5.68
March	29,425	4,337	9,178	564,333	5.88	6.77
April	14,800	3,962	5,931	352,919	3.80	4.24
May	5,800	2,385	3,280	201,679	2.10	2.43
June	4,930	1,740	2,310	137,455	1.48	1.65
July	6,450	1,220	1,948	119,778	1.25	1.44
August	5,420	870	1,506	92,600	0.97	1.12
September	4,700	910	1,413	84,079	0.91	1.01
October	2,100	870	1,175	72,248	0.75	0.86
November	3,000	1,000	1,408	83,782	0.90	1.00
December	7,200	1,160	2,242	137,855	1.44	1.66
The year	29,425	870	3,551	2,547,647	2.28	30.61

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, pages 141 and 142; discharge measurements, page 140; rating tables in Paper No. 39, pages 444 and 445.

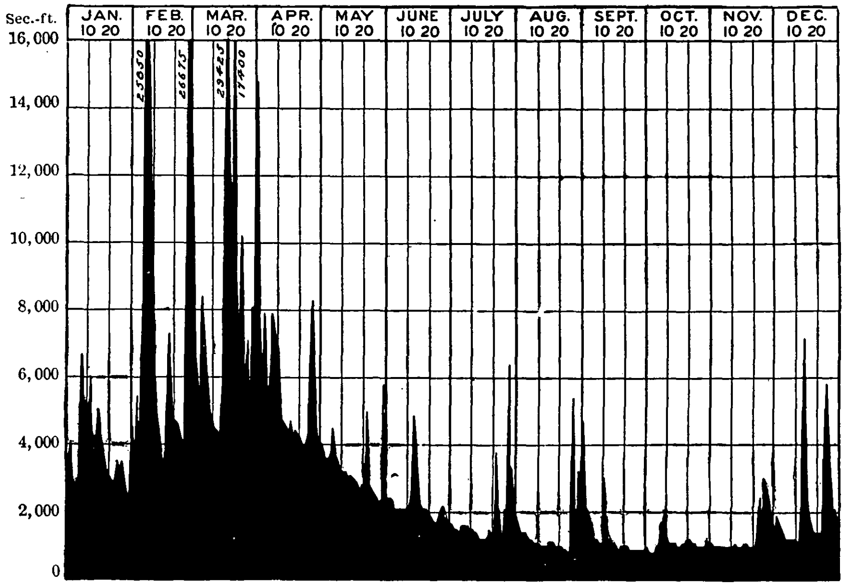


FIG. 81.—Discharge of Chattahoochee River at Oakdale, Georgia, 1899.

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

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	18, 720	4, 280	7, 483	460, 112	2. 27	2. 62
February	43, 550	4, 280	12, 903	716, 596	3. 91	4. 07
March	40, 330	7, 627	15, 696	965, 109	4. 76	5. 48
April	22, 200	6, 535	10, 157	604, 383	3. 08	3. 44
May	7, 490	3, 430	4, 716	289, 975	1. 43	1. 65
June	5, 625	2, 530	3, 625	215, 702	1. 10	1. 23
July	10, 524	1, 970	3, 419	210, 226	1. 04	1. 20
August	4, 280	1, 840	2, 819	173, 334	0. 85	0. 98
September	3, 340	970	1, 972	117, 342	0. 60	0. 67
October	3, 890	970	2, 088	128, 386	0. 63	0. 72
November	5, 880	1, 720	2, 303	137, 038	0. 70	0. 78
December	10, 800	2, 380	4, 685	288, 069	1. 42	1. 64
The year	43, 550	970	5, 989	4, 306, 272	1. 82	24. 48

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 143; discharge measurements, page 142; rating table in Paper No. 39, page 445.

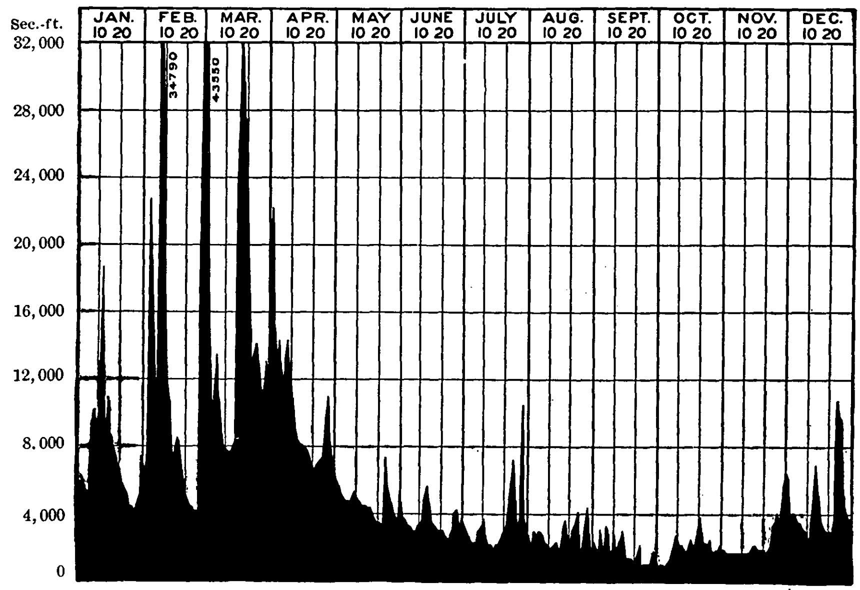


FIG. 82.—Discharge of Chattahoochee River at West Point, Georgia, 1899.

PUMPING WATER IN GEORGIA.

Prof. B. M. Hall states that very little attention has been given to artificial irrigation in Georgia, owing to the fact that the normal rainfall for the months of June, July, and August is about 13 inches; but it is not uniformly distributed through the crop season, and there is always danger of a drought that will injure the crops and materially reduce the yield. Irrigation is of special value in such a country as this, because a small flow of water accumulated gradually in a large reservoir and applied at the right time will accomplish much more when assisted by copious but irregular showers than it will in a rainless region.

In the hilly country of Georgia and adjacent States, where the streams have a rapid fall, much of the best land, such as river bottoms, creek bottoms, and other lowlands along the smaller streams, can be easily irrigated by local canals from never-failing streams, while the surplus from these same streams can be used to operate hydraulic rams for irrigating the higher plateaus. Many Rife hydraulic engines have been erected at country and suburban homes, but these have so far been used mainly for house and kitchen supply, stock and dairy use, and lawn sprinkling. Irrigation schemes have been considered, but they have not yet materialized.

In southern Georgia, southern Alabama, and Florida, different conditions exist, but they are quite as favorable to irrigation. There is everywhere a bountiful supply of water near at hand. In part of this region flowing artesian wells exist, and others are obtainable on the higher elevations. In such localities irrigation would be easy. Of course in the larger part of this region pumping by steam will be necessary, but wood for fuel is so abundant that its cost is only that of cutting and hauling a short distance. A pump lift of 50 feet is exceptional, and the plant necessary is simple and cheap. From a knowledge of the country and the ruling prices of labor at sawmills and turpentine stills, Mr. Hall makes the following estimate of the cost of operating a pumping plant consisting of a 10-horsepower boiler and a pump of sufficient capacity to lift 500 gallons per minute 50 feet high, the plant to run steadily 24 hours per day:

Fuel for 24 hours	$0.75
One engineer 12 hours	1.50
One engineer 12 hours	1.00
Helpers and incidentals	1.75
Total	$5.00

A plant of the size stated will deliver 720,000 gallons at a cost of $5, which is two-thirds of a cent for each 1,000 gallons, or a trifle more than $2.25 an acre-foot.

For a long time both canals and pumps have been used in Georgia to supply water for hydraulic gold mining, as described on page 173 of the Twentieth Annual Report, Part IV, where reference is made to the large mining canals.

Several large pumping plants have been successfully run by water power, the cost of operation being practically covered by supplies, repairs, and interest on investment, as the plants were run in conjunction with stamp mills and required no extra attendants. Considerable pumping has also been done by steam. Mr. Hall gives the details of a plant which he personally installed in 1884 and operated for about a year and a half for the Sale and Lamar Gold Mine, in Lincoln County, Georgia. The water-supply plant consisted of one 50-horsepower boiler (a 35-horsepower would have answered); one Blake duplex fire pump 7 by 14 by 12 inches; 3,000 feet of 7-inch spiral riveted pipe; and one reservoir on the hillside, at an elevation of 170 feet above the pump suction. This reservoir was simply a canal cut in clay soil, the excavated earth being used to form a berm on the lower side, thus increasing the capacity. As the earth was loosened with a plow it was thrown out with long-handled shovels. The excavation cost about 10 cents per cubic yard. The downhill side of the canal or reservoir was located on a contour line, with stakes 20 feet apart, these all being on the same level. At the upper end of the canal the water entered with a depth of 3½ feet, which was increased to give a grade on the bottom of 1 foot per half mile, the depth being 4½ feet below the contour line at the farther end. The width of the canal or reservoir varied. Where the ground was steep and rocky it was made very narrow, being not more than 5 feet at some points. Where the ground was flat and soft it was made 20 feet wide. The average dimensions of the cutting were about as follows: Length, 2,650 feet; depth, 4 feet; width, 12 feet. The berm more than doubled this capacity. The earth was spread in layers and compacted near the canal, the natural soil being stripped off in order to make proper contact with the clay. When compacted, water was pumped into the reservoir to the depth of a foot. Workmen then puddled the bottom and sides with rammers and stopped all the leaks. There were two reasons for making the reservoir long and narrow: First, in order to draw water from the farther end a half mile of piping was saved; second, as the earth was cast, instead of being hauled, the excavation was made narrow in bad ground and wide in good ground, this being the cheapest construction possible. The pump was operated steadily day and night, pumping 500 gallons per minute to an elevation of 170 feet. A duplicate pump was placed beside the one described, to take its place while packing or repairs were in progress. Often both pumps were run in conjunction, at half speed. The water was used for hydraulic mill mining, running a 2-inch giant nozzle ten hours a day under a head of 100 feet. Besides this there was a surplus of water for flooding or booming and for battery water at the mill, which was situated at the lower end of a 2,500-foot sluice flume reaching from the mine to the mill.

Cost of pumping for one day.

Four cords of pine wood, at $1	$4.00
One day engineer	2.00
One night engineer	1.50
Two helpers, at 75 cents	1.50
Oil, lights, supplies, and incidentals	1.00
Total for one day	10.00

Thus there was pumped 720,000 gallons per twenty-four hours at a total cost of $10, or at the rate of 1.4 cents per 1,000 gallons, or $5.50 per acre-foot, not counting the interest on the investment. The lift in this case (170 feet) is much higher than would ordinarily be required in districts to be irrigated.

ETOWAH RIVER.

The headwaters of this stream adjoin those of Chattahoochee River on the east and the headwater tributaries of Coosawattee River on the west. Its drainage area is on the southern slope of the Blue Ridge Mountains, the waters flowing westerly into the Gulf drainage. There are a number of fine powers on the river, the one at Cartersville being especially noted. At Rome, Georgia, the river joins the Oostanaula to form the Coosa. The station, which is at Canton, Georgia, was established by the United States Weather Bureau March 12, 1892.

Measurements by the Survey were commenced in 1896; they are made by B. M. Hall and his assistants.

Estimated monthly discharge of Etowah River at Canton, Georgia.

[Drainage area, 604 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	8,790	1,652	2,396	147,324	3.97	4.58
February, 25 days	8,790	1,652	2,987	165,890	4.95	5.15
March	15,596	1,652	3,382	207,951	5.60	6.45
April	4,474	1,652	2,344	139,478	3.88	4.33
May	1,984	1,320	1,681	103,361	2.78	3.21
June	4,142	1,320	1,644	97,825	2.72	3.03
July	3,810	1,320	1,770	108,833	2.93	3.38
August	1,984	1,154	1,534	94,322	2.54	2.93
September	1,154	325	729	43,379	1.21	1.35
October	665	225	472	29,022	0.78	0.90
November	1,403	450	614	36,536	1.02	1.14
December	2,980	590	1,098	67,513	1.82	2.10
The year	15,596	225	1,721	1,241,434	2.85	38.55

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 144; rating table in Paper No. 39, page 445.

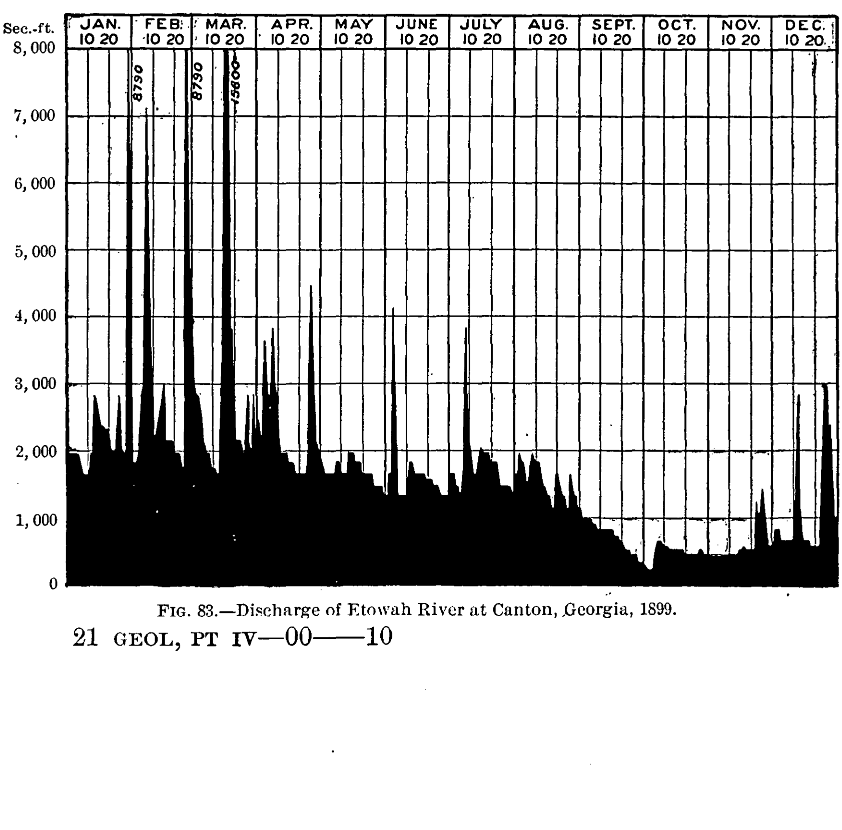


FIG. 83.—Discharge of Etowah River at Canton, Georgia, 1899.

COOSAWATTEE RIVER.

This river is formed by the junction of Ellijay and Cartecay rivers at Ellijay, Georgia. It flows in a southwesterly direction, joining the Conasauga to form the Oostanaula. Most of its drainage area is mountainous and covered with forest growth. The gaging station, which was established August 15, 1896, is at Carters, Murray County, Georgia. Measurements are made by O. P. Hall and Max Hall. Measurements of a number of the streams tributary to the Coosawattee have been made during the last season, notably of Ellijay River, Talking Rock Creek, Scared Corn Creek, and Sallacoa Creek.

Estimated monthly discharge of Coosawattee River at Carters, Georgia.

[Drainage area, 532 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,318	675	853	52,449	1.60	1.84
February	9,994	1,031	3,448	191,492	6.48	6.75
March	12,170	1,318	3,224	198,236	6.06	6.99
April	3,330	1,318	2,112	125,673	3.97	4.43
May	1,566	770	1,033	63,517	1.94	2.24
June	1,440	495	750	44,628	1.41	1.57
July	1,440	457	698	42,918	1.31	1.51
August	722	363	476	29,268	0.89	1.02
September	363	265	305	18,149	0.57	0.63
October	537	240	305	18,754	0.57	0.66
November	420	280	329	19,577	0.62	0.69
December	4,282	310	691	42,488	1.30	1.50
The year	12,170	240	1,185	847,149	2.23	29.83

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 146; discharge measurements, page 145; rating table in Paper No. 39, page 445.

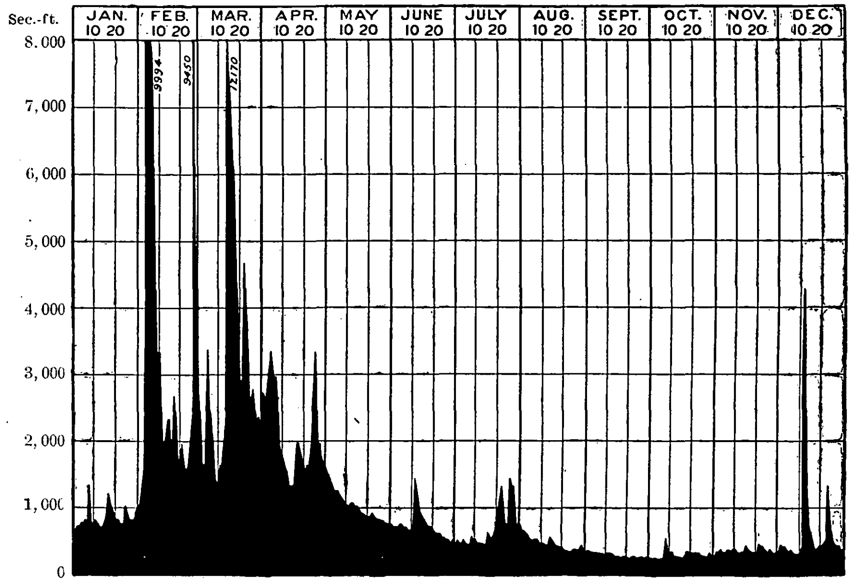


FIG. 84.—Discharge of Coosawattee River at Carters, Georgia, 1899.

OOSTANAULA RIVER.

This river is formed by the junction of Coosawattee and Conasauga rivers, about 3 miles above Resaca, Georgia. It flows southwesterly and unites with the Etowah at Rome to form the Coosa. The station, which is at Resaca, was established July 27, 1896. Measurements are made by O. P. Hall and Max Hall.

Estimated monthly discharge of Oostanaula River at Resaca, Georgia.

[Drainage area, 1,614 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	6,312	1,670	2,777	170,751	1.72	1.98
February	22,090	3,552	9,627	534,656	5.96	6.21
March	24,022	3,230	10,416	640,455	6.45	7.44
April	10,866	2,690	5,163	307,220	3.20	3.57
November	1,490	600	735	43,736	0.46	0.52
December	5,162	675	1,683	103,484	1.04	1.20

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 147; rating table in Paper No. 39, page 445.

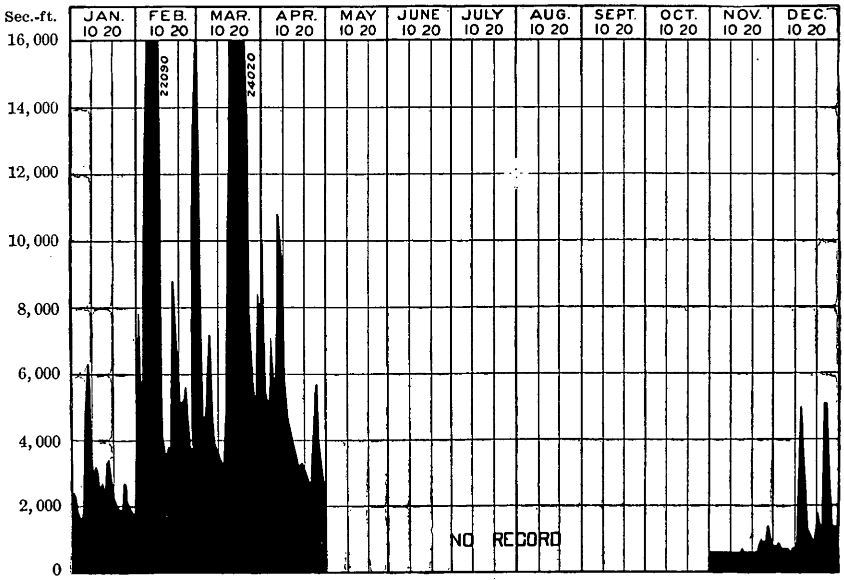


FIG. 85.—Discharge of Oostanaula River at Resaca, Georgia, 1899.

COOSA RIVER.

This river is formed by the junction of Etowah and Oostanaula rivers at Rome, Georgia. Both of the tributaries rise in the northern part of Georgia and flow chiefly through a hilly, broken country, well wooded, about a fourth of the land being under cultivation. Coosa River flows in a southwesterly direction into Alabama and joins the Tallapoosa 6 miles above Montgomery, Alabama, to form Alabama River. The following stations are maintained on the Coosa: At Rome, Georgia; at Riverside, Alabama, established September 25, 1896; at locks Nos. 4 and 5, near Riverside; and 3 miles above Wetumpka, Alabama. The measurements of discharge at the Rome and Riverside stations are made by Max Hall and others. No measurements of discharge are made at the stations at locks Nos. 4 and 5. Measurements this year (1900) will be made at Montgomery and Selma, Alabama.

Estimated monthly discharge of Coosa River at Rome, Georgia.

[Drainage area, 4,006 square miles.]

Month	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	10,519	4,060	6,092	374,582	1.52	1.75
February	54,538	8,710	22,536	1,251,586	5.62	5.85
March	57,352	7,705	26,314	1,617,985	6.57	7.57
April	28,810	6,700	13,333	793,369	3.33	3.72
May	6,700	3,100	4,783	294,095	1.19	1.37
June	6,700	2,740	3,489	207,610	0.87	0.97
July	24,388	1,950	5,499	338,120	1.37	1.58
August	3,900	1,790	2,595	159,560	0.65	0.75
September	5,500	1,550	2,219	132,040	0.55	0.61
October	2,030	1,470	1,684	103,545	0.42	0.48
November	4,700	1,470	2,009	119,544	0.50	0.56
December	13,735	1,870	4,314	265,258	1.08	1.25
The year	57,352	1,470	7,906	5,657,294	1.97	26.46

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 149; discharge measurements, page 148; rating table in Paper No. 39, page 445.

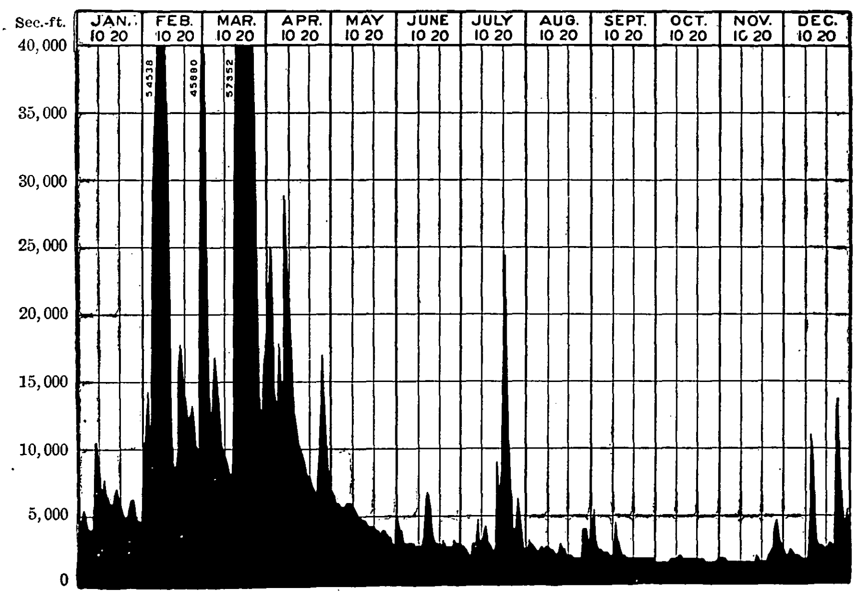


FIG. 86.—Discharge of Coosa River at Rome, Georgia, 1899.

Estimated monthly discharge of Coosa River at Riverside, Alabama.

[Drainage area, 7,065 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	17,330	6,390	10,865	668,063	1.54	1.78
February	48,410	17,330	30,974	1,720,209	4.38	4.56
March	60,880	14,740	38,094	2,342,309	5.39	6.21
April	41,010	11,410	24,915	1,482,545	3.53	3.94
May	14,000	4,900	7,742	476,037	1.10	1.27
June	7,700	3,500	4,771	283,894	0.68	0.75
July	14,740	2,760	5,318	326,991	0.75	0.86
August	10,125	2,600	3,806	234,022	0.54	0.62
September	6,530	2,330	3,555	211,537	0.50	0.56
October	3,100	2,330	2,510	154,334	0.36	0.41
November	7,100	2,395	3,086	183,630	0.44	0.49
December	26,025	2,920	10,631	653,675	1.50	1.73
The year	60,880	2,330	12,189	8,737,246	1.73	23.18

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 150; discharge measurements, page 149; rating table in Paper No. 39, page 445.

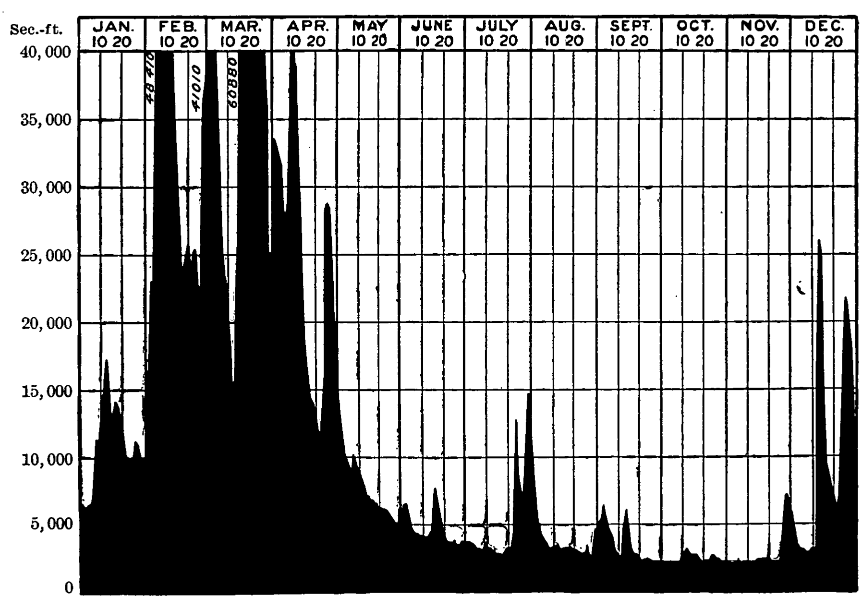


FIG. 87.—Discharge of Coosa River at Riverside, Alabama, 1899.

TALLAPOOSA RIVER.

This river rises in the west-central part of Georgia and flows in a southwesterly direction into Alabama, where it joins the Coosa, 6 miles above Montgomery, and forms Alabama River. Its upper tributaries drain an area between the Chattahoochee and Coosa basins. The station is at Milstead, Alabama. It was established August 7, 1897. Measurements are made by Max Hall.

Estimated monthly discharge of Tallapoosa River at Milstead, Alabama.

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	22,197	4,116	8,417	517,541	2.19	2.53
February	44,952	6,945	15,688	871,267	4.09	4.26
March	32,652	7,314	12,399	762,385	3.23	3.72
April	21,582	5,100	9,016	536,489	2.35	2.62
May	4,731	2,517	3,351	206,045	0.87	1.00
June	2,999	1,287	2,040	121,388	0.53	0.59
July	20,290	795	4,985	306,516	1.30	1.50
August	4,362	1,287	2,222	136,625	0.58	0.67
September	2,394	430	984	58,552	0.26	0.29
October	1,656	320	1,014	62,348	0.26	0.30
November	7,068	918	1,787	106,334	0.47	0.53
December	18,138	1,656	4,728	290,713	1.23	1.42
The year	44,952	320	5,553	3,976,203	1.45	19.43

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 153; rating table in Paper No. 39, page 445.

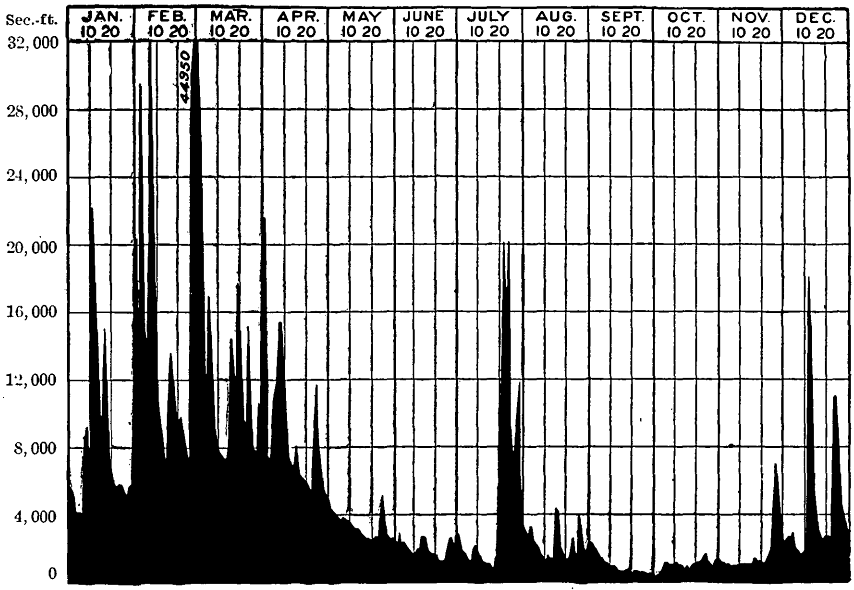


FIG. 88.—Discharge of Tallapoosa River at Milstead, Alabama, 1899.

ALABAMA RIVER.

This river is formed by the junction of Coosa and Tallapoosa rivers 6 miles above Montgomery. A number of years ago a gaging station was established by the United States Engineer Corps at Montgomery, Alabama. The readings are now taken by the Weather Bureau. There is also a station at Selma, Alabama, where the gage readings are also taken by the Weather Bureau. No discharge measurements were made at either of these places during the year 1899, but it is proposed to make measurements during the year 1900.

BLACK WARRIOR RIVER.

This river rises in the north-central part of Alabama and flows in a southwesterly direction, emptying into the Tombigbee at the southern boundary of Greene County. After the junction the latter river flows southward until it reaches Alabama River, with which it unites to form the Mobile. Most of the drainage area is flat, open country, much of it under cultivation. Above Tuscaloosa it is largely in the Carboniferous, containing pervious strata, porous shales, and limestone caves, through which considerable water is probably lost. A continuous record of gage heights at Tuscaloosa has been kept by the United States Engineer Corps since 1889. Measurements are made by B. M. Hall and Prof. George S. Wilkins, of the University of Alabama.

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

[Drainage area, 4,900 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	81,375	2,222	18,118	1,114,033	3.70	4.27
February	90,375	10,030	30,923	1,717,376	6.31	6.57
March	122,625	5,330	35,308	2,171,004	7.21	8.31
April	32,800	4,540	11,901	708,158	2.43	2.71
May	4,165	790	2,092	128,632	0.43	0.49
June	1,000	175	448	26,658	0.09	0.10
July	5,035	160	1,111	68,313	0.23	0.26
August	3,370	370	963	59,213	0.20	0.23
September	670	110	200	11,901	0.04	0.04
October	175	92	130	7,993	0.03	0.03
November	5,590	127	721	42,902	0.15	0.17
December	47,650	460	8,880	546,010	1.81	2.09
The year	122,625	92	9,233	6,602,193	1.89	25.27

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 157; discharge measurements, page 156; rating table in Paper No. 39, page 445.

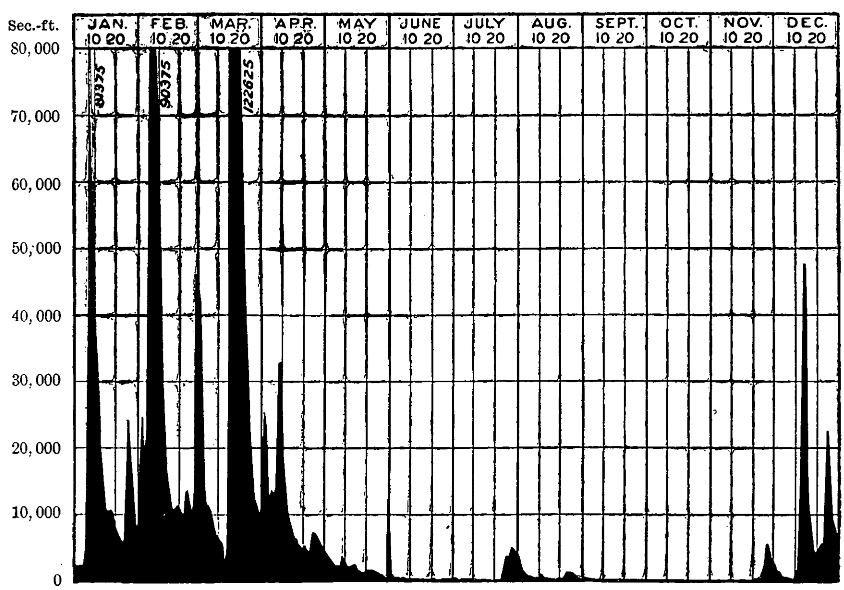


FIG. 89.—Discharge of Black Warrior River at Tuscaloosa, Alabama, 1899.

OHIO RIVER DRAINAGE.

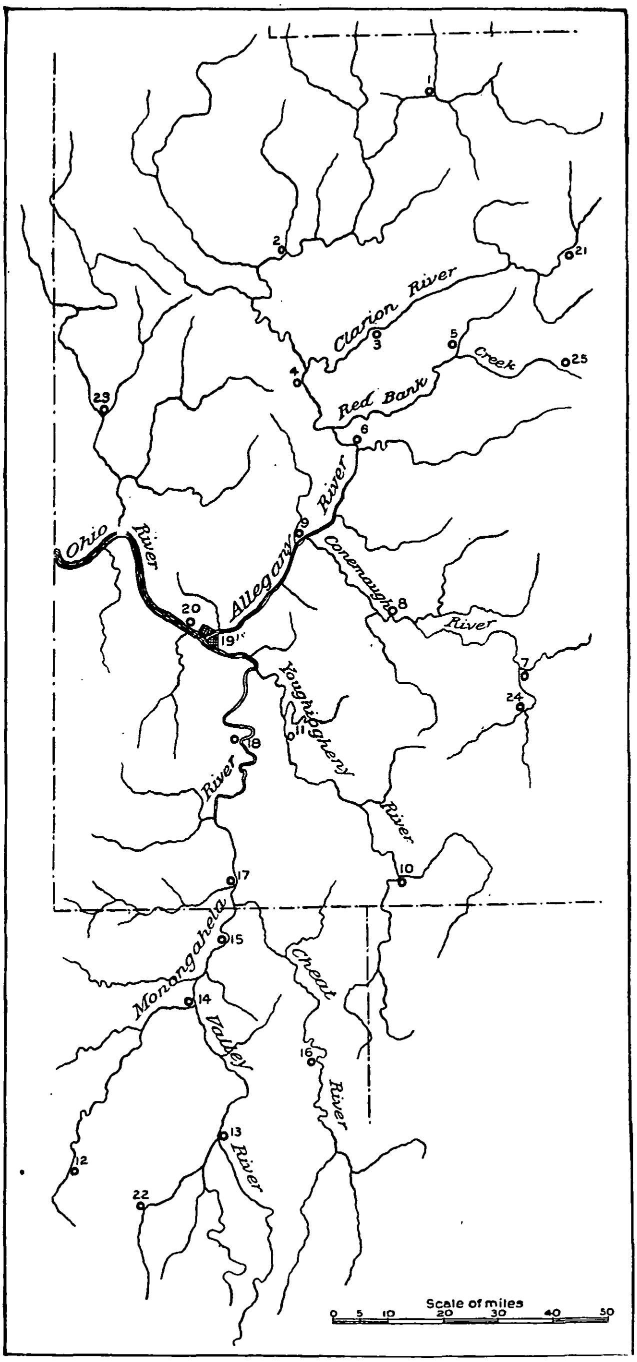


FIG. 90.—Map showing river and rainfall stations in the upper Ohio Basin. For names of stations, see next page.

A. ALLEGHENY RIVER ABOVE FRANKLIN, PENNSYLVANIA, LOOKING DOWNSTREAM AT ABOUT 1-FOOT STAGE.

B. YOUGHIOGHENY RIVER AT OHIOPYLE FALLS, PENNSYLVANIA.

Ohio River is formed by the junction, at Pittsburg, of Allegheny and Monongahela rivers. Observations of the height of these streams and of their tributaries are made at various points, as indicated by fig. 90 and by the following list, the numbers in which refer to those in the illustration.

River and rainfall stations in upper Ohio Basin.

1. Warren, Pa.
2. Oil City, Pa.
3. Clarion, Pa.
4. Parkers Landing, Pa.
5. Brookville, Pa.
6. Mahoning, Pa.
7. Johnstown, Pa.
8. Saltsburg, Pa.
9. Freeport, Pa.
10. Confluence, Pa.
11. West Newton, Pa.
12. Weston, W. Va.
13. Philippi, W. Va.
14. Fairmont, W. Va.
15. Morgantown, W. Va.
16. Rowlesburg, W. Va.
17. Greensboro, Pa.
18. Lock No. 4, Pa.
19. Pittsburg, Pa.
20. Davis Island Dam, Pa.

Rainfall stations:

21. Ridgway, Pa.
22. Buckhannon, W. Va.
23. New Castle, Pa.
24. Stoystown, Pa.
25. Dubois, Pa.

ALLEGHENY RIVER.

Allegheny River, which unites with the Monongahela at Pittsburg to form the Ohio, rises in northern Pennsylvania, flows northerly into the State of New York, then turns to the south and flows through western Pennsylvania. The headwaters have an elevation of about 2,250 feet, and adjoin those of Genesee River on the north and of the Susquehanna on the east. Its total length is about 300 miles, 47 of which are in New York State. The catchment basin on the upper waters attains a height of from 2,600 to 2,800 feet above sea level. The location of the river stations is shown on the accompanying map, fig. 90. Pl. VIII, *A*, is a view of the river above Franklin, Pennsylvania, looking downstream, at about 1-foot stage.

YOUGHIOGHENY RIVER.

The Youghiogheny rises in Garrett County, Maryland, and flows in a northwesterly direction into Pennsylvania, emptying into Monongahela River about 15 miles above Pittsburg. Its source is on the western slope of the Allegheny Mountains, at an elevation of about 2,900 feet. For 19 miles above its mouth the average fall of the stream is about 2 feet per mile, but above that point it soon increases to an average fall of nearly 5 feet per mile. The average width of the river from its mouth to West Newton, Pennsylvania, is 546 feet. The station at Friendsville, Maryland, was established August 17, 1898. Measurements are made by E. G. Paul. Pl. VIII, *B*, is a view of the river at Ohiopyle Falls, Pennsylvania.

Estimated monthly discharge of Youghiogheny River at Friendsville, Maryland.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1898.				
August 17 to 31	1,486	295	517	31,789
September	385	260	284	16,899
October	3,766	260	675	41,504
November	1,942	470	803	47,782
December	3,538	470	1,115	68,559

Estimated monthly discharge of Youghiogheny River at Friendsville, Maryland—Cont'd.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1899.				
January	3,880	710	1,417	87,128
February, 23 days	3,766	575	1,579	87,693
March	4,108	1,150	1,928	118,548
April	2,626	425	944	56,172
May	5,590	425	1,430	87,927
June	2,170	350	821	48,853
July	785	295	378	23,242
August	520	260	297	18,262
September	350	245	280	16,661
October	275	245	254	15,618
November	640	275	362	21,540
December	1,372	320	689	42,365
The year	5,590	245	873	624,009

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 160; rating table in Paper No. 39, page 445.

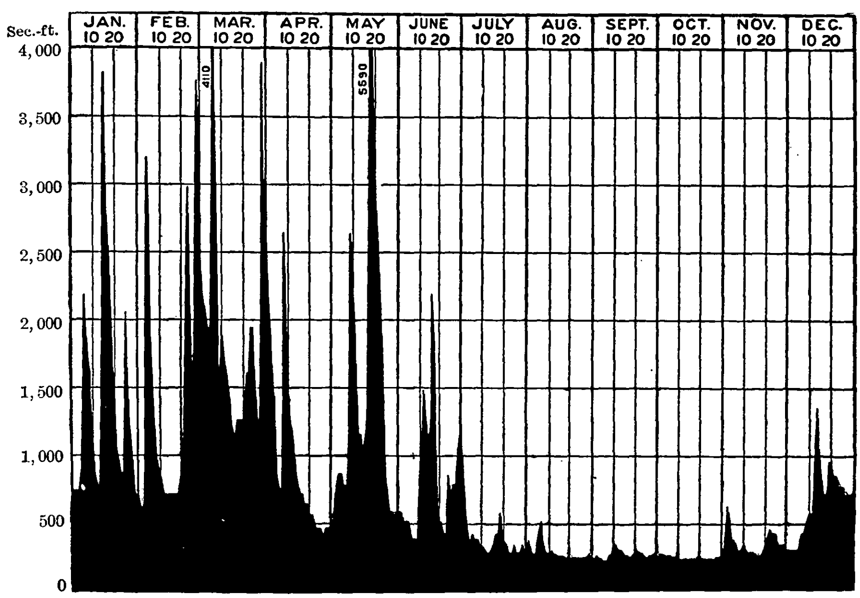


FIG. 91.—Discharge of Youghiogheny River at Friendsville, Maryland, 1899.

CHEAT RIVER.

This river rises in the eastern part of West Virginia and flows almost due north across the Pennsylvania boundary, entering Monongahela River 3 miles north of the State line. A station has been established at Uneva, West Virginia.

NEW RIVER.

Great Kanawha River rises in the Blue Ridge Mountains of North Carolina and runs northeastward into Virginia. After traversing several counties in Virginia it changes its course to the northwest and passes into the State of West Virginia. The name "New River" is applied to that part which is in North Carolina, Virginia, and West Virginia above the mouth of Gauley River. Measurements are made at Radford, Virginia, and at Fayette, West Virginia. The former station was established August 1, 1898, the latter July 29, 1895. Measurements at both stations are made by D. C. Humphreys.

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

[Drainage area, 6,200 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	31,620	5,700	9,507	584,563	1.53	1.76
February	66,616	6,240	21,952	1,219,152	3.54	3.69
March	110,527	10,922	33,867	2,082,401	5.46	6.29
April	20,210	8,346	12,044	716,668	1.94	2.16
May	29,478	5,380	11,990	737,236	1.93	2.22
June	27,157	4,200	8,625	513,223	1.39	1.55
July	5,380	1,587	3,079	189,320	0.50	0.58
August	3,840	2,037	2,739	168,415	0.44	0.51
September	3,840	2,190	2,506	149,117	0.40	0.45
October	3,780	1,775	2,833	174,194	0.46	0.52
November	3,490	2,037	2,414	143,643	0.39	0.44
December	19,190	1,662	4,394	270,177	0.71	0.82
The year	110,527	1,587	9,662	6,948,109	1.56	20.99

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 165; rating table in Paper No. 39, page 445.

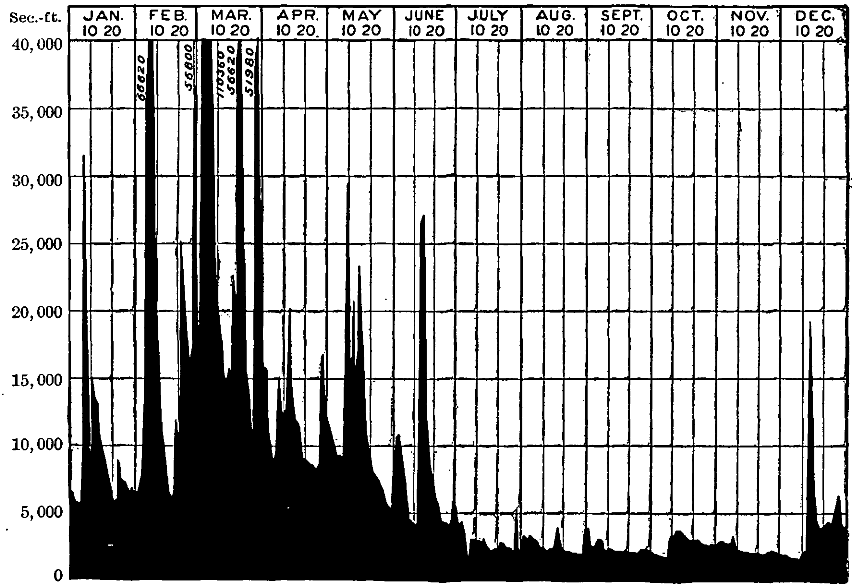


FIG. 92.—Discharge of New River at Fayette, West Virginia, 1899.

GREENBRIER RIVER.

This river rises on the western slope of the Allegheny Mountains, in Pocahontas County, West Virginia, and flows in a southwesterly direction, emptying into New River near Hinton, Summers County, West Virginia. The Greenbrier receives many short tributaries from the Allegheny Mountains. Most of its course is through a hilly, broken, and mountainous country well covered with forests. The station is at Alderson, West Virginia. It was established August 1, 1895. Measurements are made by D. C. Humphreys.

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

[Drainage area, 1,344 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	17,640	1,365	3,307	203,340	2.46	2.84
February	17,810	740	4,689	260,414	3.49	3.63
March	48,200	2,220	8,469	520,738	6.30	7.26
April	6,050	857	2,068	123,055	1.54	1.72
May	13,400	637	2,911	178,990	2.17	2.50
June	2,550	387	1,026	61,051	0.76	0.85
July	350	170	222	13,650	0.17	0.20
August	795	60	152	9,346	0.11	0.13
September	280	85	153	9,104	0.11	0.12
October	170	60	97	5,964	0.07	0.08
November	280	102	158	9,402	0.12	0.13
December	987	120	348	21,398	0.26	0.30
The year	48,200	60	1,967	1,416,452	1.46	19.76

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 164; discharge measurements, page 163; rating table in Paper No. 39, page 445.

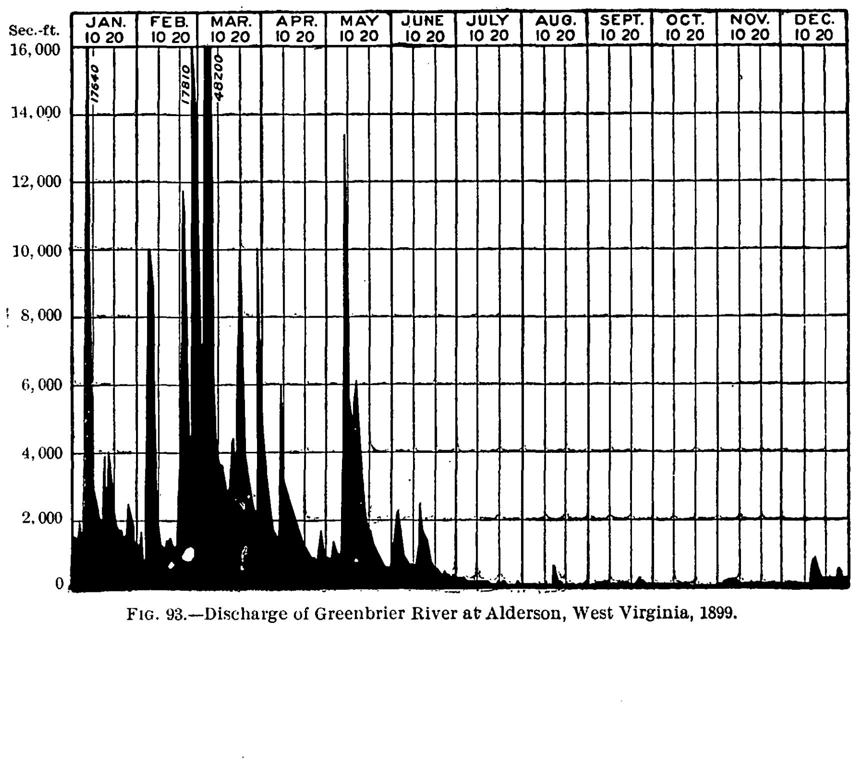


FIG. 93.—Discharge of Greenbrier River at Alderson, West Virginia, 1899.

FRENCH BROAD RIVER.

This river rises in the Blue Ridge Mountains, in the western part of North Carolina, and flows in a general northwesterly direction into Tennessee. It joins Holston River just above Knoxville, to form the Tennessee. It is approximately 250 miles long. Most of the watershed is mountainous and covered with a heavy growth of timber. There are water powers capable of development at a number of places. The station is 3 miles west of Asheville, North Carolina. It was established in September, 1895. Swannanoa River joins the French Broad 3 miles above the station. Measurements of discharge are made by E. W. Myers and R. E. Shuford.

Estimated monthly discharge of French Broad River at Asheville, North Carolina.

[Drainage area, 987 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	5,050	2,660	3,547	218,097	3.59	4.14
February	20,460	2,590	7,815	434,023	7.91	8.24
March	30,720	3,710	10,413	640,270	10.55	12.16
April	11,530	3,710	6,388	380,112	6.47	7.22
May	4,760	1,565	3,397	208,873	3.44	3.97
June	1,800	1,235	1,486	88,423	1.51	1.69
July	2,055	945	1,221	75,076	1.24	1.43
August	3,030	785	1,160	71,326	1.18	1.36
September	2,520	690	1,122	66,764	1.14	1.27
October	1,455	690	945	58,106	0.96	1.10
November	1,180	785	915	54,446	0.93	1.03
December	11,150	860	2,297	141,237	2.33	2.69
The year	30,720	690	3,393	2,436,753	3.44	46.29

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 166; rating table in Paper No. 39, page 446.

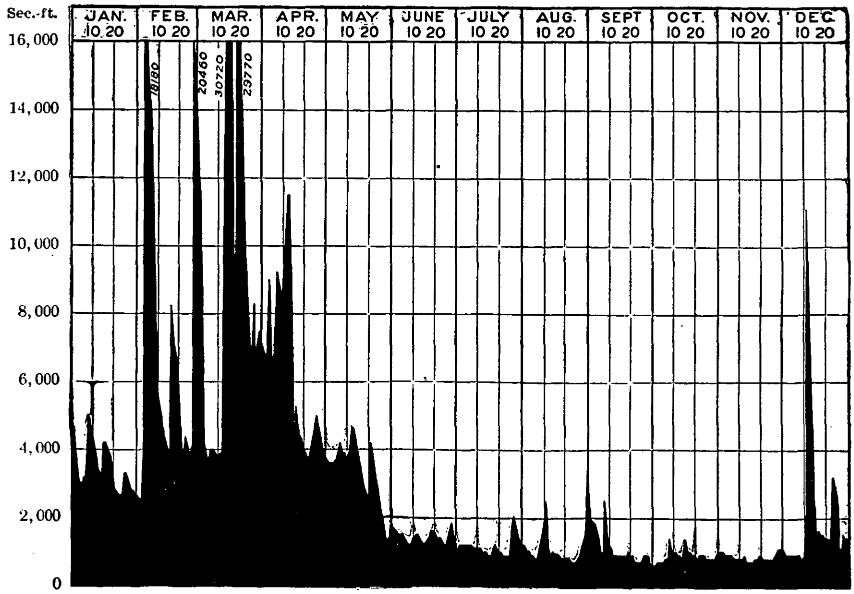


FIG. 94.—Discharge of French Broad River at Asheville, North Carolina, 1899.

TUCKASEGEE RIVER.

This river rises in the southwestern part of North Carolina, at the base of Tennessee Ridge, which separates Jackson and Transylvania counties. It flows in a northwesterly direction, emptying into the Little Tennessee at Bushnell, North Carolina. The present station, which is at Bryson, North Carolina, was established November 7, 1897. Formerly the station was located about 3 miles above Bryson. Discharge measurements are made by E. W. Myers and R. E. Shuford.

Further details concerning this river may be found on page 167 of Water-Supply Paper No. 36. The figures for the monthly discharge for 1898, with corresponding diagram, are given on page 206 of the Twentieth Annual Report, Part IV. The table given on the next page (162) of this report is a continuation of those data. The area drained consists largely of mountains covered with forest growth, from which a large amount of run-off may be expected.

Estimated monthly discharge of Tuckasegee River at Bryson, North Carolina.

[Drainage area, 662 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January, 29 days	3,150	1,072	1,733	106,558	2.62	3.02
February, 27 days	28,550	1,134	5,853	325,059	8.84	9.21
March	38,550	1,735	7,617	468,351	11.51	13.27
April	4,800	1,984	2,972	176,846	4.49	5.01
May	3,150	1,072	1,815	111,600	2.74	3.16
June	4,470	700	1,207	71,821	1.82	2.03
July	1,320	540	740	45,501	1.12	1.29
August	700	460	557	34,249	0.84	0.97
September	620	300	427	25,408	0.65	0.72
October	1,320	300	437	26,870	0.66	0.76
November	1,072	300	450	26,777	0.68	0.75
December	16,925	540	1,354	83,254	2.05	2.36
The year	38,550	300	2,097	1,502,294	3.17	42.55

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 168; discharge measurements, page 167; rating table in Paper No. 39, page 446.

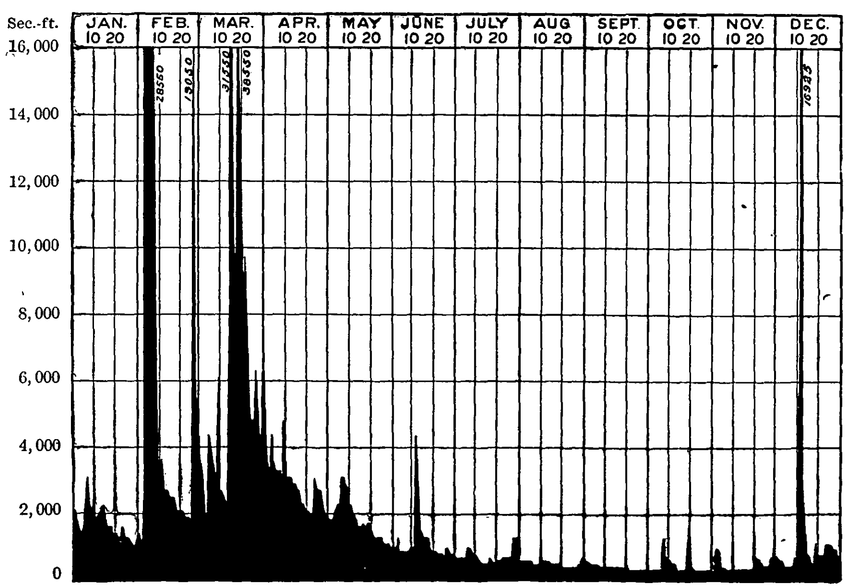


FIG. 95.—Discharge of Tuckasegee River at Bryson, North Carolina, 1899.

LITTLE TENNESSEE RIVER.

This river rises in the mountains between North Carolina and Georgia and flows in a northwesterly direction, emptying into Tennessee River at Lenoir, Tennessee. The drainage area is largely mountainous and covered with forests. The station is about a quarter of a mile from Judson, North Carolina. It was established in June, 1896. Measurements of discharge are made by E. W. Myers and R. E. Shuford.

Estimated monthly discharge of Little Tennessee River at Judson, North Carolina.

[Drainage area, 675 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	3,112	1,825	2,171	133,490	3.22	3.71
February	27,600	1,907	7,949	441,465	11.77	12.26
March	35,600	1,990	6,995	430,106	10.36	11.94
April	4,160	1,747	2,209	131,445	3.27	3.65
May	6,060	370	1,978	121,622	2.93	3.38
June	8,505	335	1,672	99,491	2.48	2.77
July	3,390	705	1,739	106,927	2.58	2.97
August	4,550	335	1,196	73,539	1.77	2.04
September	3,205	300	801	47,663	1.19	1.33
October	5,830	445	921	56,630	1.36	1.57
November	1,825	445	729	43,379	1.08	1.20
December	13,700	445	1,423	87,497	2.11	2.43
The year	35,600	300	2,482	1,773,254	3.68	49.25

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 169; discharge measurements, page 168; rating table in Paper No. 39, page 446.

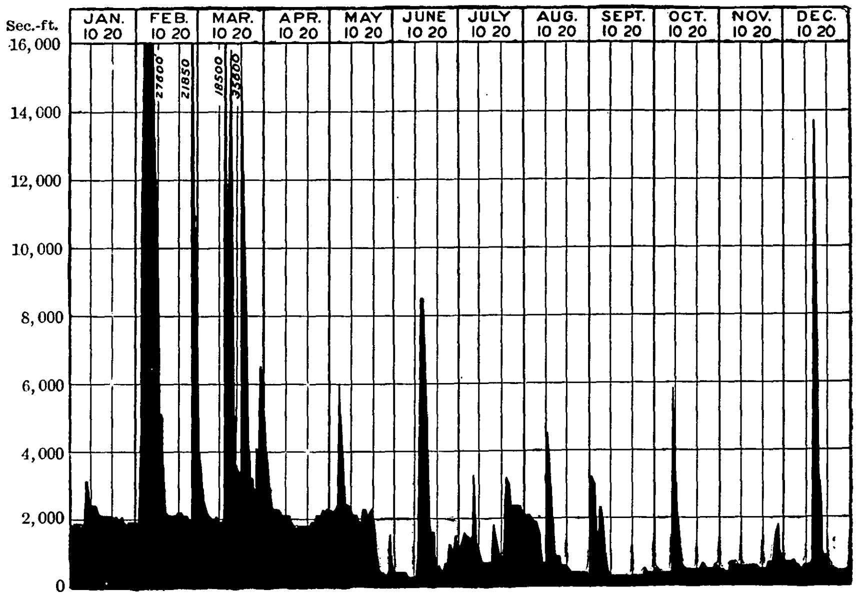


FIG. 96.—Discharge of Little Tennessee River at Judson, North Carolina, 1899.

HIWASSEE RIVER.

This river rises in the northern part of Georgia and flows through the southwestern corner of North Carolina into Tennessee, emptying into Tennessee River. The watershed is chiefly a broken and mountainous country well covered with forests. The river is measured at two places, namely, at Murphy, North Carolina, and at Charleston, Tennessee. The former station was established July 26, 1896. The latter station was originally established by the United States Engineer Corps, but is now maintained as a half-year station by the United States Weather Bureau. Discharge measurements at the Murphy station are made by E. W. Myers and R. E. Shuford and at the latter station by Max Hall.

Estimated monthly discharge of Hiwassee River at Murphy, North Carolina.

[Drainage area, 410 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,790	620	878	53,986	2.14	2.47
February	14,880	720	3,088	171,499	7.53	7.84
March	22,360	1,450	3,715	228,426	9.06	10.45
April	3,320	1,120	1,744	103,775	4.25	4.74
May	1,450	460	719	44,210	1.75	2.02
June	970	295	440	26,182	1.07	1.19
July, 21 days			556	34,187	1.36	1.57
August	840	340	404	24,841	0.99	1.14
September	620	310	373	22,195	0.91	1.01
October	840	265	339	20,844	0.83	0.95
November	905	295	356	21,183	0.87	0.97
December	6,550	340	800	49,190	1.95	2.25

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 170; rating table in Paper No. 39, page 446.

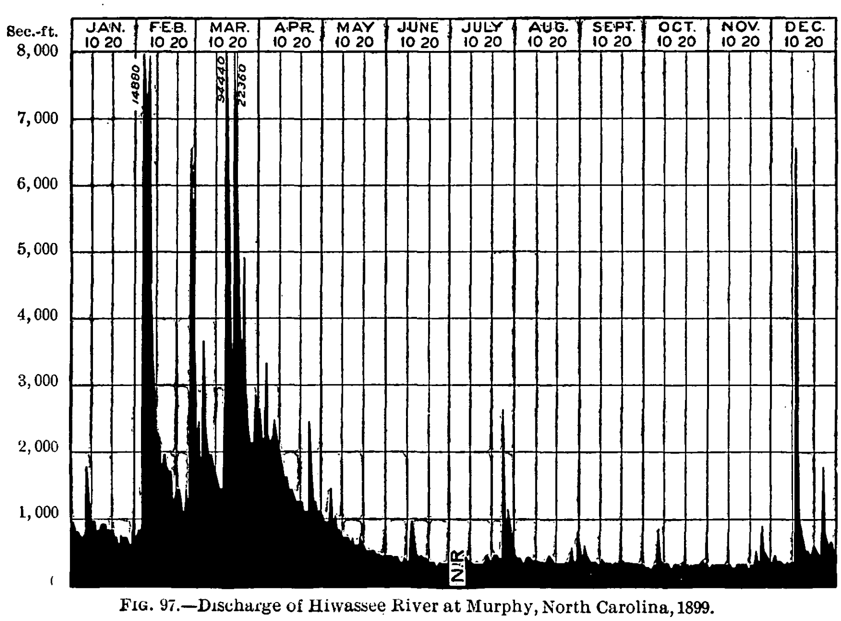


FIG. 97.—Discharge of Hiwassee River at Murphy, North Carolina, 1899.

TOCCOA RIVER.

The Toccoa rises on the northern slopes of the Blue Ridge Mountains in Georgia and flows northwesterly into Hiwassee River. The drainage area is covered with a fine growth of oak, hickory, and other hard woods. The station is at Blueridge, Georgia. It was established November 25, 1898. Measurements are made by B. M. Hall and Max Hall.

Estimated monthly discharge of Toccoa River at Blueridge, Georgia.

[Drainage area, 231 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,520	280	733	45,070	3.17	3.66
February	5,244	836	1,759	97,690	7.61	7.92
March	3,040	760	1,704	104,775	7.38	8.51
April	2,508	760	1,411	83,960	6.11	6.81
May	1,292	760	884	54,355	3.83	4.41
June	1,064	280	545	32,430	2.36	2.63
July	1,444	370	575	35,355	2.49	2.87
August	1,064	305	471	28,961	2.04	2.36
September	610	255	329	19,577	1.42	1.58
October	760	230	298	18,323	1.29	1.49
November	912	255	315	18,744	1.36	1.52
December 1 to 23	1,216	255	473	29,084	2.05	2.37
The year	5,244	230	791	568,324	3.43	46.13

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 172; rating table in Paper No. 39, page 446.

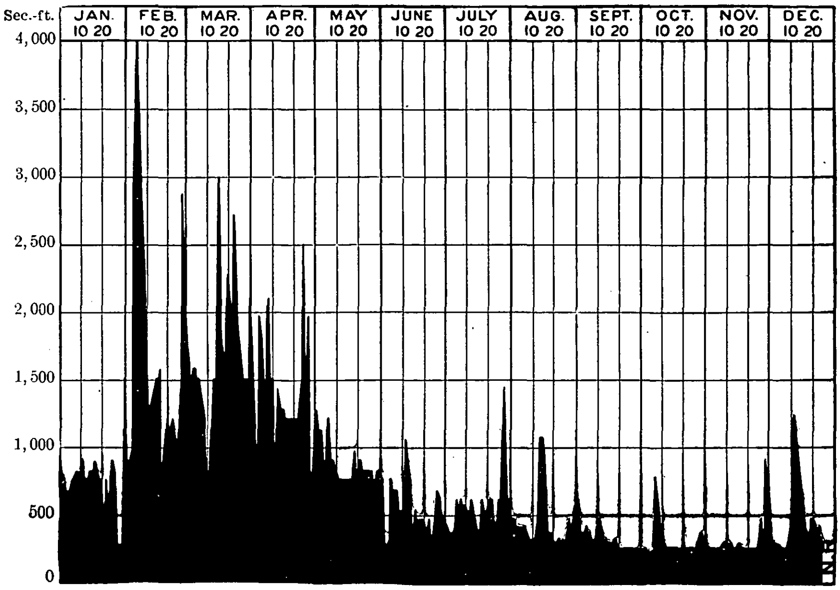


FIG. 98.—Discharge of Toccoa River at Blueridge, Georgia, 1899.

TENNESSEE RIVER.

The Tennessee is formed by the junction of French Broad and Holston rivers, 4 miles above Knoxville, Tennessee. Its course is rather circuitous. Flowing through Tennessee and Kentucky, it empties into the Ohio 50 miles above Cairo, Illinois. It is the largest affluent of Ohio River, and is about 800 miles long, including its branches. Large steamboats can ascend it about 270 miles. Its principal affluent is the Little Tennessee. Two stations are maintained on the river, one at Knoxville and the other at Chattanooga. Measurements at both stations are made by Max Hall.

Lenoir, Tennessee, is supplied with water power from Town Creek, a rapid stream which passes through its limits on the east and enters Tennessee River about a quarter of a mile from the center of the city. Two dams have been constructed on this stream, one of which is shown on Pl. VII, *B*, page 108. It is built of masonry. Another, about 1,000 feet farther downstream, is of heavy timbers supported by stone abutments. The latter dam furnishes power for a flour mill and elevator located between the two dams. The lower dam furnishes power for a cotton hosiery factory. Town Creek is supplied by many springs in the hills, and has been used for power for nearly a century.

Estimated monthly discharge of Tennessee River at Chattanooga, Tennessee.

[Drainage area, 21,418 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	112, 560	25, 450	47, 250	2, 905, 289	2. 21	2. 55
February	233, 150	30, 720	95, 554	5, 306, 801	4. 46	4. 64
March	244, 000	55, 210	142, 700	8, 774, 281	6. 66	7. 68
April	137, 360	39, 710	69, 286	4, 122, 803	3. 23	3. 59
May	65, 130	22, 040	40, 450	2, 487, 173	1. 89	2. 18
June	35, 990	15, 600	23, 088	1, 373, 831	1. 08	1. 20
July	27, 930	10, 430	15, 053	925, 573	0. 70	0. 81
August	22, 040	8, 040	11, 900	731, 702	0. 56	0. 64
September	15, 840	7, 300	10, 118	603, 063	0. 47	0. 53
October	10, 635	6, 600	7, 851	482, 739	0. 37	0. 43
November	10, 635	6, 775	8, 216	488, 886	0. 38	0. 43
December	41, 880	8, 820	22, 061	1, 356, 478	1. 03	1. 19
The year	244, 000	6, 600	41, 127	29, 557, 619	1. 09	25. 87

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 175; discharge measurements, page 174; rating table in Paper No. 39, page 446.

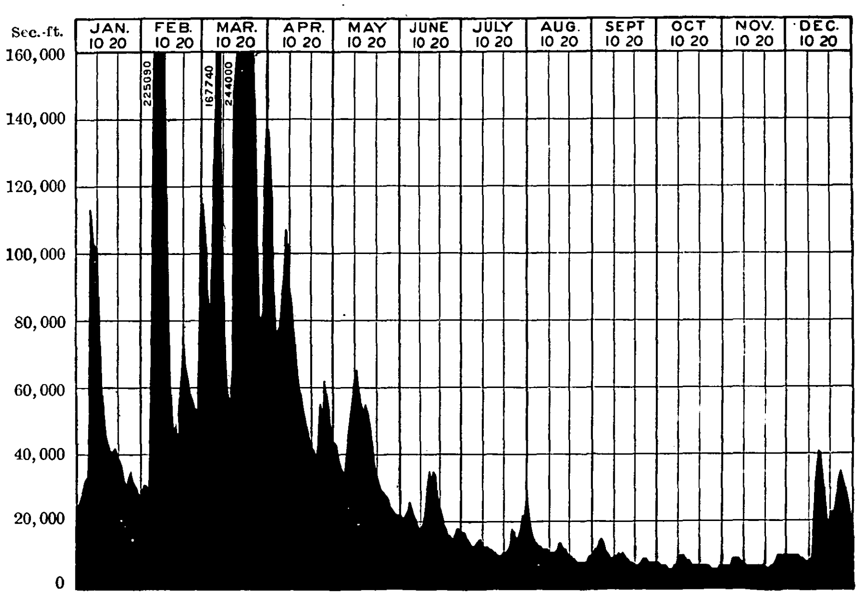


FIG. 99.—Discharge of Tennessee River at Chattanooga, Tennessee, 1899.

OLENTANGY RIVER.

This river rises in the north-central part of Ohio and flows in a southerly direction into the Scioto at Columbus. Its watershed is in general flat and for the most part cultivated. The station, which is at Columbus, was established November 22, 1898. Discharge measurements are made under the direction of C. N. Brown, professor of civil engineering, Ohio State University.

Estimated monthly discharge of Olentangy River at Columbus, Ohio.

[Drainage area, 514 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	10,180	230	1,686	103,668	3.28	3.78
February	2,660	230	574	31,878	1.11	1.15
March	4,500	412	1,554	95,552	3.02	3.47
April	2,370	90	397	23,623	0.77	0.85
May	465	36	111	6,825	0.22	0.25
June	1,412	55	291	17,316	0.57	0.63
July	222	25	71	4,366	0.14	0.16
August	1,520	25	159	9,776	0.31	0.36
September	25	8	13	774	0.03	0.03
October	25	8	10	615	0.02	0.02
November	55	25	48	2,856	0.09	0.10
December	1,740	25	311	19,123	0.61	0.70
The year	10,180	8	435	316,372	0.85	11.50

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 176; discharge measurements, page 175; rating table in Paper No. 39, page 446.

SCIOTO RIVER.

This river drains the central portion of the State of Ohio, and flows in a general southerly direction into Ohio River at the city of Portsmouth. Its watershed is flat and extensively cultivated above Columbus, while in the southern part it is hilly, with a comparatively small portion under cultivation. The station is at Columbus. It was established November 22, 1898. Measurements are made under the direction of C. N. Brown, professor of civil engineering, Ohio State University.

Estimated monthly discharge of Scioto River at Columbus, Ohio.

[Drainage area, 1,047 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	16,110	510	3,143	193,255	3.00	3.47
February	4,825	130	850	47,206	0.81	0.84
March	6,920	935	3,263	200,634	3.12	3.60
April	3,510	170	783	46,592	0.75	0.83
May	215	100	153	9,408	0.15	0.17
June	720	13	146	8,687	0.14	0.16
July	430	5	117	7,194	0.11	0.13
August	1,975	9	205	12,605	0.20	0.23
September	13	5	9	535	0.01	0.01
October	59	9	18	1,107	0.02	0.02
November	75	15	38	2,261	0.04	0.05
December	1,110	35	278	17,093	0.27	0.31
The year	16,110	5	750	546,577	0.72	9.70

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 177; rating table in Paper No. 39, page 446.

WABASH RIVER.

Wabash River rises in northeastern Indiana, receiving some drainage from western Ohio. It flows in a general westerly direction across Indiana, and turning to the south forms the southern portion of the boundary between that State and Illinois. The upper part of the drainage basin is notably flat and marshy, the run-off being exceedingly slow. In portions of its upper course the river has been artificially improved in order to aid in the drainage of valuable farming lands. Measurements of the stream have been made at two points, namely, at Lafayette, Indiana, by William D. Pence, professor of civil engineering, Purdue University, and at Terre Haute, Indiana, by Malverd A. Howe, director of the department of civil engineering and architecture, Rose Polytechnic Institute. The Weather Bureau has also maintained observations of river height at Lafayette, 58 miles above Terre Haute, also at Terre Haute, 90 miles above Vincennes, and at Mount Carmel, Illinois, 50 miles above the junction with the Ohio.

At Lafayette the drainage area, according to the report of the Weather Bureau, is 6,200 square miles, and the width of the river at low stages is 375 feet. The gage is an oak plank 36 feet long, slightly inclined and fastened to the south end of the east pier of the Main street bridge. The bench mark is the curbing at the northeast corner of Main and Second streets, and is 33.57 feet above the zero of the gage. The highest water was on February 17, 1883, 33.8 feet, and the lowest in August, 1895, 0.3 foot. The danger line is at 11 feet. The station was discontinued by the Weather Bureau November 20, 1895.

The discharge measurements at Terre Haute were made by Professor Howe, by means of float rods. The measurement of July, 1897, was checked by the use of a current meter, approximately the same result being obtained.

Discharge measurements of Wabash River at Terre Haute, Indiana.

Date.	Gage height.	Discharge.
	Feet.	*Second-feet.*
November, 1887	—0.2	1,007
October, 1890	0.9	1,706
October, 1892	1.1	1,458
September, 1894	0.7?	1,565
July, 1897	1.6	3,684

At Terre Haute the drainage area, as reported by the Weather Bureau, is 11,200 square miles, and the width of the river at low water 540 feet. The gage is in two sections, attached to piers of the railroad bridge of the Big Four Route, the upper section being from 6 to 30 feet, and the lower section from zero to 6 feet. The bench mark of the city waterworks near the bridge is on the top of the cement curb of the old pump house, 28 feet above the zero of the gage. The Big Four bench mark is the letter S of the lettering W & S on the north side of the east abutment of the Big Four bridge, 38.7 feet above the zero of the gage. The highest water was on February 18, 1883, 27.7 feet, and the lowest in August, 1895, —0.8 foot. The danger line is at 16 feet. Record of the height of water in the river can also be kept at the well of the city waterworks, which is connected with the river by large mains.

At Mount Carmel, Illinois, the drainage area, according to the Weather Bureau record, is 26,300 square miles and the width of the river at low water is 970 feet. The river gage is an oak board attached to the first pier of the railroad bridge from the west side of the river. The flat top of the surface of the pier is 29.3 feet above the zero of the gage. The highest water was on August 7, 1875, 28.3 feet, and the lowest was in November, 1895, —0.2 foot. The danger line is at 15 feet.

MISSISSIPPI RIVER DRAINAGE.

DES PLAINES RIVER.

This river is described in the Twentieth Annual Report, Part IV, page 218. It drains an area of 630 square miles immediately to the west and northwest of the city of Chicago. Its waters are tributary to Illinois River. Monthly flow for the years 1886 to 1898 have been given in the volume above noted. The details of flow, by days, for the years 1896, 1897, and 1898, are given in the following table.[1]

Daily discharge, in second-feet, of Des Plaines River at Riverside, Illinois, for 1896.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	284	164	1,749	1,006	218	418	0	176	0	403	1	305
2	330	164	1,096	844	203	248	0	156	0	494	1	203
3	380	184	736	630	203	203	0	136	0	494	12	184
4	412	184	555	534	203	164	0	100	0	494	55	100
5	412	164	454	380	184	118	0	77	0	454	111	77
6	330	111	427	330	144	89	0	66	0	403	164	66
7	248	100	736	296	103	66	0	44	0	345	144	66
8	164	89	856	264	77	66	0	28	0	305	136	66
9	111	89	844	212	66	44	0	12	0	264	124	89
10	111	89	736	184	55	50	0	6	0	248	176	89
11	77	89	680	184	44	6	0	6	0	233	248	89
12	111	89	555	218	44	6	0	12	0	218	494	111
13	77	89	380	248	39	22	0	22	0	203	630	144
14	55	89	355	330	32	22	0	32	0	184	580	144
15	39	89	257	454	28	12	0	44	276	144	454	144
16	28	89	233	466	18	22	0	28	284	111	380	144
17	18	89	233	418	9	28	0	18	412	89	330	144
18	9	89	257	330	6	6	0	9	380	77	330	144
19	6	77	305	248	4	0	0	6	370	66	315	124
20	6	73	434	218	1	0	0	6	355	55	305	111
21	6	73	403	454	6	0	0	6	355	55	305	233
22	6	77	434	630	6	0	0	6	380	62	296	144
23	12	100	454	494	22	0	0	6	380	55	284	77
24	77	284	454	826	22	0	0	4	380	32	264	22
25	111	976	427	826	111	0	0	1	380	12	264	12
26	144	3,088	434	514	796	0	1	1	330	6	276	6
27	144	3,472	380	454	1,392	0	12	0	296	6	403	6
28	156	4,194	380	395	904	0	44	0	284	4	427	6
29	156	3,498	670	330	630	0	62	0	284	4	248	44
30	164	......	1,468	264	454	0	89	0	330	1	380	44
31	164	......	1,357	......	526	......	124	0	......	1	......	44
Mean	140	619	604	433	211	53	11	33	182	178	271	103

[1] The figures for 1899 have not yet been computed, but will be estimated by Mr. G. M. Wisner, assistant engineer of the sanitary district of Chicago.

Daily discharge, in second-feet, of Des Plaines River at Riverside, Illinois, for 1897.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	100	514	380	3,406	1,838	44	89	6	0	0	0	6
2	284	474	355	2,579	1,343	39	89	6	0	0	0	6
3	2,898	424	305	2,226	1,066	28	89	1	0	0	0	6
4	7,720	418	203	1,919	934	28	89	1	0	0	0	6
5	6,268	418	164	1,618	826	32	89	0	0	0	0	6
6	5,090	418	248	1,343	680	12	84	0	0	0	0	6
7	8,660	434	330	1,152	534	12	73	0	0	0	0	6
8	8,240	466	454	976	418	9	66	0	0	0	0	6
9	6,854	494	916	796	330	12	44	0	0	0	0	6
10	4,936	454	1,878	670	248	22	39	0	0	0	0	6
11	3,433	434	2,289	555	218	22	22	0	0	0	0	6
12	2,060	434	2,992	494	184	12	22	0	0	0	0	6
13	1,248	403	2,491	427	124	6	22	0	0	0	0	6
14	1,357	474	2,876	427	111	6	22	0	0	0	1	6
15	1,357	534	2,060	446	111	6	22	0	0	0	6	6
16	1,096	630	1,704	427	111	6	22	0	0	0	12	6
17	1,794	736	1,618	494	111	44	22	0	0	0	12	6
18	3,232	916	1,578	514	95	454	22	0	0	0	6	6
19	3,807	1,036	1,642	454	89	630	18	0	0	0	6	4
20	3,028	1,114	3,807	380	77	555	18	0	0	0	6	4
21	3,294	1,794	6,729	305	66	494	12	0	0	0	12	1
22	1,878	2,136	7,382	284	73	380	12	0	0	0	39	0
23	1,448	2,060	7,176	380	73	284	9	0	0	0	22	0
24	1,507	1,749	5,924	796	89	276	9	0	0	0	12	0
25	1,378	1,468	4,194	1,468	77	233	6	0	0	0	6	0
26	1,322	1,036	3,052	2,060	77	227	12	0	0	0	6	0
27	1,308	1,287	2,546	1,528	66	212	12	0	0	0	6	0
28	1,168	796	2,436	1,066	66	184	6	0	0	0	6	0
29	964	....	2,766	856	55	124	4	0	0	0	6	0
30	754	....	3,606	1,794	44	89	1	0	0	0	6	0
31	605	....	4,020	....	44	......	1	0	......	0	......	0
Mean	2,874	841	2,520	1,061	328	149	34	0	0	0	6	4

Daily discharge, in second-feet, of Des Plaines River at Riverside, Illinois, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0	75	350	880	98	120	1,060	75	0	10	75	64
2	0	98	300	700	98	120	940	69	0	10	69	53
3	0	98	430	625	98	120	650	58	0	10	58	53
4	0	98	260	550	98	109	430	47	0	10	53	53
5	0	98	400	430	98	98	300	36	0	10	75	47
6	0	86	450	350	98	98	230	20	0	10	69	47
7	0	64	470	260	98	86	180	5	0	10	53	53
8	0	64	1,000	230	98	75	160	5	0	10	64	53
9	0	86	2,370	245	92	75	120	3	0	10	75	10
10	0	120	3,518	300	86	75	109	3	0	10	120	10
11	0	1,090	6,000	430	86	98	98	0	0	15	790	10
12	15	3,960	8,740	375	81	109	92	0	0	20	850	10
13	47	4,110	8,960	350	81	120	75	0	0	20	600	0
14	75	3,550	7,700	230	75	160	69	0	5	20	600	0
15	98	2,370	5,953	215	75	200	58	10	10	25	423	0

Daily discharge, in second-feet, of Des Plaines River at Riverside, Illinois, for 1898—Cont'd.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
16	98	1,785	4,540	180	69	230	53	36	30	25	350	0
17	98	1,315	3,420	140	75	215	30	47	30	30	300	0
18	53	1,120	2,370	160	86	200	25	58	30	30	400	0
19	53	1,500	4,400	160	86	180	20	75	20	36	388	0
20	75	1,650	6,950	160	98	180	20	64	10	41	338	75
21	260	1,740	5,515	160	230	180	15	53	10	41	300	300
22	400	1,570	3,960	160	260	160	15	30	10	47	230	450
23	510	1,350	2,920	160	245	120	10	15	10	47	160	350
24	400	1,060	2,325	160	215	120	10	10	10	53	140	300
25	300	1,000	1,740	140	200	400	10	5	10	64	140	260
26	200	760	1,315	120	180	3,960	10	3	10	75	120	245
27	120	510	1,650	109	160	5,000	10	3	10	98	98	300
28	103	430	3,690	109	140	4,615	10	0	10	109	75	120
29	98	....	3,160	98	140	3,130	30	0	10	109	75	98
30	81	....	2,280	98	120	2,050	64	0	10	92	64	64
31	75	....	1,200	....	120	......	75	0	......	75	......	53
Mean	102	1,134	3,172	276	122	747	161	24	8	38	238	99

ILLINOIS RIVER.

Illinois River rises in the northeastern part of the State of Illinois and flows in a general southwesterly direction across the State, discharging into Mississippi River about 20 miles above the mouth of the Missouri. A general description of the river has been given in a paper by Mr. Frank Leverett on the water resources of Illinois, printed in the Seventeenth Annual Report, Part II, beginning on page 735. Statistics have also been collected by Mr. Lyman E. Cooley and published (1891) in a pamphlet entitled Lake and Gulf Waterways. The flow of the river is now influenced to a considerable extent by the Chicago Drainage Canal, which was completed in 1899 and brings into the river, from Lake Michigan, more than 10,000 second-feet of water.

It is proposed to improve Illinois River, with the view to making a direct connection between the Great Lakes and Mississippi River. There is also under construction what is known as the Illinois and Mississippi Canal, commonly known as the Hennepin Canal, the object of which is to furnish a navigable waterway from Lake Michigan to Mississippi River at the mouth of Rock River, near Rock Island, Illinois, in connection with the upper Illinois River and the Chicago Drainage Canal. The plans contemplate the construction of a canal at least 80 feet wide and 7 feet deep. This canal is to begin at the great bend of Illinois River, and extend, by way of the valleys of Bureau, Pond, and Cowcatcher creeks, to the summit level, an ascent of 196 feet, thence to Rock River, above the mouth of Green River, and down Rock River to its mouth. The length of the proposed canal is about 75 miles and the descent from the summit level to the low-water level of Mississippi River is 93 feet. The feeder canal is to be 29

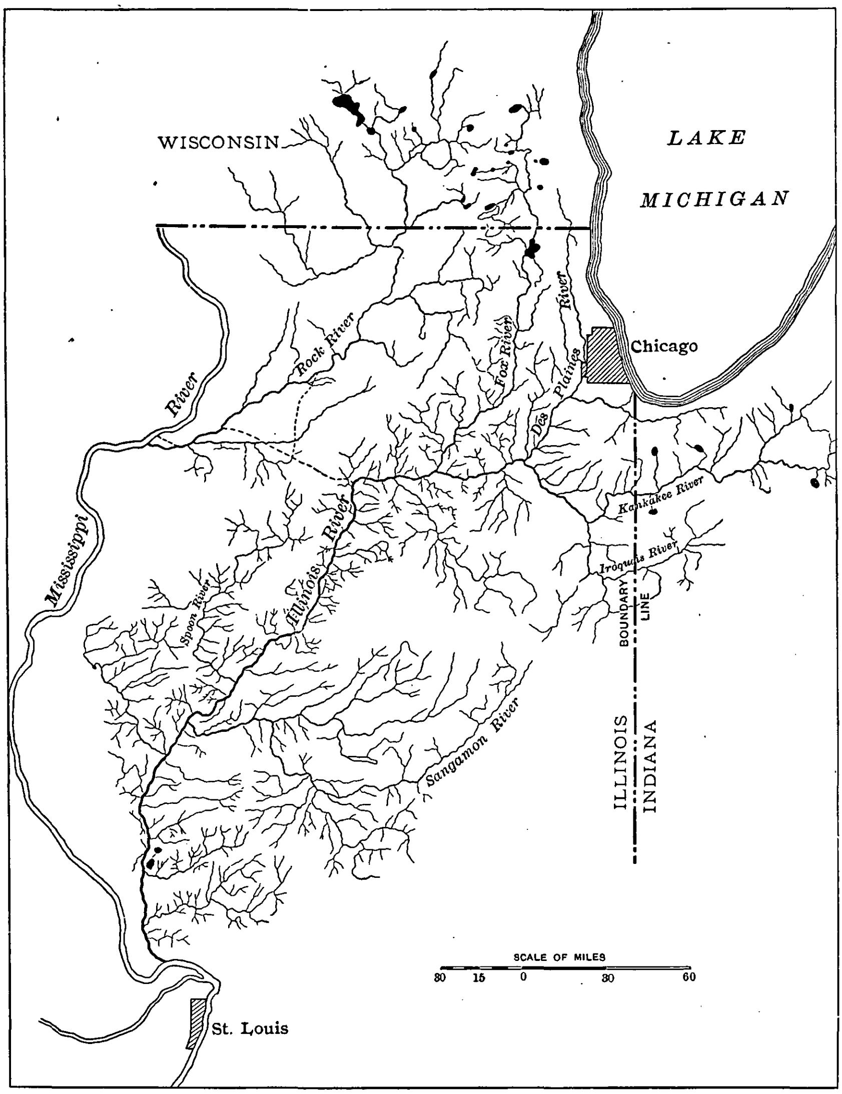


FIG. 100.—Drainage basin of Illinois River.

miles in length, taking water from Rock River near the town of Sterling, Illinois.

Few facts are known concerning the natural flow of Illinois River. From the report of the Chief Signal Officer, United States Army, for the year ending June 30, 1891, page 225, the following figures have been taken:

Discharge of Illinois River.

Locality.	Gage height.	Discharge.
	Feet.	*Second-feet.*
Willow Island	1.3	2,788
Copperas Creek, 24 miles below Peoria	1.7	2,509
Spring Lake, 30 miles below Peoria	1.5	2,527
Frederick	1.3	2,590
Lagrange, 15 miles above Naples	4.3	9,746
Naples	3.9	10,366
Bedford, 17 miles below Naples	4.0	9,134

The low-water discharge of Illinois River is stated to be less than 2,000 second-feet, while the mean discharge of the Upper Mississippi is 105,000 second-feet and of the Missouri 120,000 second-feet. Rock River at its lowest known stage—October 11, 1870—was discharging 2,446 second-feet.

Observations of the height of water in Illinois River have been made by the Weather Bureau at Peoria, 65 miles above Beardstown, and at Beardstown, 70 miles above the junction of the Illinois with the Mississippi. At Peoria the width of the river at low water is 600 feet, and the drainage area, as reported by the Weather Bureau, is 15,700 square miles.[1] The river gage is nailed to a pile in the protecting work of the draw pier of the Peoria wagon bridge, and is 40 feet upstream from the pier. The bench mark is the top of the water table on the southeast corner of the court-house, 77.45 feet above the zero of the gage. The top surface of the bottom chord of the bridge directly over the center of the pivot pier is 27.66 feet above the zero of the gage. The highest water was on May 9, 1892, 21.9 feet; the lowest on October 7, 1890, 2.6 feet; the danger line is at 14 feet.

At Beardstown the drainage area, according to the Weather Bureau, is 24,700 square miles, and the width of the river at low water is 975 feet. Locks 12 miles below the city prevent the river falling below 6 feet. The river gage is on the south side of the channel pier of the Chicago, Burlington and Quincy Railroad bridge, and belongs to the railroad company. It is attached to a pile which is one of a long row. The gage is constructed of hard pine, and the graduation is cut into its face. The bench mark, which is the top of the uppermost stone of the northeast corner of the foundation of the reddish brick house at the foot of Jefferson street, is 20.55 feet above zero of gage. The top

[1] According to Lyman E. Cooley (page 68 of the Report of the State Board of Health on Water Supplies of Illinois, 1889) it is 13,479 square miles.

of the tie on the bridge is 34.63 feet above zero of gage. The highest water was in 1889, 21.3 feet; the lowest on August 12, 1887, 0.0; danger line is at 12 feet.

Systematic observations of the height of water are being taken by the United States Engineer Corps, nine gages being set between Joliet and Utica. Frequent discharge measurements are being made, at various heights of water, under the direct charge of Mr. James A. Seddon.

Gage readings have been maintained at various points on the lower river, particularly at the Government locks and dams. The results of these are given in the annual reports of the Chief of Engineers, United States Army, beginning with that for 1890. The longest series of readings on lower Illinois River is that at Kampsville, Illinois, beginning in 1881. Other points of observation are at Lagrange and at Copperas Creek.

Bacteriological examinations of the water of the river have been made at the University of Illinois since May, 1899. Samples have been collected at least once a week from stations located so as to give the fullest information possible of the condition of the water in its course from Chicago to the mouth of the river. The collecting stations, named in order from the upper end of the stream, are as follows: Bridgeport, Lockport, Joliet, Morris, Ottawa, Lasalle, Henry, Averyville, Pekin, Wesley, Havana, Beardstown, Kampsville, and Grafton.

Samples are also taken from Des Plaines River at Lockport, from the Kankakee at Wilmington, from the Fox at Ottawa, from the Big Vermilion at Lasalle, from the Sangamon at Chandlerville, and from the Mississippi at Grafton, all in the State of Illinois; also above the mouth of Illinois River at Alton, Illinois, at Mitchell, Illinois, and at Jefferson Barracks, Missouri. Samples are also taken from Missouri River at West Alton. These samples are secured by trained collectors, shipped in iced cases, and analyzed to determine the number of bacteria per cubic centimeter and the presence or absence of *Bacilli coli-communis*.

It has been found that during warm weather the water gradually clears from its polluted condition after leaving Chicago, so that north of Peoria it has not more than the normal number of bacteria for rivers. At the latter place, however, much contamination again occurs, but before the water reaches the Mississippi it is once more as free from bacteria as is that of streams considered pure. In the winter purification is much slower, and evidences of the sewage admitted to the headwaters are to some extent found throughout the course of the river. But it also appears that the Mississippi above the mouth of the Illinois, and the Missouri at West Alton, Illinois, carry as many bacteria in the winter as does the Illinois in the lower part of its course.

A very interesting comparison is to be made during the next few months to determine what effect, if any, is caused by the entrance at Chicago of the larger volume of lake water and the admixture therewith of the increased amount of sewage. Up to the present time it seems the effect is less than the fluctuations caused by other conditions, such as variations in rainfall.

Besides the foregoing investigations, the biological station of the Natural History Survey has carried on field work by the Plankton method, seeking to ascertain fluctuations in the quantity of life in the water and to determine the relative numbers of the different organisms present; also to analyze their relations to one another and the various factors of their environment. For this purpose, from 1894 to 1899, quantitative collections have been made at regular intervals in the river near Havana, in adjacent bottom-land waters, and in tributary streams. The final report of this investigation has not yet been published, but the foregoing facts have been obtained from Prof. Charles A. Kofoid, superintendent of the Natural History Survey.

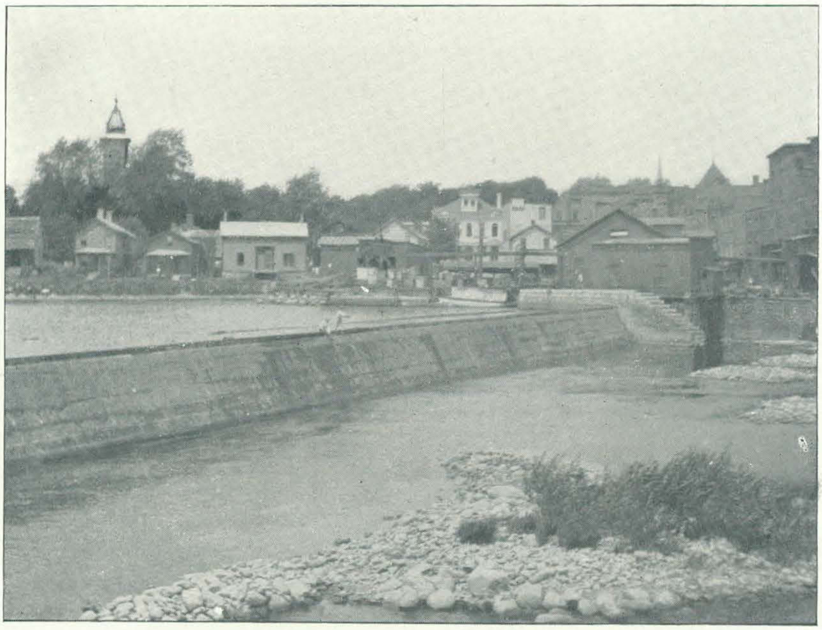
At Havana, Illinois, a town between Peoria and Beardstown, the river has a maximum width of about 600 feet at the lowest stage of the water and a depth of from 8 to 9 feet. The current at this point is sluggish. On the bottoms adjacent to the river are a number of spring-fed lakes, which form part of the river at times of high water.

A series of chemical examinations of the water supply of the State of Illinois have been conducted since 1895 under the direction of Prof. Arthur W. Palmer, of the University of Illinois. A preliminary report was made in 1897, and a later report is being prepared for publication in 1900. The object of the examination is the prevention of the dissemination of disease through the use of impure water. Arrangements have been made by which any citizen of the State may have the water which he uses, or in which he is interested, analyzed free of charge, and a report is made indicating whether the water is wholesome or impure and likely to be injurious. The work is grouped as follows:

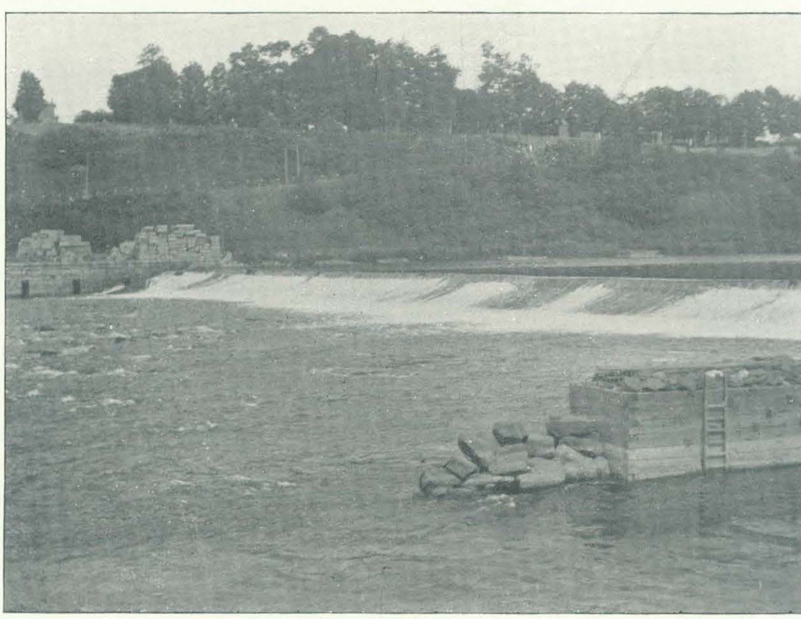
(1) Sanitary analyses of waters from house wells and other private and public sources of supply for private citizens and others.

(2) General investigation of the surface waters of the State, embracing an extensive series of examinations of the waters of Illinois River and its tributaries, including the Illinois and Michigan Canal and Lake Michigan; also Mississippi River above and below the mouth of the Illinois. This work has been going on for the last five years, having been undertaken for the purpose of determining the normal condition of the waters of Illinois River before the opening of the Chicago Drainage Canal.

(3) Quantitative analyses of mineral matters contained in waters from springs, flowing wells, and other sources.



A. DAM ON SENECA RIVER AT BALDWINSVILLE, NEW YORK.



B. DAM ON OSWEGO RIVER BETWEEN OSWEGO AND FULTON, NEW YORK.

GREAT LAKES DRAINAGE.

MAUMEE RIVER.

The Maumee is formed by the junction of St. Joseph and St. Marys rivers near Fort Wayne, Indiana, and flows in a northeasterly direction through Ohio, emptying into Lake Erie at Toledo. The southern part of the watershed is flat, the northern part gently rolling and in places hilly. The hilly section was formerly covered with timber, but the best of it has now been cut. Two dams have been built on the Maumee, one at Defiance, to supply water for the Ohio State canals, and the other at Grand Rapids, for furnishing water power. The station is at Watertown, Ohio.

SANDUSKY RIVER.

This river rises in the north-central part of Ohio, and flows in a westerly and northerly direction into Sandusky Bay, an arm of Lake Erie. Its watershed is largely used for farming and pasturage, having only an occasional patch of forest. Sixteen dams have been built along the river, in order to utilize the water power. Only five of them are now in use, but the flow is more or less obstructed by all. Two stations have been established on the river, one at Mexico, 6 miles above Tiffin, and the other at Fremont about 15 miles from the mouth of the river. Both stations were established in November, 1898. Discharge measurements at both places are made by B. H. Flynn.

NIAGARA RIVER.

In the fall of 1897 the Board of Engineers on Deep Waterways made a short series of measurements of the outflow of Niagara River, which were repeated the following midsummer. The results of these measurements will probably be published in the final report of the board, now in preparation. They have already been given in part in a paper read by C. B. Stewart before the Western Society of Engineers, December 20, 1899.

Measurements of Niagara River, as well as of St. Marys, St. Clair, and St. Lawrence rivers, have been made at various times by the Corps of Engineers, United States Army, the results of which are being prepared for publication in the annual report of the Chief of Engineers for the year ending June 30, 1900.

SENECA RIVER.

This stream has its source in the lake of the same name in central New York. Its general course is northeasterly until its junction with Oneida River, in Onondaga County, where the two unite to form Oswego River, which flows northwesterly, entering Lake Ontario at the city of Oswego. Oswego Canal is fed from Seneca River. Fig. 101 is a map of the drainage basins of Seneca and Oswego rivers. The station on Seneca River is located at the dam at Baldwinsville, a view of which is shown in Pl. IX, *A*.

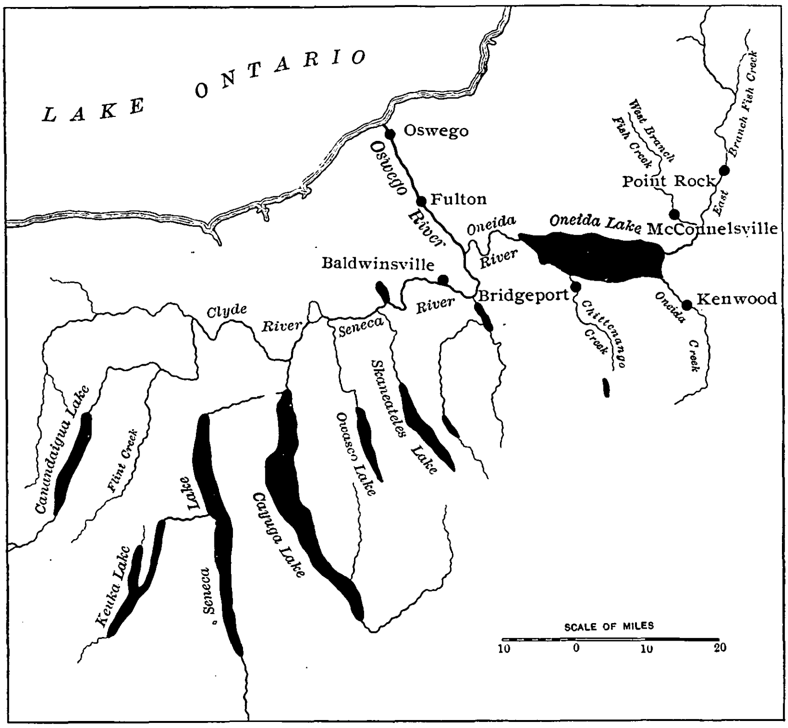


FIG. 101.—Drainage basins of Seneca and Oswego rivers.

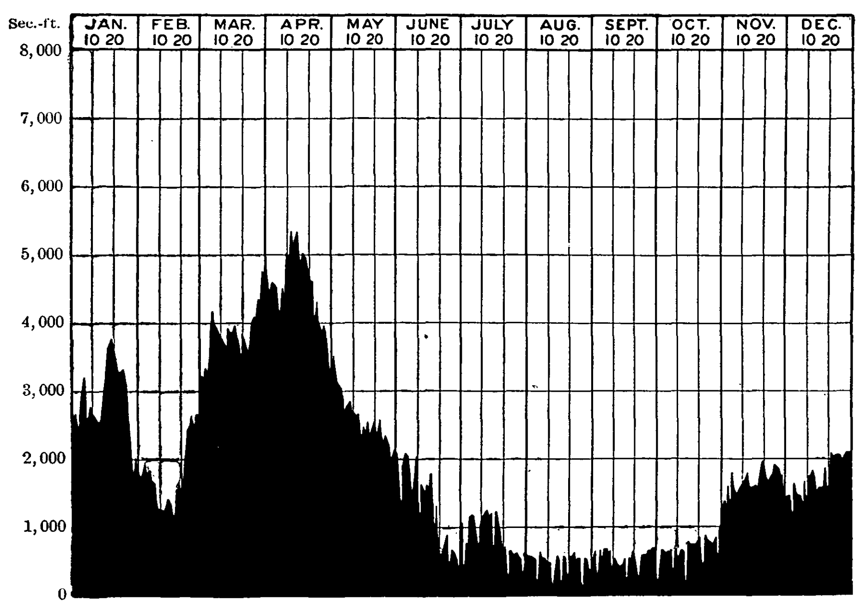
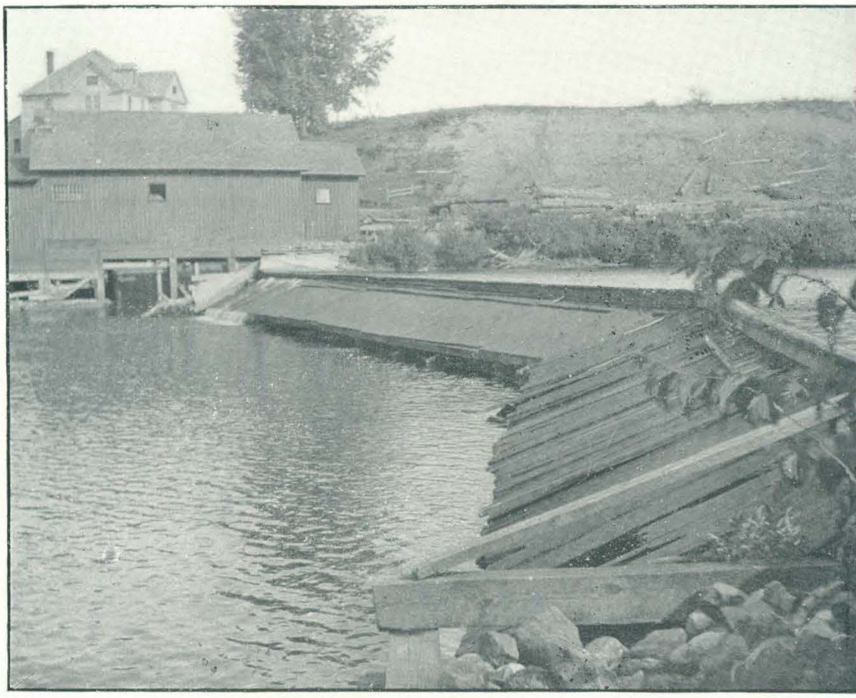
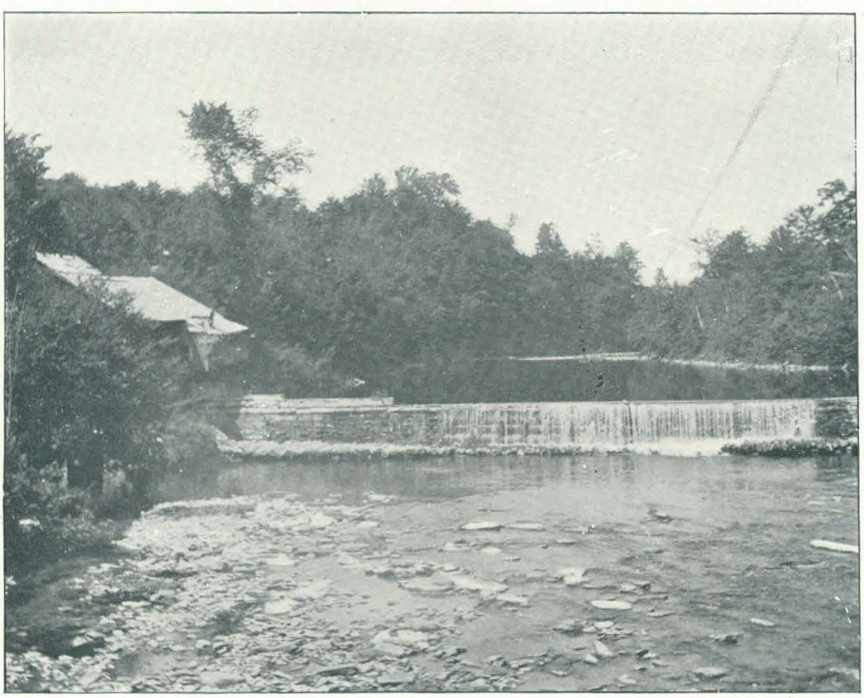


FIG. 102.—Discharge of Seneca River at Baldwinsville, New York, 1899.



A. DAM ON WEST BRANCH OF FISH CREEK AT McCONNELLSVILLE, NEW YORK.



B. DAM ON EAST BRANCH OF FISH CREEK AT POINT ROCK, NEW YORK.

CHITTENANGO CREEK.

This creek rises in Madison County, New York, and flows in a northeasterly direction between Madison and Onondaga counties into Oneida Lake, the outlet of which is Oneida River, a tributary of the Oswego. Observations for computations of flow are made at Bridgeport, New York, by Robert E. Horton.

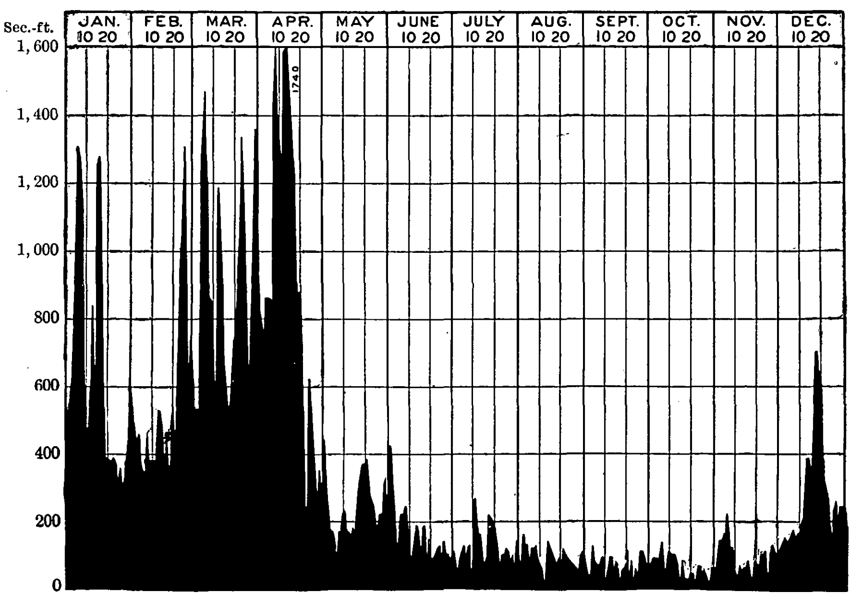


FIG. 103.—Discharge of Chittenango Creek at Bridgeport, New York, 1899.

FISH CREEK.

Fish Creek is formed by the junction of the West Branch and the East Branch, in Oneida County, New York. The West Branch rises in Oneida County and flows in a southerly direction. The East Branch rises in Lewis County and also flows in a southerly direction. The main Fish Creek flows in a westerly direction, emptying into the east end of Oneida Lake, the outlet of which is Oneida River, a tributary of Oswego River. The West Branch is measured at McConnellsville, New York. The East Branch is measured above Point Rock, New York. Pl. X, *A*, shows the dam on the West Branch at McConnellsville; Pl. X, *B*, the dam on the East Branch at Point Rock.

OSWEGO RIVER.

The Oswego is formed by the junction of Oneida and Seneca rivers in Onondaga County, New York. It flows northwesterly, emptying into Lake Ontario at the city of Oswego. A map of the drainage basins of Seneca and Oswego rivers will be found on page 180, fig. 101. Measurements are made at Fulton and at Oswego. Pl. IX, *B*, is a view of one of the dams on Oswego River between Oswego and Fulton.

BLACK RIVER.

This river rises in Herkimer County, New York, and flows in a northeasterly direction into Black River Bay, an arm of Lake Ontario.

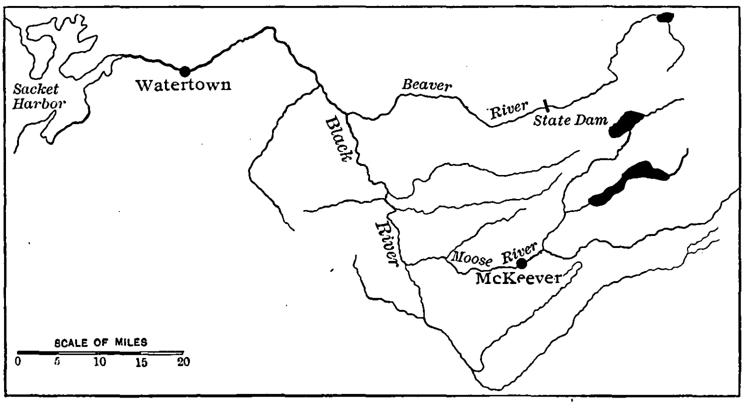


FIG. 104.—Drainage basin of Black River.

The station, which was established February 22, 1897, is at Watertown. The discharge of the river has been computed by Robert E. Horton.

UPPER MISSOURI RIVER DRAINAGE.

MIDDLE CREEK.

This creek, a tributary of East Gallatin River, has its source on the northern slope of the Gallatin Range. Although it drains a small area, it is an important stream, on account of its water supply, which is used for irrigation purposes in the vicinity of Bozeman, Montana. The station is located 9 miles south of Bozeman. Discharge measurements are made under the direction of Samuel Fortier.

Estimated monthly discharge of Middle Creek at Bozeman, Montana.

[Drainage area, 55 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			425	26,132	7.73	8.91
February *a*			475	26,381	8.64	9.00
March *a*			425	26,132	7.73	8.91
April						
May 7 to 31	515	440	472	29,022	8.58	8.73
June	665	500	586	34,869	10.65	11.88
July	605	470	533	32,773	9.69	10.01
August	470	425	446	27,424	8.11	9.35
September	432	410	418	24,873	7.60	8.48
October	425	410	411	25,271	7.47	8.61

a Approximate.

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 27, page 70; discharge measurements, page 74; rating table, page 75. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 36, page 197; rating table in Paper No. 39, page 446.

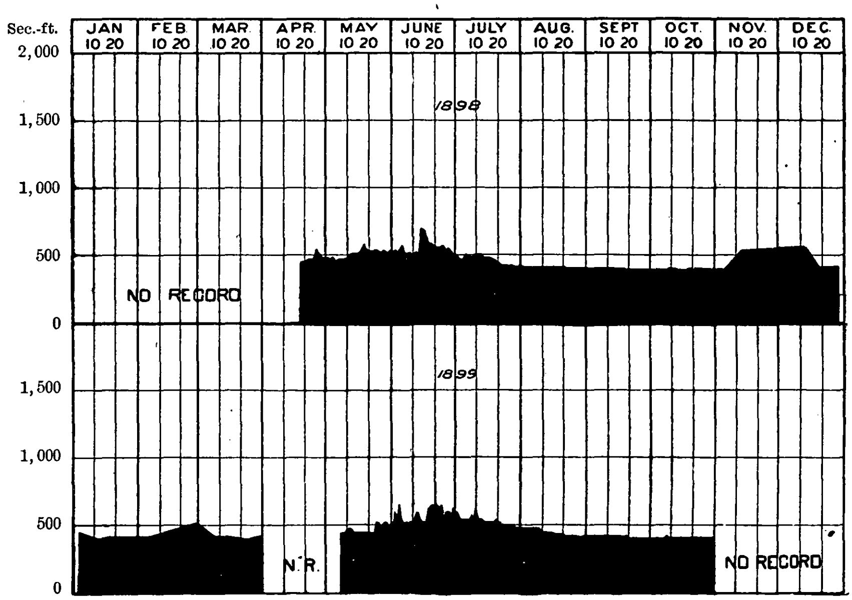


FIG. 105.—Discharge of Middle Creek at Bozeman, Montana, 1898 and 1899.

WEST GALLATIN RIVER.

This stream rises in the northwestern corner of Yellowstone National Park and flows in a northerly direction, joining Madison and Gallatin rivers at Threeforks, Montana, to form the Missouri. The upper 75 miles of its course is in a canyon, the scenery of which rivals many noted canyons of Yellowstone Park. Surveys have been made for a road up this canyon, in order to reach the road system which the Government has built in the Park, but the plans have not yet been carried out. About 10 miles above Salesville, Montana, the river leaves its canyon and enters Gallatin Valley, which, for a number of years has been noted for its fertility. Large crops of hay and cereals are yearly matured there. The land is irrigated from canals fed by the Gallatin and its tributaries, including Middle Creek, Bozeman Creek, and East Gallatin River. On certain bench lands against the sides of the surrounding mountains, dry farming is practiced, or, in other words, the crops are raised without irrigation. Two stations are maintained on the river, one near Salesville, established a number of years ago, and the other at Logan, near the mouth of the river. Measurements of discharge are made under the supervision of Samuel Fortier.

Estimated monthly discharge of West Gallatin River at Salesville, Montana.

[Drainage area, 860 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			700	43,041	0.81	0.93
February *a*			700	38,876	0.81	0.84
March *a*			670	41,197	0.78	0.90
April	850	650	731	43,497	0.85	0.94
May	2,030	710	1,228	75,507	1.43	1.65
June	9,700	1,460	5,563	331,021	6.47	7.22
July	7,200	1,870	4,566	280,752	5.31	6.12
August	1,870	1,010	1,319	81,102	1.53	1.76
September	1,010	850	914	54,387	1.06	1.18
October	850	850	850	52,264	0.99	1.14
November *a*			850	50,579	0.99	1.10
December *a*			750	46,116	0.87	1.00

a Approximate.

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 36, page 196; rating table in Paper No. 39, page 446.

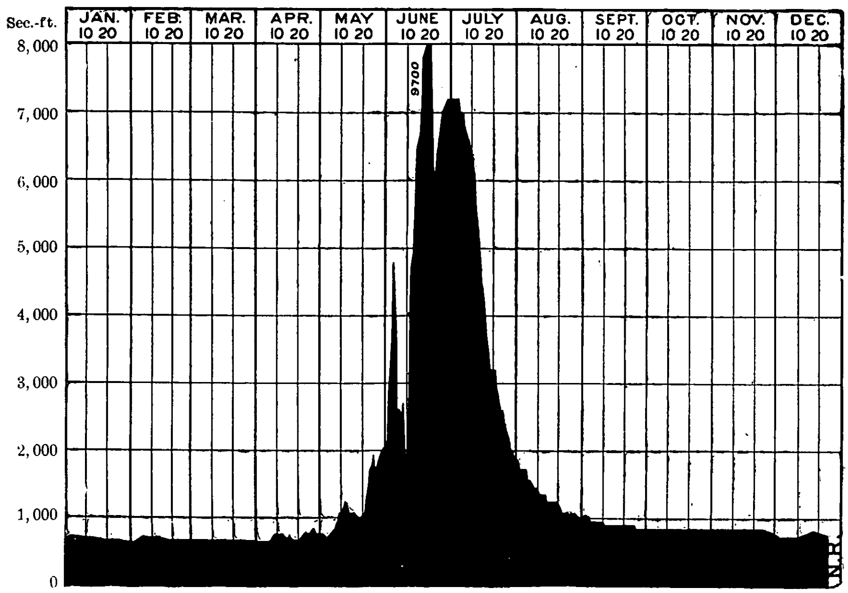


FIG. 106.—Discharge of West Gallatin River at Salesville, Montana, 1899.

MADISON RIVER.

Madison River rises in the central portion of Yellowstone National Park and flows in a general northerly direction, joining the Jefferson and Gallatin rivers near Threeforks, Montana, to form the Missouri. Some distance beyond the western boundary of Yellowstone Park is an opening of considerable extent known as Upper Madison Valley. Below Meadow Creek the bluffs close in again, and the river is in canyon to below the mouth of Cherry Creek. Beyond this it gradually opens into the lower valley. The country above the headwaters of the stream is too high for profitable farming, except for summer stock ranging. Less water can be advantageously used for irrigation from this stream than from the other two tributaries of the Missouri, but the fall is admirably adapted to power purposes, and a number of surveys have been made in that direction. The station, which was established May 2, 1897, is 3 miles below the Redbluff iron county bridge over the Madison and about 1½ miles below the mouth of Cherry Creek. Discharge measurements are made at the highway bridge. Cherry Creek enters between the bridge and the gage rod, and it is necessary to measure its discharge whenever the main river is measured. The measurements are made under the direction of Samuel Fortier.

Estimated monthly discharge of Madison River at Redbluff, Montana.

[Drainage area, 2,085 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 16 to 30	2,962	2,637	2,843	169,171	1.36	1.52
May	6,050	1,175	3,051	187,599	1.46	1.68
June	10,275	6,050	8,385	498,941	4.02	4.49
July	8,650	2,800	5,159	317,215	2.47	2.85
August	3,612	2,150	2,727	167,677	1.31	1.51
September	2,150	2,150	2,150	127,934	1.03	1.15
October	1,825	1,825	1,825	112,215	0.88	1.01
November *a*			1,825	108,595	0.88	0.98

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 206; discharge measurements, page 205; rating table in Paper No. 39, page 446.

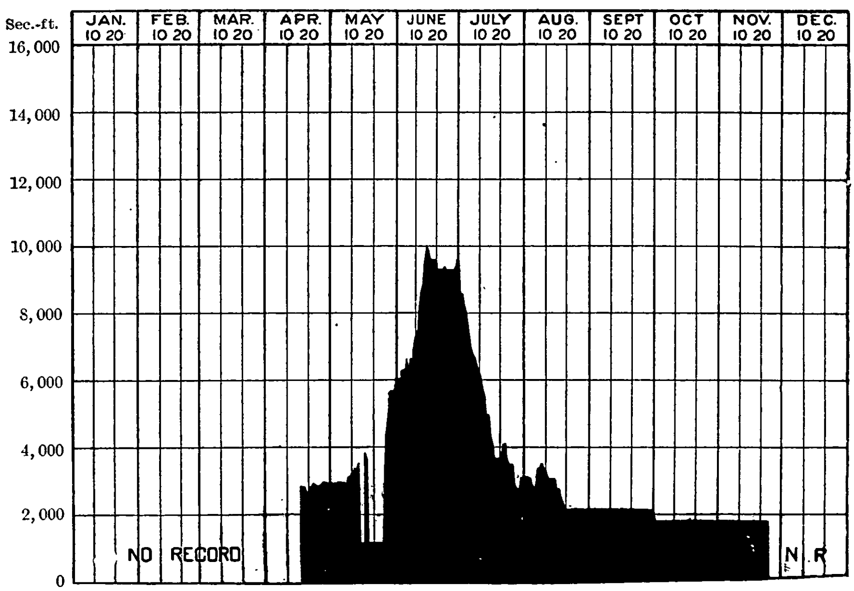


FIG. 107.—Discharge of Madison River at Redbluff, Montana, 1899.

JEFFERSON RIVER.

This river is formed by the junction of the Bighole and Beaverdam rivers near Twin Bridges, Montana. The former stream has its source in the highest parts of the Rocky Mountains which form the Continental Divide and the State boundary line between Montana and Idaho. Jefferson River is one of the three streams that unite at Threeforks to form the Missouri. Irrigation is practiced to a limited extent in the upper reaches of the Jefferson, mainly for forage plants. From Twin Bridges downstream to the mouth of North and South Boulder creeks is an area of tillable land, which, however, has been little utilized up to the present time. The river is in canyon from Boulder Creek to about Willow Creek, where the gorge gradually widens into Gallatin Valley. The station is at Sappington, Montana. Measurements are made by Samuel Fortier. Those for 1899 will be found in Water-Supply Paper No. 37, page 207.

MISSOURI RIVER.

The Missouri is formed by the junction of the Jefferson, Madison, and Gallatin rivers at Threeforks, Montana. Observations of gage heights on the upper part of the river are maintained at Townsend, Montana, by the Missouri River Commission. Measurements of discharge are made at that point under the direction of Samuel Fortier.

Estimated monthly discharge of Missouri River at Townsend, Montana.

[Drainage area, 14,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 4 to 30	8,825	2,000	5,790	344,529	0.40	0.45
May	14,300	5,400	9,687	595,630	0.67	0.77
June	52,525	13,450	29,158	1,735,021	2.01	2.24
July	31,900	5,850	14,130	868,820	0.97	1.12
August	5,850	3,750	4,866	299,199	0.34	0.39
September	3,625	3,000	3,350	199,339	0.23	0.26
October	4,950	3,000	3,864	237,588	0.27	0.31
November	4,375	3,625	4,067	242,003	0.28	0.31
December	12,400	3,250	4,375	269,008	0.30	0.35

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 208; rating table in Paper No. 39, page 446.

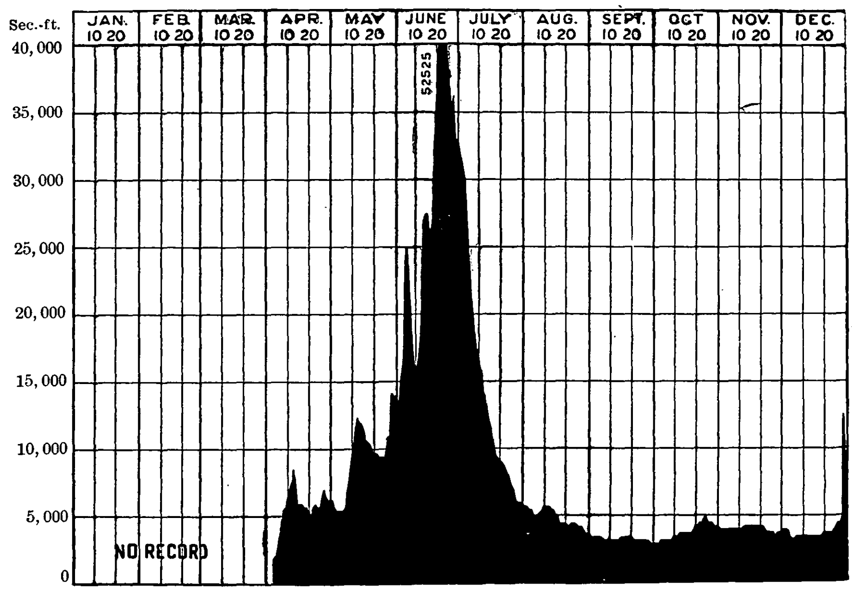


FIG. 108.—Discharge of Missouri River at Townsend, Montana, 1899.

MILK RIVER.

This river rises on the eastern slope of the Rocky Mountains, in the extreme northern part of Montana. The headwater tributaries have a general northeasterly direction across the international boundary line into British territory, where a large area is drained. The river reenters the United States farther to the east, and flows in a general southerly direction to Havre, Montana. Its course is then easterly until it joins the Missouri near Glasgow, Montana, at the southwestern corner of the Fort Peck Indian Reservation. The valley of the river is fertile and well adapted to the raising of hardier grains. Development in this direction has been somewhat slow until within the last few years. The area drained by Milk River is, to a large extent, rolling prairie lands, excellent for grazing purposes and covered with a good growth of grass. The discharge measurements show the amount of water available for the canals, a number of which have recently been constructed along the river below Havre, as described in the Eighteenth Annual Report, Part IV, page 286. The present station is located at Havre, Montana. It was established May 15, 1898. The river is subject to violent floods of short duration, and its bed, being composed of gravels and clay, is likely to change after each freshet. Measurements of discharge are made from a car and cable of 200-feet span, swung across the river a short distance above the gage. Measurements are made by C. W. Ling.

Estimated monthly discharge of Milk River at Havre, Montana.

[Drainage area, 7,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			430	26,440	0.06	0.07
April	2,880	620	1,365	81,223	0.19	0.21
May	1,680	570	1,006	61,857	0.14	0.16
June *a*			940	55,934	0.13	0.14
July *a*			241	14,818	0.03	0.03
August *a*			196	12,052	0.03	0.03
September	235	84	131	7,795	0.02	0.02
October	110	80	94	57,798	0.01	0.01
November *a*			190	11,306	0.03	0.03
December *a*						

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 210; discharge measurements, page 209; rating tables in Paper No. 39, page 447.

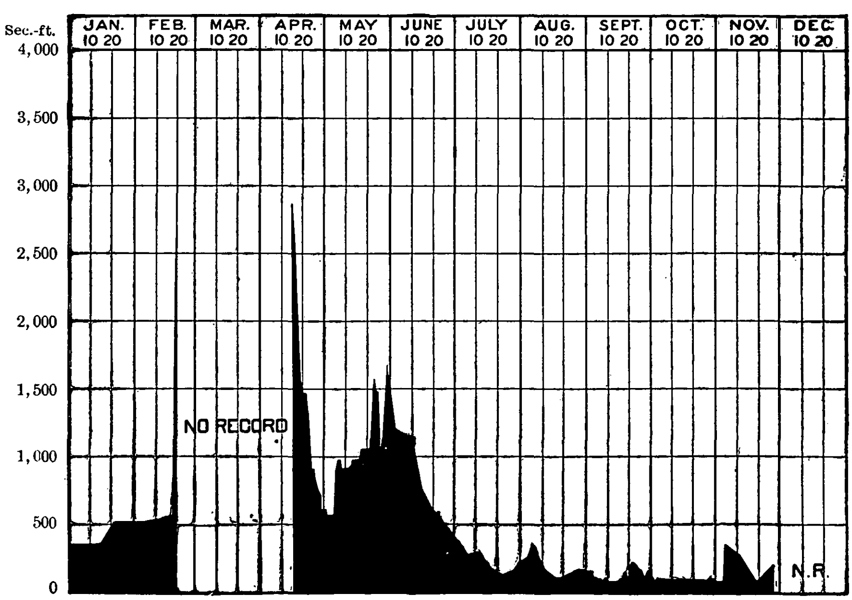


FIG. 109.—Discharge of Milk River at Havre, Montana, 1899.

YELLOWSTONE DRAINAGE BASIN.

YELLOWSTONE RIVER.

The Yellowstone has its source in Yellowstone Lake in the National Park, and flows in a northerly direction into Montana. Its course is thence easterly until its junction with the Missouri, near the North Dakota line. Owing to the numerous springs of the National Park, which contribute to its flow, and also to the fact that the lake acts as a regulator, the discharge where it crosses the Montana line is large for a river in that section of country. Yellowstone Valley is the largest body of irrigable land in Montana, having a length of about 500 miles. At present it is principally utilized as a range for a vast number of cattle and sheep. With its comparatively low altitude of 2,500 feet the section is well adapted to the future development of irrigation. The station, established May 2, 1897, is at Livingston, Montana, at the mouth of the canyon. Measurements are made by Samuel Fortier.

CLEAR CREEK.

This creek is one of the most important tributaries of Powder River. Its source is in the summit of the Bighorn Mountains. The irrigation system diverting water from the creek has been described in detail in earlier reports. The point of measurement is about 4 miles west of Buffalo, Wyoming, where there is a flume, erected in 1889. Of late years this station is not considered as important as formerly, on account of the diversions of water which have taken place within the basin. The earlier discharge measurements established a rating for the measuring flume, and it has not been necessary to make any since.

Estimated monthly discharge of Clear Creek near Buffalo, Wyoming.

[Drainage area, 118 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			15	922	0.13	0.15
February *a*			15	833	0.13	0.14
March *a*			15	922	0.13	0.15
April *a*			40	2,380	0.34	0.38
May	228	29	100	6,149	0.85	0.98
June	778	169	360	21,421	3.05	3.40
July	447	209	305	18,754	2.58	2.96
August	266	33	77	4,735	0.65	0.75
September	46	33	37	2,202	0.31	0.35
October	46	25	37	2,275	0.31	0.36
November	33	25	31	1,845	0.26	0.29
December *a*			26	1,599	0.22	0.25

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 213; rating table in Paper No. 39, page 447.

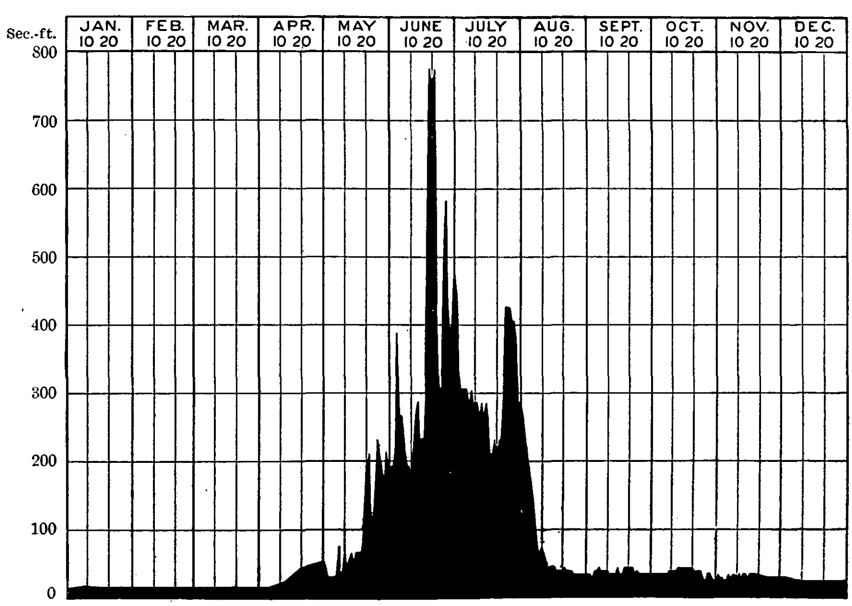


FIG. 110.—Discharge of Clear Creek near Buffalo, Wyoming, 1899.

ROCK CREEK.

Rock Creek has its source in the summit of the Bighorn Mountains, on the north side of Cloud Peak. It flows eastward, and enters Clear Creek below Buffalo, Wyoming. Its length is about 30 miles. Mr. E. B. Mather, of Buffalo, states that a ditch is being built from Piney Creek to the North Fork of Rock Creek. When this is completed, it is intended to begin construction of the dam at Cloud Peak Lake. The first step will be to construct a tunnel 12 feet below the present lake surface and about 150 feet long. About half the distance will be through an open cut, the remainder through rock. As soon as a steel gate has been placed in the tunnel, work will be begun on a rock and gravel dam. By means of these improvements the water in the lake can be raised fully 40 feet above its present level, as shown in the report of Mr. Hiram M. Chittenden.

PLATTE RIVER DRAINAGE.

LARAMIE RIVER.

This river, a tributary of the North Platte, which it enters at Fort Laramie, Wyoming, has its source in the mountains of northern Colorado, its headwaters adjoining those of the Cache la Poudre on the west. Irrigation is practiced on a small scale in Colorado, but principally for hay ranches, the elevation being too great for diversified farming. After crossing the Wyoming line Laramie River soon leaves its canyon and enters the Laramie Plains, which are extensively irrigated from the main stream and its various tributaries, notably Little Laramie River, the low-water flow of which is now entirely used. Lower down, the river passes through another canyon, and finally enters the plain of Lower Laramie River, which extends from the eastern edge of Laramie Hills to the mouth of the river. Two stations are maintained on the Laramie, one at Woods Landing, Wyoming, near the State line, and the other at Uva, Wyoming, near its mouth. Measurements at both stations are made by A. J. Parshall.

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

[Drainage area, 435 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			750	46,116	1.72	1.98
February *a*			720	39,987	1.66	1.73
March *a*			720	442,711	1.66	1.91
April	720	177	571	33,977	1.31	1.46
May	2,617	125	1,284	78,950	2.95	3.40
June	4,502	2,037	3,221	191,663	7.40	8.26
July	3,197	320	1,253	77,044	2.88	3.32
August	512	60	191	11,744	0.44	0.51
September	85	45	56	3,332	0.13	0.14
October	92	45	65	3,997	0.15	0.17
November *a*			70	4,165	0.16	0.18
December *a*			150	9,223	0.35	0.40

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 216; discharge measurements, page 215; rating table in Paper No. 39, page 447.

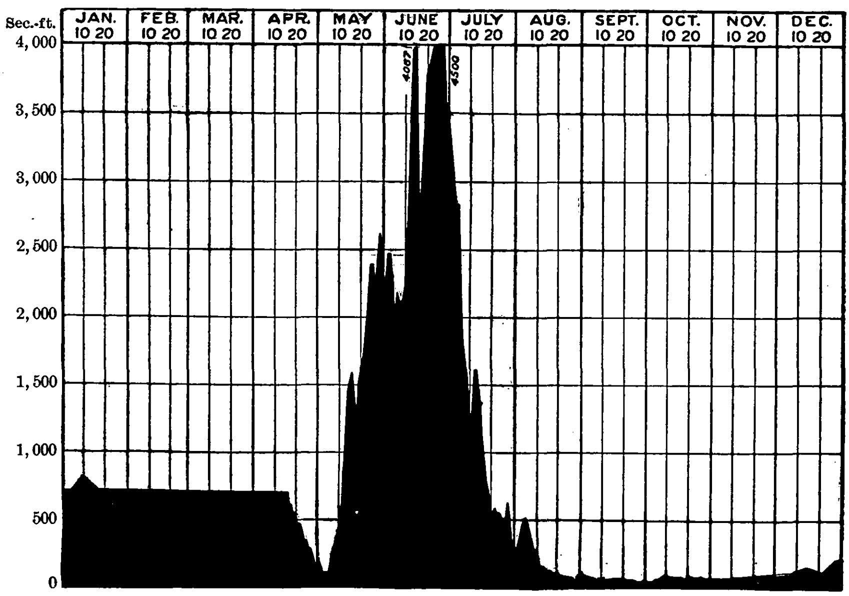


FIG. 111.—Discharge of Laramie River at Woods Landing, Wyoming, 1899.

Estimated monthly discharge of Laramie River at Uva, Wyoming.

[Drainage area, 3,179 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			100	6,149	0.031	0.036
February *a*			110	6,109	0.035	0.036
March *a*			130	7,993	0.041	0.047
April	3,259	100	987	58,731	0.310	0.35
May	2,538	185	1,178	72,432	0.37	0.43
June	3,611	1,714	2,706	161,018	0.849	0.94
July	2,950	335	1,536	94,445	0.483	0.55
August	300	80	203	12,482	0.064	0.074
September	140	30	55	3,273	0.017	0.019
October	140	30	72	4,427	0.023	0.026
November *a*			120	7,141	0.038	0.043
December *a*			160	9,838	0.050	0.058

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply Paper No. 37, page 217: discharge measurements, page 216; rating table in Paper No. 39, page 447.

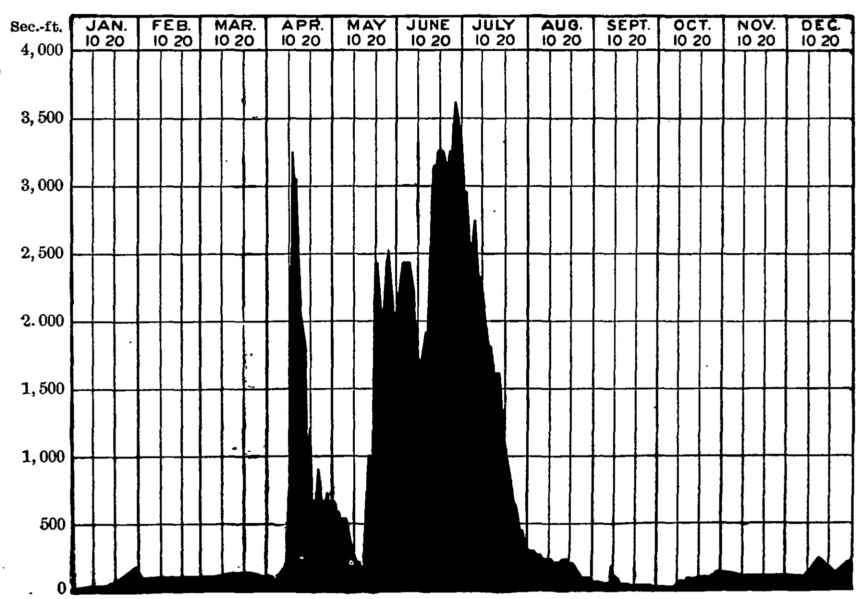
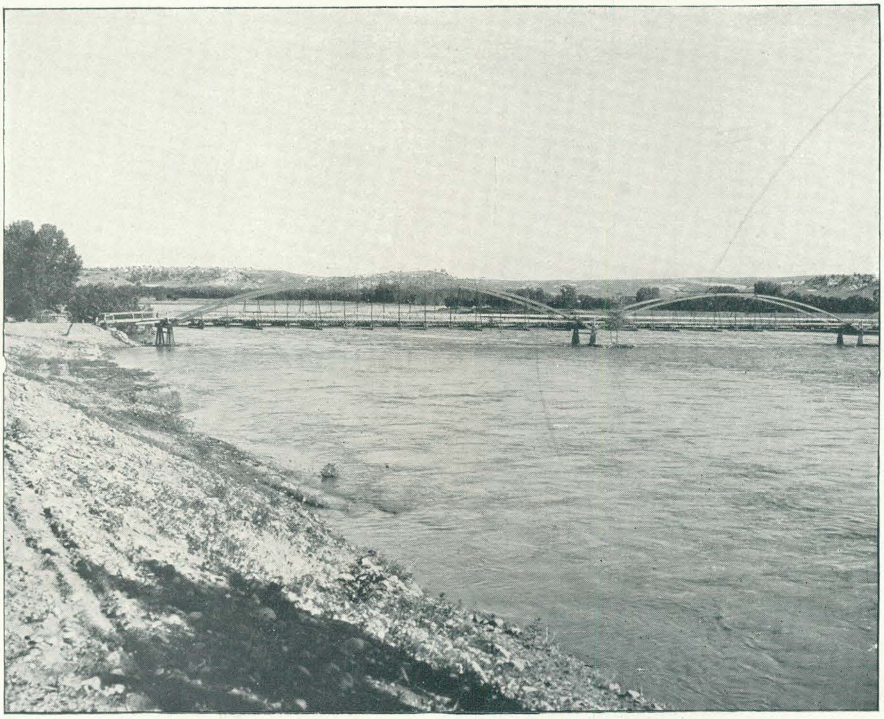


FIG. 112.—Discharge of Laramie River at Uva, Wyoming, 1899.

A. GRAND ENCAMPMENT CREEK, WYOMING, LOOKING DOWNSTREAM FROM PERYAM'S BRIDGE



B. NORTH PLATTE RIVER AT FORT LARAMIE, WYOMING.

GRAND ENCAMPMENT CREEK.

This stream rises in the mountains known as Sierra Madre, in southern Wyoming, and flows in a northerly direction, discharging into North Platte River. Its waters are used for irrigation and for power and mining purposes at Grand Encampment. During the year 1900 A. J. Parshall made five measurements at Peryam's ranch, and a daily record was kept from May 16 to October 1. The measurement made May 16, 1900, was for the purpose of obtaining a knowledge of the discharge of the river after the spring floods. The conditions at that point are favorable, measurements being made from a road bridge. The mean velocity on the day mentioned was 6.23 feet per second, and the discharge 2,050 second-feet. Later in the season low-water measurements were made of the two forks of the river and of all ditches taking water above the station. Pl. XI, *A*, is a view of the river, looking downstream from Peryam's bridge, where a gage rod has been set and measurements are made at low water.

NORTH PLATTE RIVER.

The North Platte has its source in the mountains of North Park, in northern Colorado. The general elevation of the park is 8,000 feet. It is surrounded by mountains which attain elevations of 12,000 feet. There is considerable irrigation from small ditches, which are used almost entirely, however, to flood native grass lands for forage purposes. On entering Wyoming the river passes through a short, narrow canyon, and then flows northerly through the upper Platte Valley, which extends from the State line down to Fort Steele. After passing the latter place it continues in a northerly direction, receiving a number of important tributaries, notably Sweetwater River, in the basin of which considerable irrigation is practiced. The only station in Wyoming at present maintained on the North Platte is at Orin Junction. The measurements are not altogether satisfactory, on account of the bridge piers, which interfere to a considerable extent with the uniform flow. The measurements at Orin Junction are made by A. J. Parshall. After passing into Nebraska the North Platte does not receive any tributaries of importance. A number of canals divert water between the State line and North Platte. In Nebraska the first station is at Gering. It was established May 29, 1897, and measurements are made by R. H. Willis. The next station on the North Platte is located at Camp Clarke, Nebraska. It was established June 27, 1896, and measurements are made by R. H. Willis. The fourth station is at North Platte. It is 3½ miles above the junction of the South Platte, and was established in 1894. Measurements are made by Glenn E. Smith and Charles P. Ross. Pl. XI, *B*, is a view of North Platte River at Fort Laramie, Wyoming.

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

[Drainage area, 14,828 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
February *a*			9,000	499,835	0.61	0.63
March *a*			6,000	368,926	0.40	0.46
April 6 to 31	18,430	1,830	8,562	509,477	0.58	0.64
May	17,120	3,110	10,472	643,898	0.71	0.82
June	22,960	13,712	17,737	1,055,425	1.20	1.34
July	17,770	2,400	9,203	565,870	0.62	0.71
August	2,400	240	1,169	71,879	0.08	0.09
September	720	170	328	19,517	0.022	0.025
October	895	205	499	30,682	0.034	0.039
November *a*			500	29,752	0.034	0.038

a Approximate.

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 218; rating table in Paper No. 39, page 447.

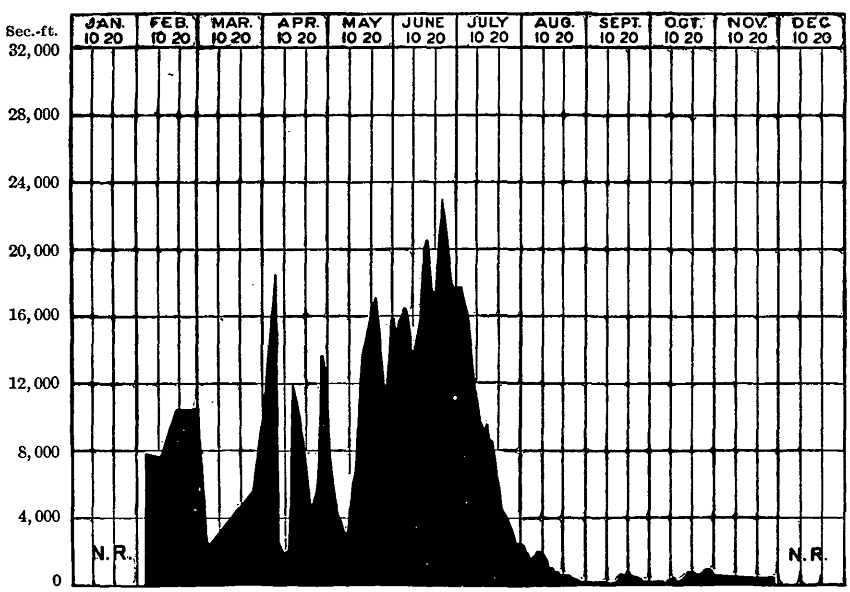


FIG. 113.—Discharge of North Platte River at Orin Junction, Wyoming, 1899.

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

[Drainage area, 24,340 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 10 to 30	14, 080	3, 155	9, 448	562, 195	0. 39	0. 44
May	15, 290	4, 991	9, 649	593, 294	0. 40	0. 46
June	23, 500	10, 352	16, 025	953, 554	0. 66	0. 73
July	18, 085	4, 582	10, 823	665, 480	0. 45	0. 52
August	5, 197	1, 454	2, 964	182, 249	0. 12	0. 14
September	1, 316	584	844	50, 221	0. 035	0. 039
October	2, 275	893	1, 501	92, 293	0. 062	0. 071

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 219; rating table in Paper No. 39, page 447.

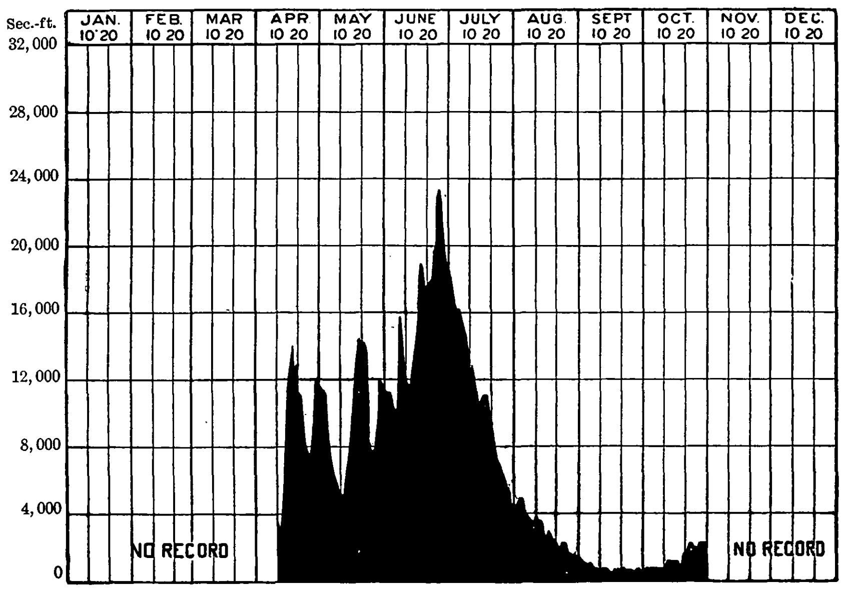


FIG. 114.—Discharge of North Platte River at Gering, Nebraska, 1899.

Estimated monthly discharge of North Platte River at Camp Clarke, Nebraska.

[Drainage area, 24,830 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 5 to 30	11,030	2,648	6,659	396,238	0.27	0.30
May	19,050	3,841	10,257	630,678	0.41	0.47
June	23,560	11,575	16,400	975,868	0.66	0.73
July	20,500	3,950	12,230	751,993	0.49	0.56
August	5,335	1,189	2,834	174,256	0.11	0.13
September	1,858	682	1,076	640,264	0.043	0.048
October 1 to 21	1,894	1,105	1,372	84,361	0.055	0.063

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 220; rating table in Paper No. 39, page 447.

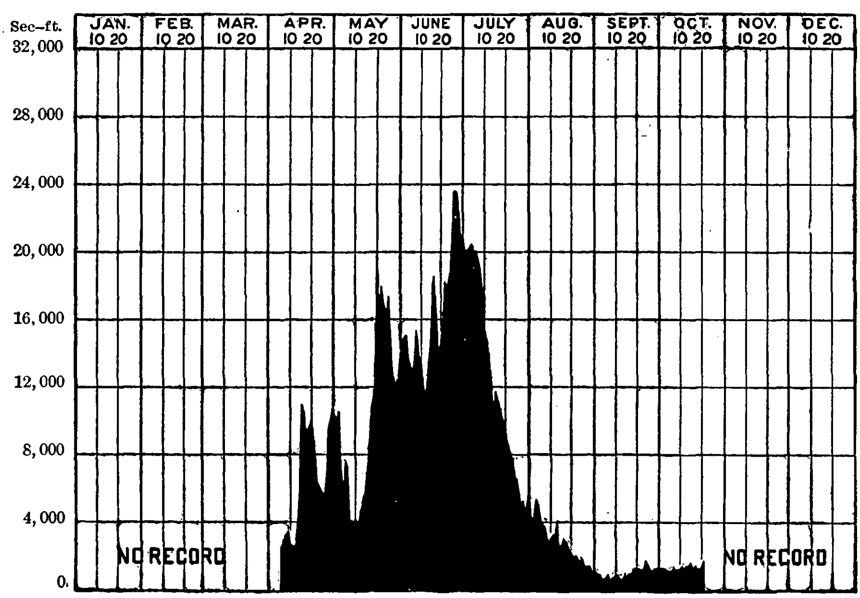
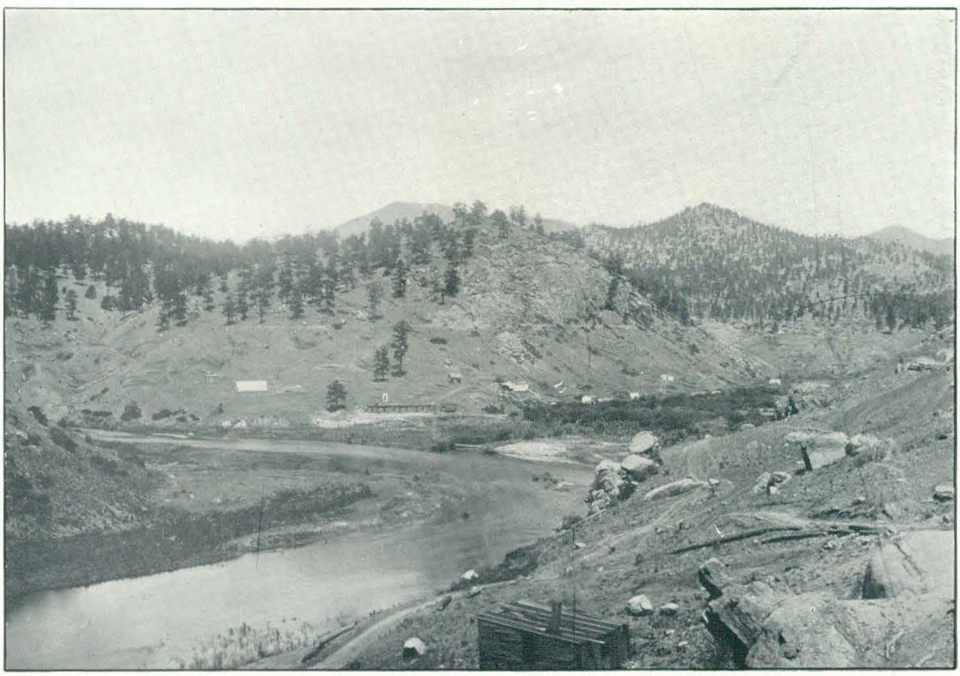


FIG. 115.—Discharge of North Platte River at Camp Clarke, Nebraska, 1899.

A. GOOSE CREEK RESERVOIR SITE, COLORADO, LOOKING TOWARD DAM SITE.



B. GOOSE CREEK RESERVOIR SITE FROM NEAR SPILLWAY.

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

[Drainage area, 28,517 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	7,437	5,757	6,263	385,097	0.22	0.25
February	7,437	7,437	7,437	413,030	0.26	0.27
March	7,997	4,637	6,814	418,979	0.24	0.28
April	9,851	3,023	6,509	387,312	0.23	0.26
May	13,373	4,607	9,196	565,444	0.32	0.37
June	18,305	10,961	13,845	823,835	0.49	0.55
July	16,257	4,917	10,743	660,566	0.38	0.44
August	6,317	1,322	3,866	237,771	0.14	0.16
September	2,215	850	1,148	68,311	0.04	0.04
October	1,557	622	964	59,274	0.034	0.039
November	2,275	1,270	1,813	107,881	0.06	0.07
December	4,433	1,700	3,274	201,310	0.11	0.13
The year	18,305	622	5,989	4,328,810	0.210	2.859

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 221; rating table in Paper No. 39, page 447.

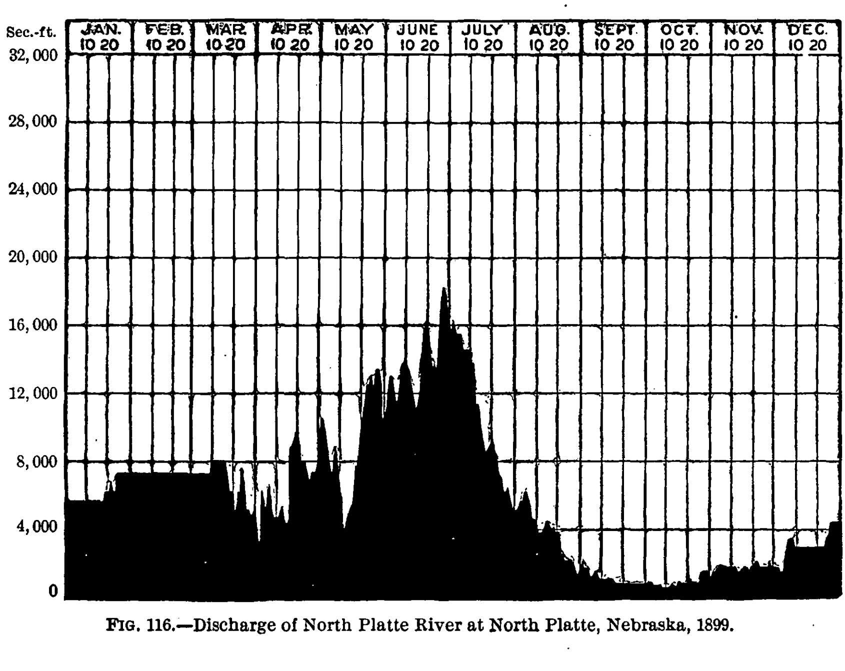


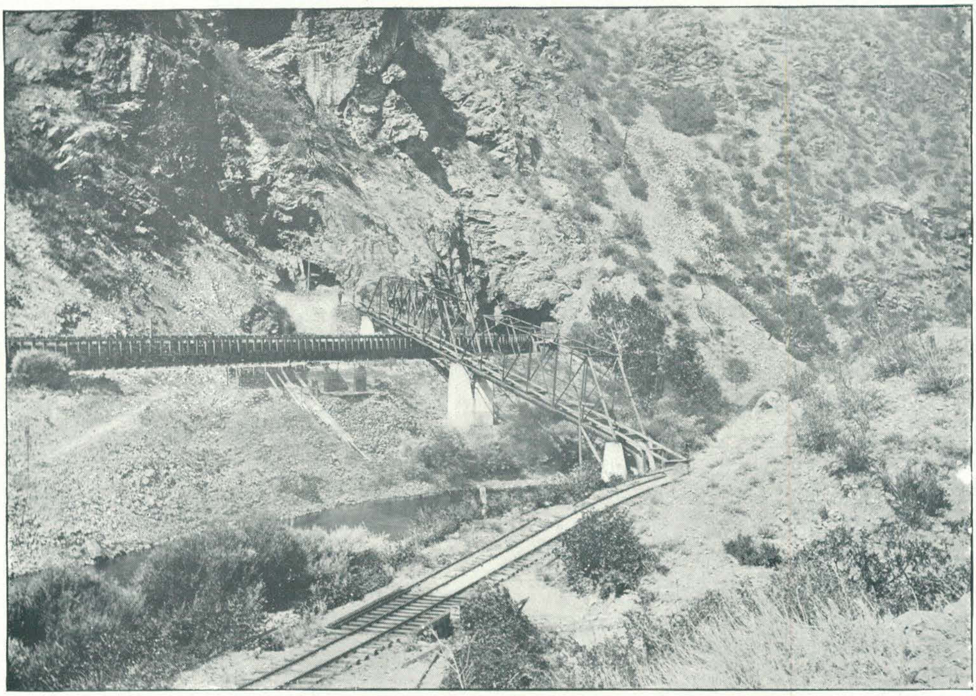
FIG. 116.—Discharge of North Platte River at North Platte, Nebraska, 1899.

SOUTH PLATTE RIVER.

The headwater tributaries of this stream have their source in the high mountain peaks surrounding the basin known as South Park. The average elevation of the valley is 8,000 feet, while the peaks attain elevations as high as 13,000 feet. Considerable irrigation on a small scale is practiced, but chiefly for forage crops, as on account of the high altitude the hardier products only can be grown. A number of smaller streams which rise on the eastern slope of the Rocky Mountains drain easterly into the South Platte. The principal tributaries are, in order downstream, Bear Creek, Clear Creek, South Boulder Creek, Boulder Creek, St. Vrain Creek, Big Thompson Creek, and Cache la Poudre River. Stations have been maintained on these tributary streams, as well as at Lake Cheesman, Colorado, on the South Fork of South Platte River, and also one on Goose Creek. The next gaging station downstream, on the main river, is at Platte Canyon, the third at Denver, and the last one at Orchard, Colorado. Besides the measurements of discharge at regular stations a number of other measurements were made in the basin during 1899. The measurements of Goose Creek and of the South Fork of South Platte River are made by J. A. Runner. The estimated monthly discharges at these two localities for the year 1899 are given in tabular form on pages 210 and 211 of this report. Measurements at the other stations are made by A. L. Fellows.

The following views in South Platte drainage basin illustrate important constructions:

Pl. XII, *A*, is a view of Goose Creek reservoir site, Colorado, looking toward the dam site. The picture was taken July 30, 1899. Pl. XII, *B*, is a view of Goose Creek reservoir from point near spillway. Pl. XIII, *A*, shows the Denver Union Water Company's pipe line and the flume of Highline ditch at Platte Canyon, Colorado. Pl. XIII, *B*, is a view of Wellington Lake dam, near Buffalo, Colorado. Pl. XIV, *A*, is a view, taken August 5, 1899, of Morrison, Colorado. Pl. XIV, *B*, is a view of Clear Creek Canyon above Forkscreek, Colorado.



A. DENVER UNION WATER COMPANY'S PIPE LINE AND FLUME OF HIGHLINE DITCH, PLATTE CANYON, COLORADO.

B. DAM OF WELLINGTON LAKE NEAR BUFFALO, COLORADO.

Estimated monthly discharge of South Platte River at Platte Canyon, Colorado.

[Drainage area, 2,620 square miles.]

Month	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	710	236	454	27,015	0.173	0.19
May	1,009	386	760	46,731	0.29	0.33
June	2,175	850	1,346	80,093	0.51	0.57
July	1,845	596	1,161	71,387	0.44	0.51
August	1,365	284	587	36,093	0.22	0.25
September	333	104	233	13,864	0.09	0.10
October	213	75	154	9,469	0.06	0.07
November	213	48	160	9,521	0.06	0.07
December	284	10	160	9,830	0.06	0.07

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 225; discharge measurements, page 224; rating table in Paper No. 39, page 448.

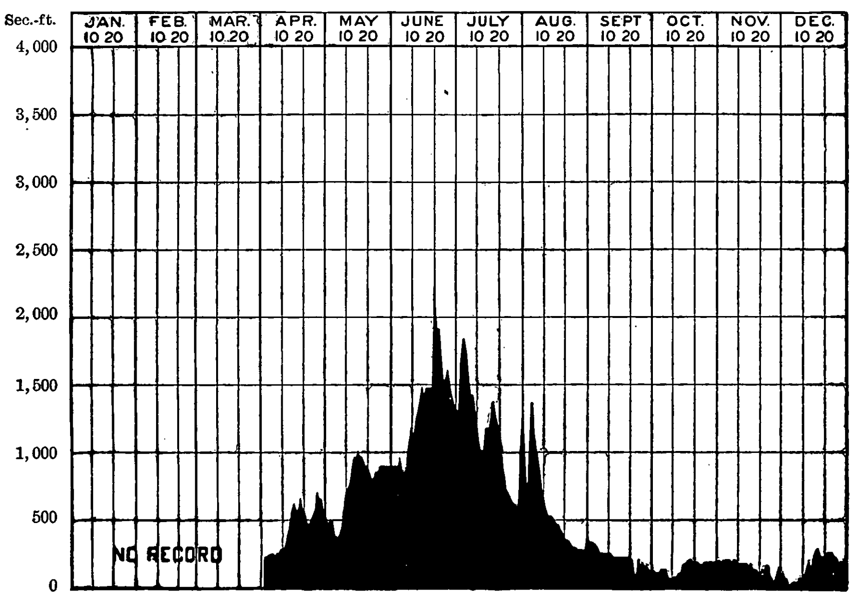


FIG. 117.—Discharge of South Platte River at Platte Canyon, Colorado, 1899.

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

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	81	42	55	3,382	0.014	0.016
February	672	42	196	10,885	0.051	0.053
March	672	201	409	25,149	0.106	0.12
April	713	288	466	27,729	0.12	0.13
May	713	288	432	26,563	0.11	0.13
June	1,338	359	821	48,853	0.21	0.23
July	1,338	121	637	39,168	0.17	0.20
August	1,422	216	527	32,404	0.14	0.16
September	422	121	286	17,018	0.075	0.083
October	145	65	109	6,702	0.028	0.032
November	288	110	202	12,020	0.053	0.059
December	250	90	146	8,977	0.038	0.044
The year	1,422	42	357	258,850	0.093	1.257

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 226; discharge measurements, page 225; rating table in Paper No. 39, page 448.

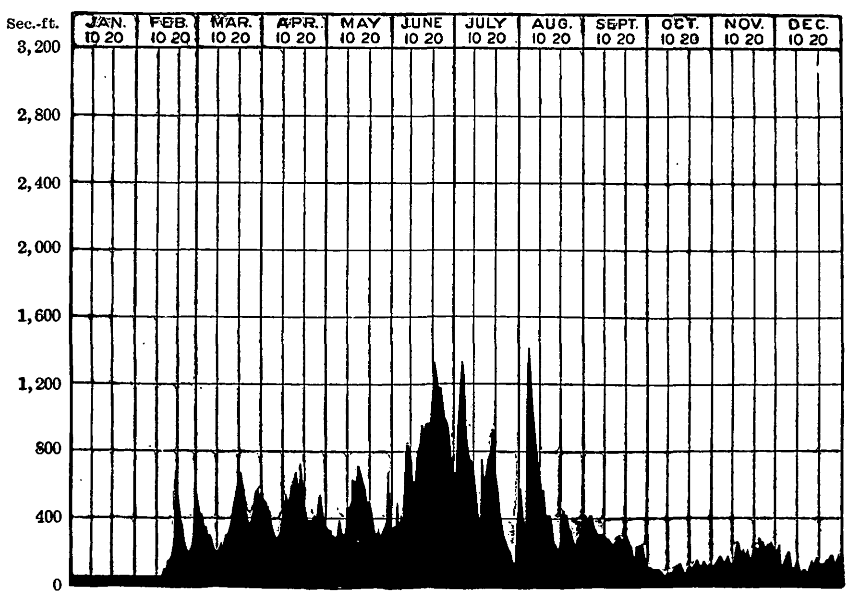


FIG. 118.—Discharge of South Platte River at Denver, Colorado, 1899.

A. MORRISON, COLORADO, ON BEAR CREEK.

B. CLEAR CREEK CANYON ABOVE FORKSCREEK, COLORADO.

Estimated monthly discharge of South Platte River at Orchard, Colorado.

[Drainage area, 12,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	3,026	2,838	2,880	177,085	0.24	0.28
February	3,966	2,838	3,321	184,439	0.27	0.28
March	3,966	1,258	2,377	146,156	0.19	0.22
April	1,419	1,258	1,325	78,843	0.11	0.12
May	1,258	115	465	28,592	0.038	0.044
June	3,512	9	1,198	71,286	0.098	0.11
July	2,868	267	1,593	97,950	0.13	0.15
August	2,868	40	761	46,792	0.062	0.071
September	158	19	45	2,678	0.004	0.004
October	614	158	429	26,378	0.035	0.04
November	936	614	799	47,544	0.065	0.072
December	2,546	936	1,544	94,937	0.13	0.15
The year	3,966	9	1,395	1,002,680	0.114	1.541

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 227; discharge measurements, page 226; rating table in Paper No. 39, page 448.

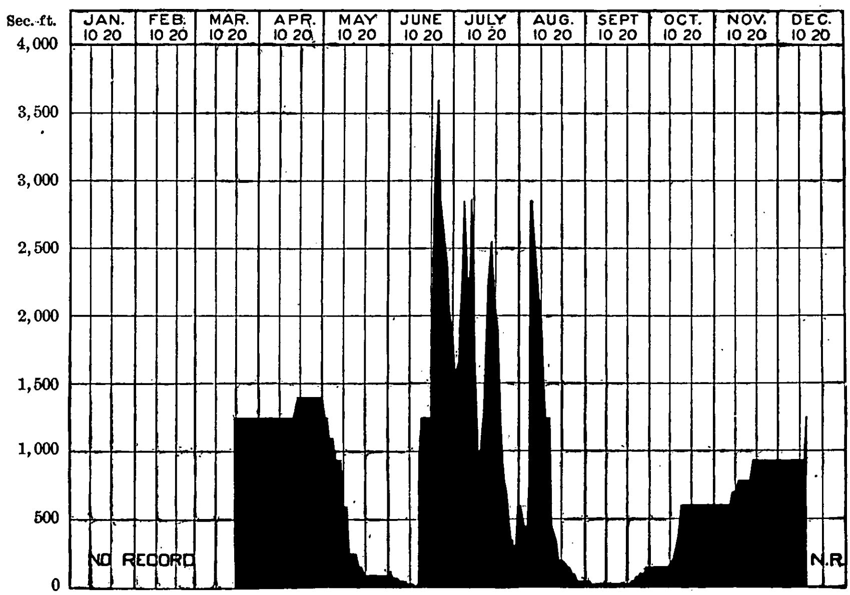


FIG. 119.—Discharge of South Platte River at Orchard, Colorado, 1899.

Estimated monthly discharge of Bear Creek at Morrison, Colorado.

[Drainage area, 170 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 16 to 30	99	56	84	4,998	0.49	0.55
May	153	41	103	6,333	0.61	0.70
June	109	52	93	5,534	0.55	0.61
July	130	56	86	5,288	0.51	0.59
August	325	28	104	6,395	0.61	0.70
September	44	22	31	1,845	0.18	0.20
October 1 to 21	25	17	21	1,291	0.12	0.14

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 228; rating table in Paper No. 39, page 448.

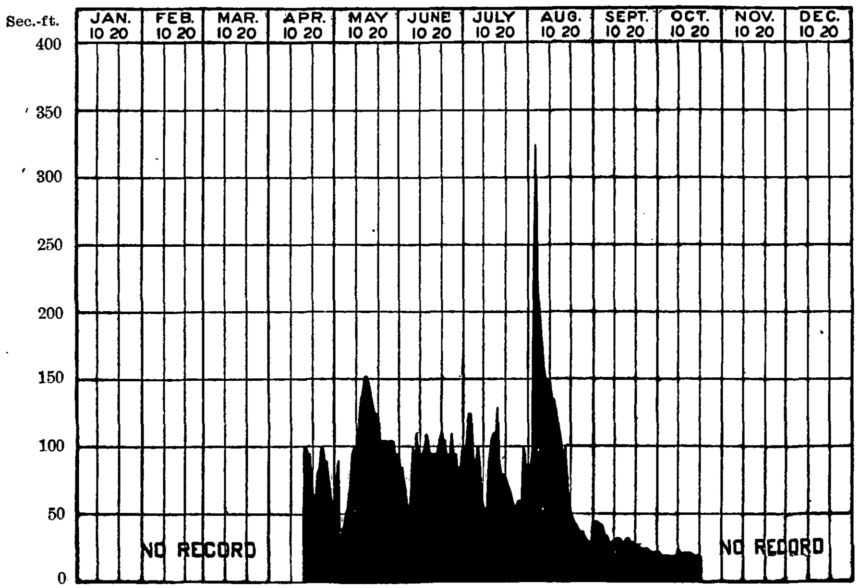


FIG. 120.—Discharge of Bear Creek at Morrison, Colorado, 1899.

Estimated monthly discharge of Clear Creek at Forkscreek, Colorado.

[Drainage area, 345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	403	51	180	10,711	0.52	0.58
May 1 to 19	1,202	192	581	35,724	1.68	1.94
June 7 to 30	1,373	775	1,081	64,324	3.13	3.49
July	1,202	614	791	48,637	2.30	2.66
August	692	299	440	27,055	1.28	1.48
September	349	155	214	12,734	0.62	0.69
October	155	133	141	8,670	0.41	0.47
November	155	32	77	4,582	0.22	0.24
December				3,935		

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 229; rating table in Paper No. 39, page 448.

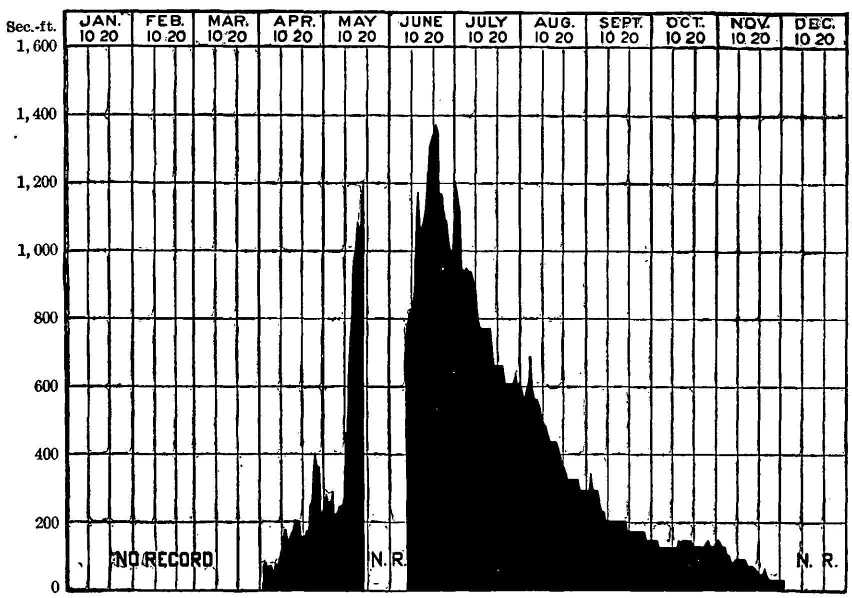


FIG. 121.—Discharge of Clear Creek at Forkscreek, Colorado, 1899.

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

[Drainage area, 125 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	262	20	115	6,843	0.92	1.02
May	413	102	278	17,094	2.22	2.56
June	536	277	416	24,754	3.33	3.72
July	394	94	243	14,942	1.94	2.24
August	193	49	91	5,595	0.73	0.84
September	60	20	35	2,083	0.28	0.31

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 230; rating table in Paper No. 39, page 448.

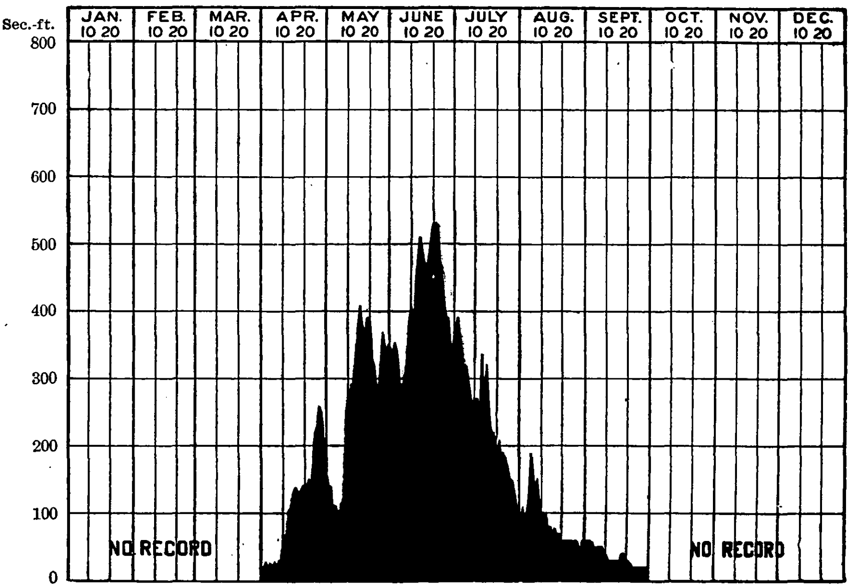


FIG. 122.—Discharge of South Boulder Creek at Marshall, Colorado, 1899.

Estimated monthly discharge of Boulder Creek at Boulder, Colorado.

[Drainage area, 179 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May	495	182	323	19,861	1.81	2.09
June	745	320	458	27,253	2.56	2.86
July	557	232	339	20,844	1.89	2.18
August	395	100	213	13,097	1.19	1.37
September	170	48	83	4,939	0.46	0.52
October	92	30	47	2,890	0.26	0.30
November	92	23	38	2,261	0.21	0.23
December *a*	....	....	60	3,689	0.34	0.39
1898.						
May	399	75	233	14,327	1.30	1.50
June	566	316	447	26,598	2.50	2.79
July	350	75	213	13,097	1.19	1.37
August	184	29	62	3,812	0.35	0.40
September	98	5	30	1,785	0.17	0.19
October	20	3	8	492	0.04	0.05
November	138	3	40	2,380	0.22	0.24
1899.						
April	276	21	117	6,962	0.65	0.72
May	504	133	353	21,705	1.97	2.27
June	826	412	663	39,451	3.70	4.13
July	826	366	577	35,479	3.22	3.71
August	619	123	265	16,294	1.48	1.71
September	211	36	87	5,177	0.49	0.55
October	50	28	39	2,398	0.22	0.25
November	36	14	24	1,428	0.13	0.14

a Approximate.

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 231; rating table in Paper No. 39, page 448.

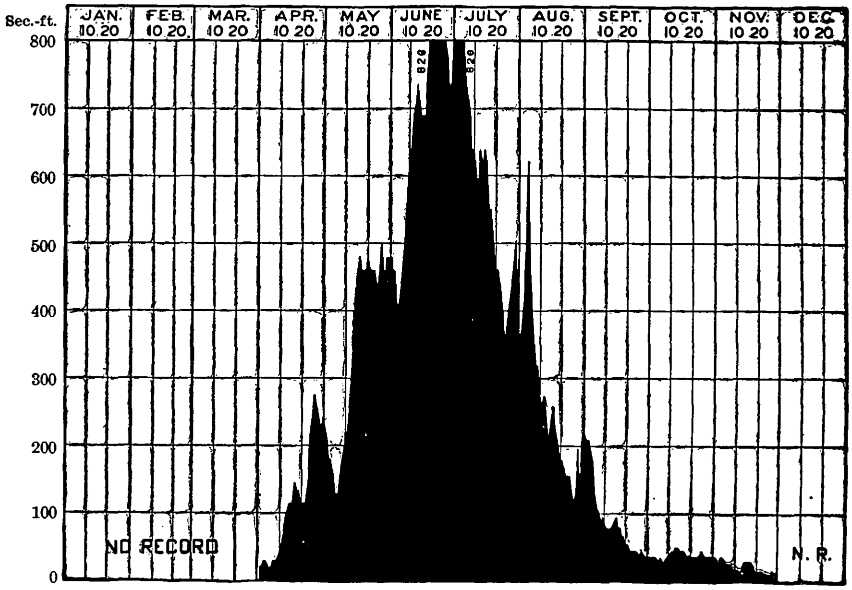


FIG. 123.—Discharge of Boulder Creek at Boulder, Colorado, 1899.

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

[Drainage area, 209 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	508	31	215	12,793	1.03	1.15
May	353	104	260	15,987	1.24	1.43
June	1,145	327	739	43,973	3.54	3.95
July	985	384	650	39,967	3.11	3.59
August	761	104	299	18,385	1.43	1.65
September	123	31	85	5,058	0.41	0.46
October	57	19	40	2,460	0.19	0.22
November	37	13	21	1,250	1.00	1.11

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 232; rating table in Paper No. 39, page 448.

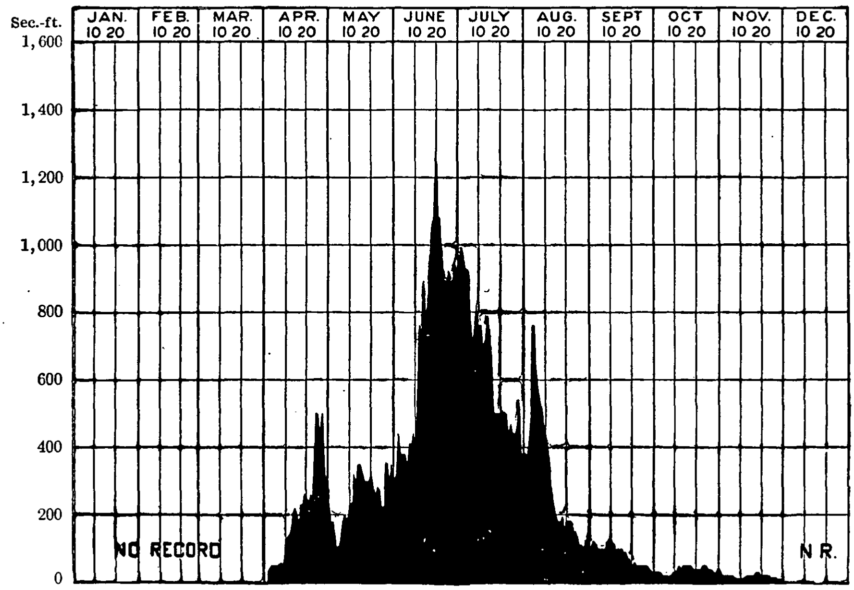


FIG. 124.—Discharge of St. Vrain Creek at Lyons, Colorado, 1899.

Estimated monthly discharge of Big Thompson Creek at Arkins, Colorado.

[Drainage area, 305 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maxi-mum.	Mini-mum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	331	4	140	8,331	0.46	0.52
May	510	146	303	18,631	0.99	1.14
June	1,685	451	917	54,565	3.01	3.36
July	1,189	416	653	40,152	2.14	2.47
August	589	146	283	17,401	0.93	1.07
September	146	35	92	5,474	0.30	0.33
October 8 to 31	116	35	64	3,935	0.21	0.24

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 234; discharge measurements, page 233; rating table in Paper No. 39, page 448.

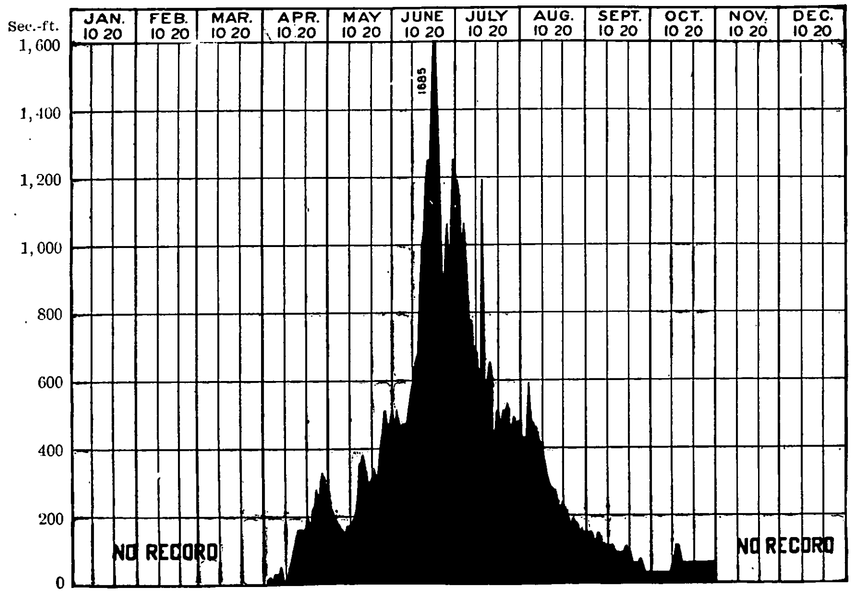


FIG. 125.—Discharge of Big Thompson Creek at Arkins, Colorado, 1899.

The following tables of the discharge of the South Fork of South Platte River and of Goose Creek at Lake Cheesman have been prepared by Mr. J. A. Runner in connection with estimates and surveys for the company constructing the large storage reservoir at that locality, views of which are shown in Pl. XII.

Estimated monthly discharge of South Fork of South Platte River at Lake Cheesman, Colorado.

[Drainage area, 1,677 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
August	830	160	321	19,737	0.19	0.22
September	175	100	136	8,093	0.08	0.09
October	145	24	80	4,919	0.05	0.06
November			118	7,021	0.07	0.08
December			63	3,874	0.04	0.05

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 224; discharge measurements, page 223; rating table in Paper No. 39, page 447.

Estimated monthly discharge of Goose Creek at Lake Cheesman, Colorado.

[Drainage area, 86 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
August	75	12	33	2,029	0.38	0.44
September	18	10	14	833	0.16	0.18
October	12	10	10	615	0.12	0.14
November			10	595	0.12	0.13
December			8	492	0.09	0.10

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 223; rating table in Paper No. 39, page 447.

LOUP RIVER.

Loup River is formed by the junction of the North Loup and the Middle Loup at St. Paul, Nebraska, and 60 miles below it enters Platte River near Columbus, Nebraska. Cedar River is a tributary of Loup River, flowing southeasterly and emptying into the Loup at Fullerton, about 30 miles below St. Paul. The station on the Loup is at Columbus, Nebraska. Measurements of discharge are made by Glenn E. Smith.

The North Loup has its source among the sand hills in the western portion of Cherry County, Nebraska, and drains the country midway between Niobrara River on the north and Middle Loup River on the south. It has a general easterly course, joining the Middle Loup at St. Paul, Nebraska, to form the main Loup River. Calamus River is a tributary of North Loup River, entering it near Burwell, Nebraska. The station on the North Loup is at St. Paul. Measurements are made by Glenn E. Smith.

Like the North Loup, the Middle Loup has its source in the sand hills of Cherry County, Nebraska, and flows in a general southeasterly direction. Oak Creek is a small stream which drains the area east of Loup, Nebraska, and flows southeasterly into the Middle Loup. The Middle Loup also is measured at St. Paul, the measurements being made by Glenn E. Smith and Adna Dobson.

Estimated monthly discharge of North Loup River at St. Paul, Nebraska.

[Drainage area, 4,024 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 18 to 30	2,925	1,350	1,711	101,812	0.42	0.47
May	1,610	867	1,141	70,157	0.28	0.32
June	7,500	883	1,533	91,220	0.38	0.43
July	2,250	672	1,034	63,578	0.26	0.30
August	1,500	743	1,049	64,501	0.26	0.30
September	1,156	793	888	52,840	0.22	0.24
October	1,300	801	907	55,770	0.23	0.26

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 238; rating table in Paper No. 39, page 448.

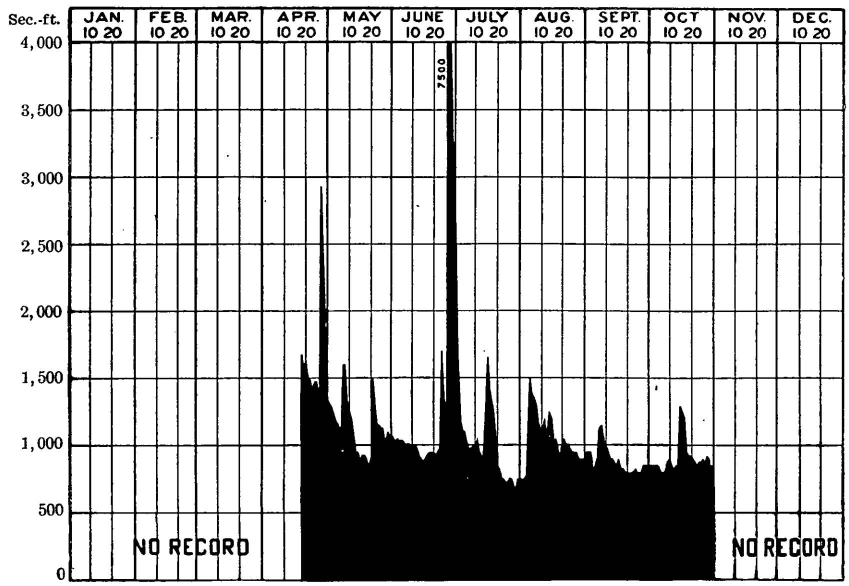


FIG. 126.—Discharge of North Loup River at St. Paul, Nebraska, 1899.

Estimated monthly discharge of Middle Loup River at St. Paul, Nebraska.

[Drainage area, 6,849 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 18 to 30	1,372	856	1,019	60,635	0.148	0.17
May	1,518	706	1,036	63,702	0.15	0.17
June	14,000	547	1,444	85,924	0.21	0.23
July	1,920	780	1,007	61,918	0.147	0.16
August	2,133	964	1,207	74,216	0.176	0.21
September	1,110	938	1,019	60,635	0.148	0.17
October	1,193	958	1,109	68,190	0.162	0.18

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 240; discharge measurements, page 239; rating table in Paper No. 39, page 448.

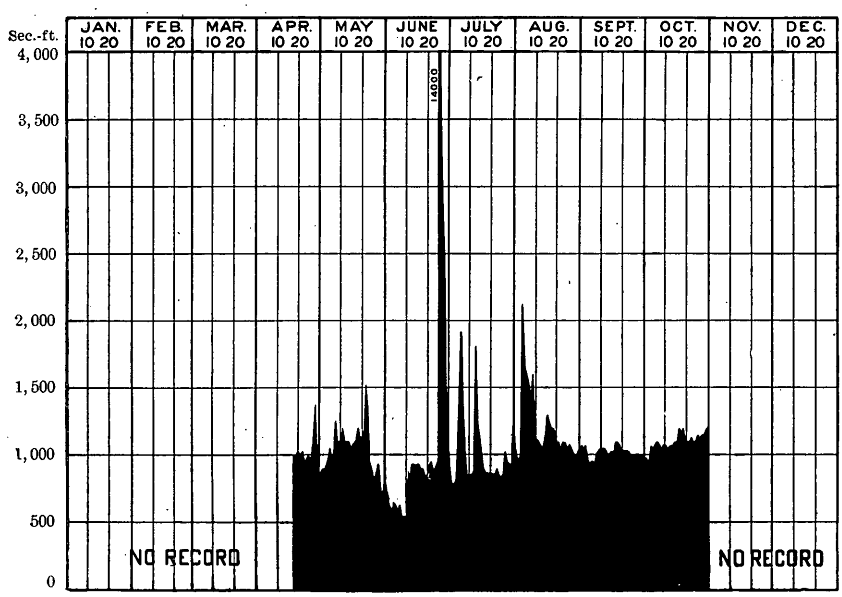


FIG. 127.—Discharge of Middle Loup River at St. Paul, Nebraska, 1899.

Estimated monthly discharge of Loup River at Columbus, Nebraska.

[Drainage area, 13,542 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	5,526	2,336	3,280	195,173	0.24	0.27
May	4,871	1,911	3,035	186,615	0.22	0.25
June	7,713	1,804	3,893	231,650	0.29	0.33
July	6,984	596	2,155	132,506	0.16	0.18
August	3,258	1,278	2,357	144,926	0.17	0.20
September	2,945	1,847	2,142	127,458	0.16	0.18
October	2,524	1,315	1,914	117,687	0.14	0.16

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 241; rating table in Paper No. 39, page 449.

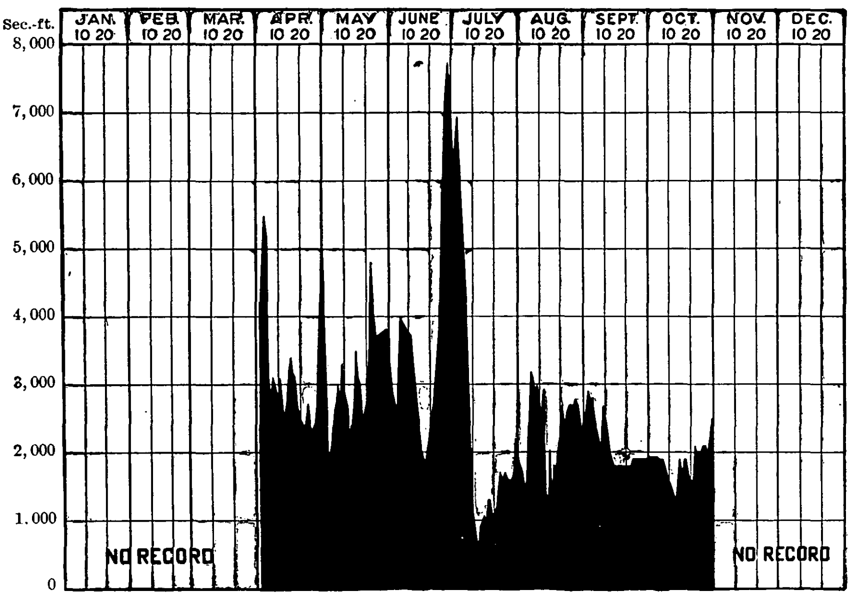


FIG. 128.—Discharge of Loup River at Columbus, Nebraska, 1899.

PLATTE RIVER.

The lower Platte is a sandy stream, the bed shifting during the high stages and considerable water being lost during the summer. The station is at Columbus, Nebraska. It was established in 1895. The measurements are made by Glenn E. Smith and Adna Dobson.

Estimated monthly discharge of Platte River at Columbus, Nebraska.

[Drainage area, 56,867 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	23,700	3,600	8,600	511,734	0.15	0.17
May	25,770	4,700	10,373	637,815	0.18	0.21
June	25,540	5,000	13,747	818,775	0.24	0.27
July	24,850	3,380	14,551	894,712	0.26	0.30
August	10,400	1,861	5,658	347,897	0.10	0.12

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 243; discharge measurements, page 242; rating table in Paper No. 39, page 449.

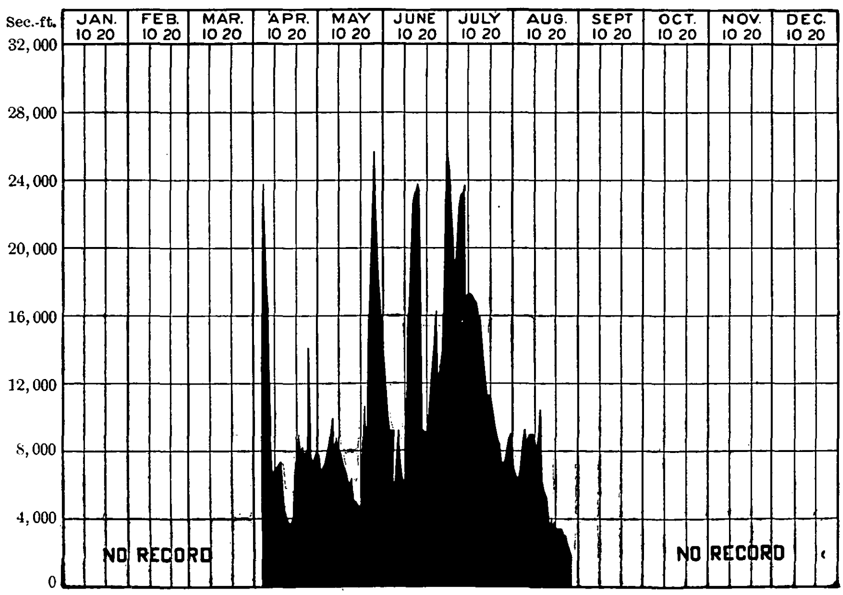


FIG. 129.—Discharge of Platte River at Columbus, Nebraska, 1899.

GROUND WATER AT KEARNEY, NEBRASKA.[1]

Much has been said concerning the ground water, or underflow, in the valley of Platte River, and public attention has been called to the subject. In order to obtain data, a number of wells were put down in a south-north line across the Platte Valley at Kearney, Nebraska, and an observer was employed to make weekly measurements of the height of the water surface in each well. The temperature of the air and the direction and force of the wind at the time of the observation were also noted. The observations were continued for a period of two years. A map showing the location of the wells and a profile of the water table at the time observations were commenced were published on pages 39 and 40 of Water-Supply and Irrigation Paper No. 12.

A diligent effort has been made to ascertain whether the height of water in the wells varies with the other observed quantities, in the hope that the influences which are mainly effective in controlling the height of the water table might be discovered.

The diagrams for the wells near the river show that they are subject to some influence which does not affect those farther back. They are markedly subject to occasional and irregular variations from the normal height. The suggestion that this influence may be connected with the river itself is discredited by the fact that the height of water surface in the river does not bear any discoverable relation to the height of water in the wells which are nearest the river. Neither does any relation, except a most general one, seem to exist between the height of water in adjacent wells on opposite sides of the river; nor does the record afford any indication that the direction or force of wind has any uniform or appreciable effect upon the height of the ground water. This is not, however, in accord with the apparently reliable testimony of residents of the valley, to the effect that the height of water in the wells is directly affected by the wind.

As to the effect of temperature, nothing more definite can be said than that the water table is in general higher during the warmer than during the colder seasons. On the other hand, there are several instances where, for weeks at a time, the water rose steadily at the same time that the temperature was falling. The reverse, falling water and rising temperature, is also true in some cases. It was expected that the effect of temperature would be more plainly discernible, as it has been shown to have a preponderating influence on subterranean supplies,[2] and has been made a prominent factor in some of the latest formulas for computing the perennial flow of streams.

[1] Report by Prof. O. V. P. Stout, University of Nebraska, Lincoln, Nebraska.
[2] Bull. 38, Utah Agr. Exp. Station.

A diagram of barometric pressures, data for which were furnished by the United States Weather Bureau, has been prepared, and careful search has been made, but without result, to distinguish the effect of this element upon the water height.

The diagram of monthly rainfall, also prepared from United States Weather Bureau records, when superposed upon the diagrams of water heights for the several wells, reveals a general and apparently definite influence by this element. There are, however, many pronounced changes in water height, which can not be accounted for by increase or diminution of the supply from rainfall.

The gradients of the water surface in the direction of the line of wells are subject to many variations. These variations are mainly due to the rise or fall, which is considerable, in the water surface of wells near the river. The crossing of diagrams for different wells indicates that the gradient in some places has at times suffered a reversal of direction.

ELKHORN RIVER.

This river rises in the sand hills in Rock County, Nebraska, and flows in a general southeasterly direction, entering Platte River 30 miles above its mouth. The bed of the river is of sand and mud. Two stations are maintained on the river—one at Norfolk, Nebraska, and the other at Arlington, Nebraska. Measurements of discharge at both stations are made by Glenn E. Smith.

Estimated monthly discharge of Elkhorn River at Norfolk, Nebraska.

[Drainage area, 2,474 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 7 to 30	553	427	503	29,931	0.20	0.22
May	1,750	374	745	45,808	0.30	0.35
June	2,200	296	550	32,727	0.22	0.24
July	820	246	376	23,119	0.15	0.17
August	334	156	254	15,617	0.10	0.12
September	203	80	168	9,997	0.07	0.08
October	237	180	217	13,343	0.09	0.10

NOTE.—Gage heights for 1899 are given in Water Supply and Irrigation Paper No. 37, page 244; discharge measurements, pages 243 and 244; rating table in Paper No. 39, page 449.

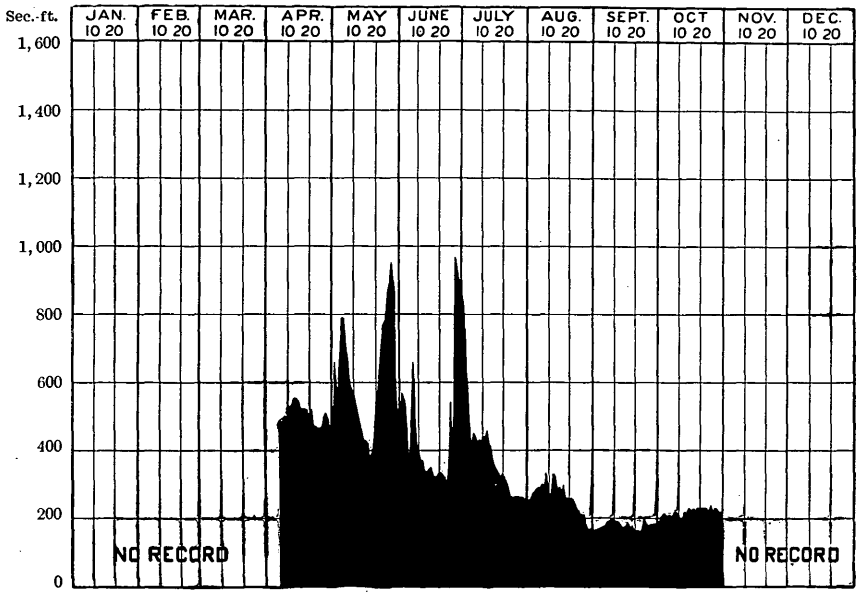


FIG. 130.—Discharge of Elkhorn River at Norfolk, Nebraska, 1899.

Estimated monthly discharge of Elkhorn River at Arlington, Nebraska.

[Drainage area, 5,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
May, 12 days	2,480	793	1,567	96,351	0.26	0.30
June	4,315	1,006	1,701	101,217	0.28	0.31
July	1,443	538	871	53,556	0.15	0.17
August	811	384	563	34,618	0.094	0.108
September	392	288	326	19,398	0.055	0.061
October	437	284	361	22,197	0.060	0.069

NOTE.—Gage height and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 245; rating table in Paper No. 39, page 449.

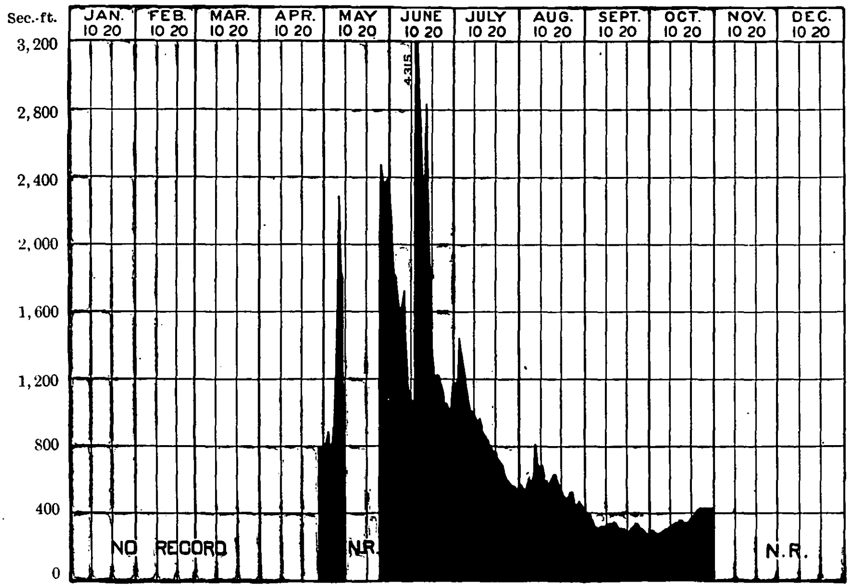


FIG. 131.—Discharge of Elkhorn River at Arlington, Nebraska, 1899.

KANSAS RIVER DRAINAGE.

REPUBLICAN RIVER.

This river rises, by several branches, in the eastern part of Colorado, and runs eastward into Nebraska. In the southern part of Nebraska it traverses extensive semiarid plains. It enters Kansas at about longitude 98° west. Its estimated length is 550 miles. It unites with Smoky Hill River at Junction, Kansas, to form Kansas River. The station, which was established April 26, 1895, is at Junction. Measurements of discharge are made by W. G. Russell.

Estimated monthly discharge of Republican River at Superior, Nebraska.

[Drainage area, 22,347 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 19 to 31	956	601	706	43,411	0.031	0.036
April	842	375	578	34,393	0.026	0.029
May	1,800	292	511	31,420	0.023	0.026
June	4,036	141	531	31,597	0.021	0.023
July	1,384	209	458	28,162	0.020	0.023
August	868	136	303	18,631	0.014	0.016
September	102	6	50	2,975	0.002	0.002
October	101	24	53	3,259	0.002	0.002

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 247; discharge measurements, page 246; rating table in Paper No. 39, page 449.

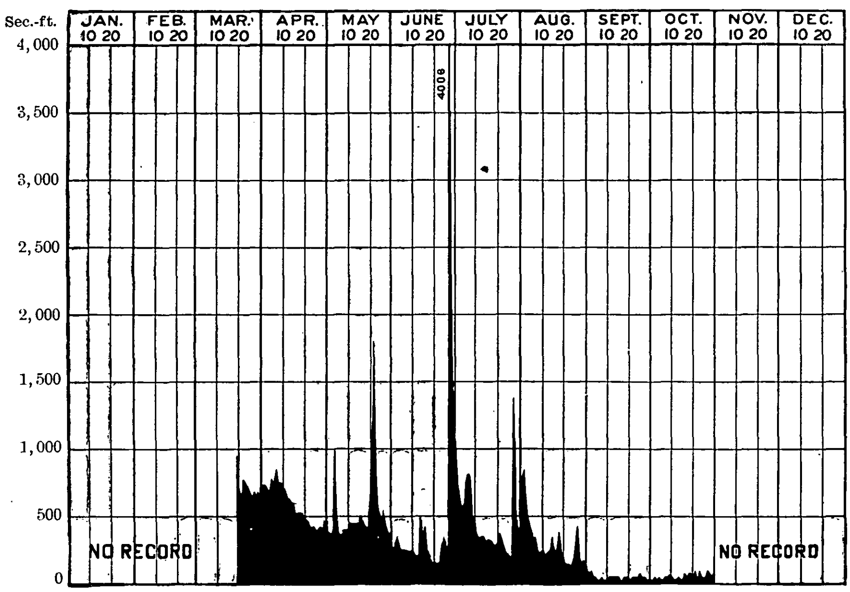


FIG. 132.—Discharge of Republican River at Superior, Nebraska, 1899.

Estimated monthly discharge of Republican River at Junction, Kansas.

[Drainage area, 25,837 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	870	500	702	43,165	0.027	0.031
February	1,020	555	768	42,653	0.030	0.031
March	2,320	870	1,432	88,050	0.055	0.063
April	1,020	615	870	51,769	0.034	0.038
May	7,750	500	1,515	93,154	0.059	0.068
June	12,000	475	1,959	116,569	0.076	0.085
July	3,570	395	1,415	87,005	0.055	0.063
August	2,395	295	838	51,527	0.032	0.037
September	345	100	187	11,127	0.007	0.008
October	1,140	35	302	18,569	0.012	0.014
November	395	63	175	10,413	0.007	0.008
December	800	205	488	30,006	0.019	0.022
The year	12,000	35	888	644,007	0.034	0.468

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 249; discharge measurements, page 248; rating table in Paper No. 39, page 449.

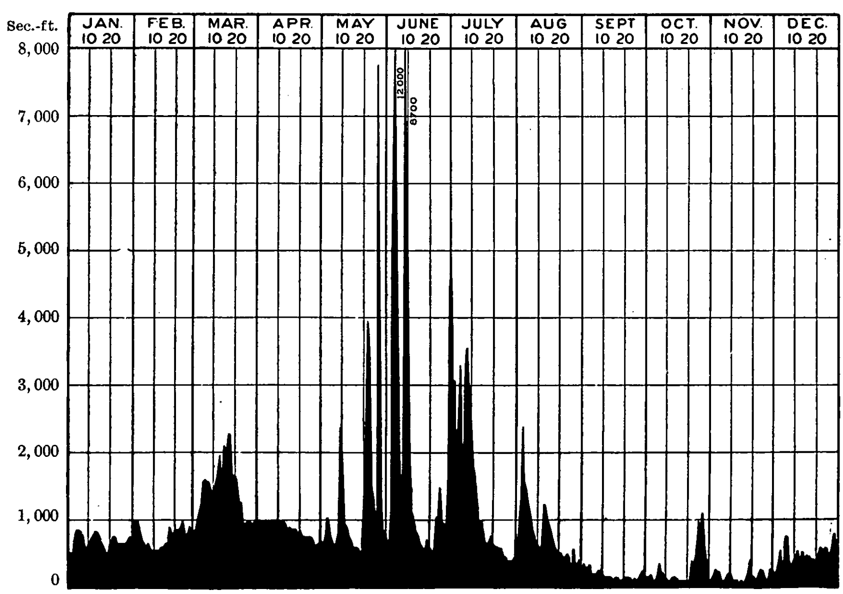


FIG. 133.—Discharge of Republican River at Junction, Kansas, 1899.

SUBIRRIGATION IN WESTERN KANSAS.

The accompanying plan, fig. 134, shows the irrigation system used by Mr. A. Linn, of Osborne, Kansas. The upper portion only of the system is shown. The width from left to right is 363 feet. In this distance there is a fall of 20 inches. The total length of the land irrigated, from north to south, is 512 feet, and in this distance there is a fall of 36 inches. At *AA* are two wells which furnish water, the supply being obtained by means of windmills. *BB* are the mains, consisting of 3-inch vitrified tile laid in cement. These mains are interrupted by reservoir tubes *CC*, consisting of 12-inch sewer pipe in 2½ feet lengths. These tubes are connected, by pieces of tile 3 feet in length, to the submains marked *DD*. The latter consist of 3-inch

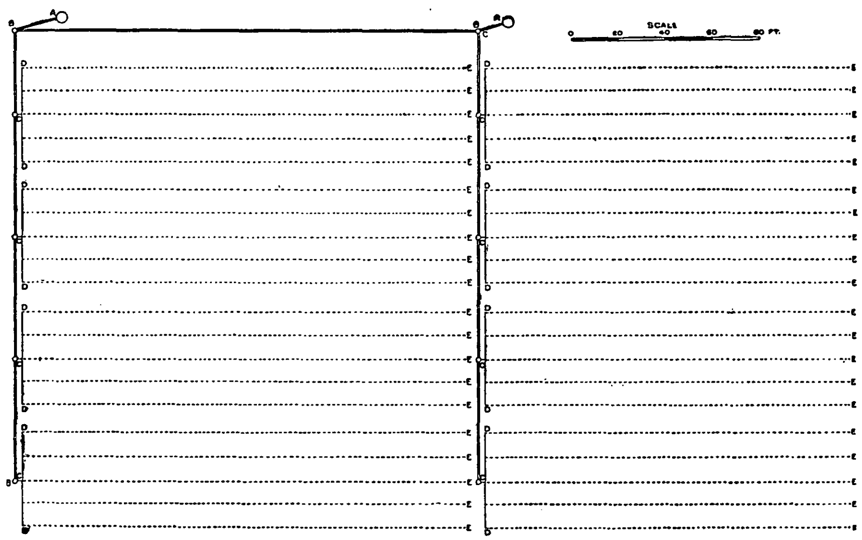


FIG. 134.—Plan of subirrigation system.

vitrified tiles 40 feet in length laid parallel with the mains. Openings are made in these tiles at intervals of 10 feet, the laterals leading to the distributing system marked *EE*. These also are 3-inch drain tiles laid end to end and extending across the land, those from the west main extending to within 5 feet of the east main and those from the latter within the same distance of the east boundary. The free ends are closed with cement. The lines of tile of the distributing system are 10 feet apart. There are, as indicated, five tiles in each section.

All the tiles are placed 12 inches beneath the surface of the ground. The reservoir tubes are fitted so that the water can be shut off at any point and turned into any section. The cost of putting in the tile is about $100 to the acre, not including labor. This system has been in operation five years and has given satisfaction.

SMOKY HILL RIVER.

This river rises in eastern Colorado and flows in an easterly direction, joining Republican River at Junction, Kansas, to form the Kansas. Its two principal tributaries are the Solomon and Saline rivers. The former river rises in western Kansas and flows in an easterly direction until it joins the Smoky Hill near Solomon, Kansas. The station on the Solomon is at Niles, Kansas. It was established May 5, 1897. Saline River, which, like the Solomon, is a sand-hill stream, enters the Smoky Hill a short distance below Salina, Kansas, and about 9 miles, by railroad, above the mouth of Solomon River. The station on the Saline is at Salina, Kansas. It was established May 4, 1897. The station on Smoky Hill River is at Ellsworth, Kansas. It was established April 17, 1895. Measurements at the three stations are made by W. G. Russell.

Estimated monthly discharge of Solomon River at Niles, Kansas.

[Drainage area, 6,815 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	303	131	178	10,944	0.026	0.030
February	202	147	178	9,886	0.026	0.027
March	315	125	177	10,883	0.026	0.030
April	159	90	128	7,617	0.019	0.021
May	2,364	85	304	18,692	0.045	0.052
June	6,240	131	1,789	106,453	0.262	0.29
July	3,895	147	580	35,663	0.085	0.098
August	1,283	105	272	16,725	0.039	0.045
September	131	53	88	5,236	0.013	0.014
October	1,152	37	126	7,747	0.018	0.021
November	120	53	81	4,820	0.012	0.013
December	131	62	99	6,087	0.015	0.017
The year	6,240	37	328	236,880	0.048	0.646

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 250; discharge measurements, page 249; rating table in Paper No. 39, page 449.

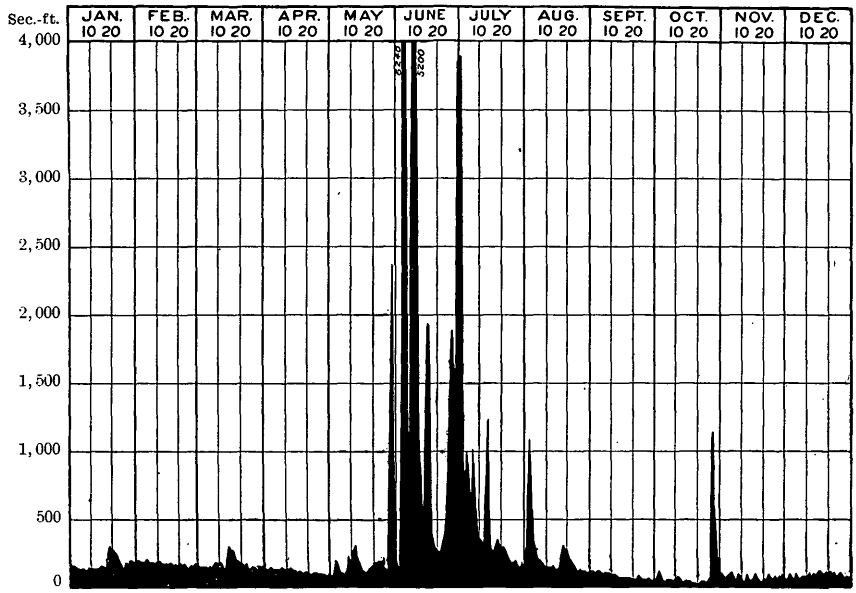


FIG. 135.—Discharge of Solomon River at Niles, Kansas, 1899.

Estimated monthly discharge of Saline River at Salina, Kansas.

[Drainage area, 3,311 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	110	60	67	4,120	0.020	0.023
February	102	50	63	3,499	0.019	0.020
March	117	50	80	4,919	0.024	0.028
April	72	30	53	3,154	0.016	0.018
May	1,010	18	155	9,531	0.047	0.054
June	5,000	110	1,334	79,378	0.403	0.45
July	684	132	279	17,155	0.084	0.097
August	152	62	100	6,149	0.030	0.035
September	102	55	68	4,046	0.021	0.023
October	386	40	79	4,858	0.024	0.028
November	181	70	88	5,236	0.027	0.030
December	102	70	84	5,165	0.025	0.029
The year	5,000	18	204	147,210	0.062	0.835

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 251; discharge measurements, page 250; rating table in Paper No. 39, page 449.

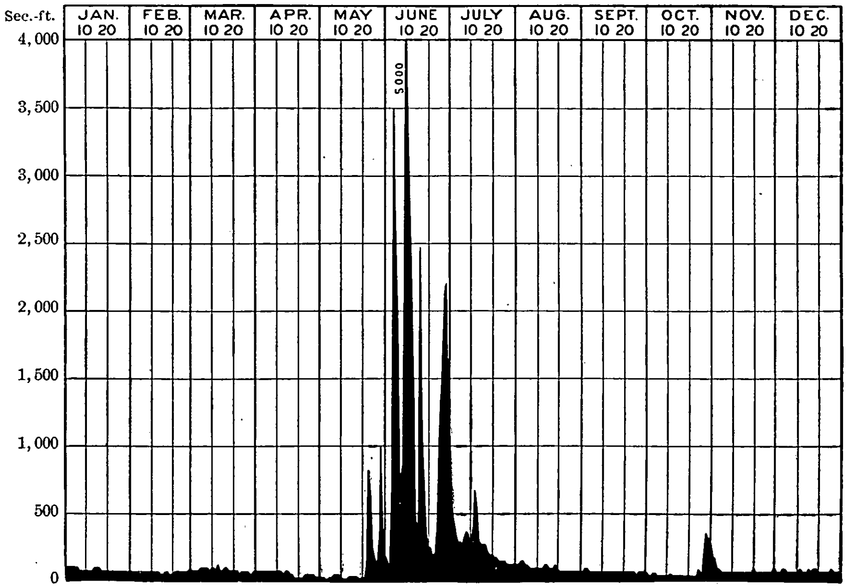


FIG. 136.—Discharge of Saline River at Salina, Kansas, 1899.

Estimated monthly discharge of Smoky Hill River at Ellsworth, Kansas.

[Drainage area, 7,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	75	14	44	2,705	0.0055	0.0063
February	84	42	63	3,499	0.0079	0.0082
March	75	19	40	2,460	0.0050	0.0058
April	35	10	20	1,190	0.0025	0.0028
May	23	10	11	676	0.0014	0.0016
June	3,890	10	492	29,276	0.0617	0.069
July	7,947	56	832	51,158	0.1043	0.120
August	862	42	152	9,346	0.0190	0.022
September	75	19	46	2,737	0.0058	0.0064
October	124	14	48	2,951	0.0060	0.0069
November	42	19	30	1,785	0.0038	0.0043
December	35	19	27	1,660	0.0034	0.0039
The year	7,947	10	150	109,443	0.0189	0.2572

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 252; discharge measurements, page 249, rating table in Paper No. 39, page 449.

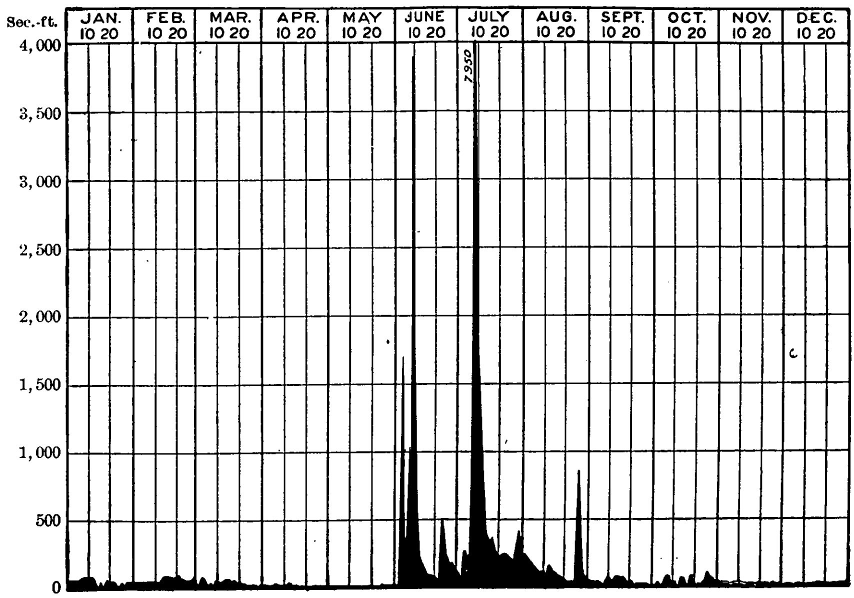


FIG. 137.—Discharge of Smoky Hill River at Ellsworth, Kansas, 1899.

BLUE RIVER.

This river is one of the principal tributaries of Kansas River. It drains a part of southeastern Nebraska and northeastern Kansas, and enters Kansas River at Manhattan, Kansas. Its tributaries extend almost to Platte River. The drainage basin receives a copious rainfall, and the run-off is therefore considerably larger than from the more western tributaries of Kansas River. The station, established April 12, 1895, is at Manhattan, Kansas. Measurements are made by W. G. Russell.

Estimated monthly discharge of Blue River at Manhattan, Kansas.

[Drainage area, 9,490 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	910	680	721	44,333	0.08	0.09
February	1,080	770	876	48,651	0.09	0.09
March	7,240	792	1,845	113,445	0.19	0.22
April	1,325	702	944	56,172	0.10	0.11
May	29,693	635	4,081	250,931	0.43	0.49
June	30,030	1,325	4,767	283,656	0.50	0.56
July	10,371	885	2,699	165,955	0.28	0.32
August	6,367	305	1,532	94,199	0.16	0.18
September	635	400	498	29,633	0.05	0.06
October	2,212	287	597	36,708	0.06	0.07
November	612	460	536	31,894	0.06	0.07
December	747	380	524	32,220	0.06	0.07
The year	30,030	287	1,635	1,187,797	0.17	2.33

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 253; discharge measurements, page 252; rating table in Paper No. 39, page 449.

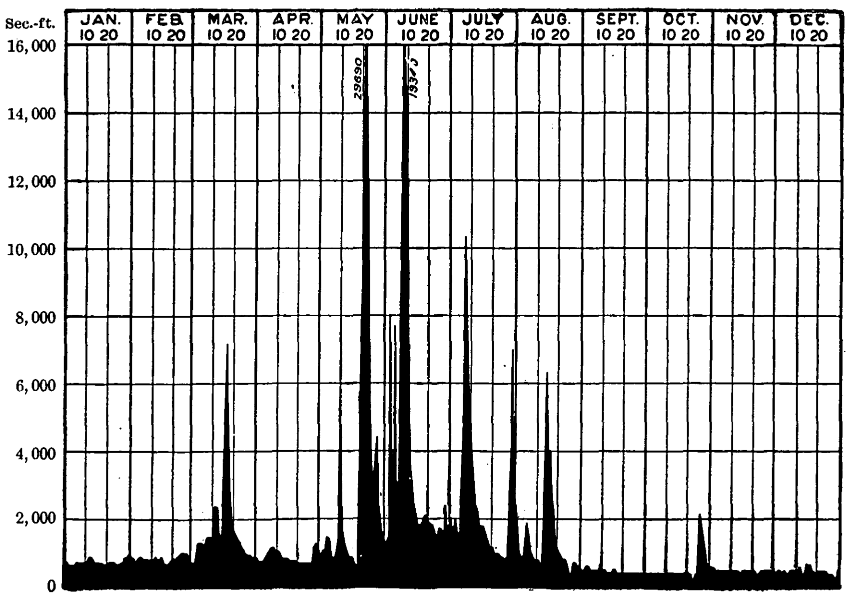


FIG. 138.—Discharge of Blue River at Manhattan, Kansas, 1899.

KANSAS RIVER.

Kansas River is formed by the junction of Republican and Smoky Hill rivers at Junction, Kansas. The river traverses fertile plains in which bituminous coal abounds. It enters Missouri River about 1 mile above Kansas City. Two stations have been maintained on Kansas River, one at Lecompton, Kansas, and the other at Lawrence, Kansas. The latter station has been discontinued. The Lecompton station was established April 16, 1899. Measurements are made by E. C. Murphy and W. G. Russell.

Estimated monthly discharge of Kansas River at Lecompton, Kansas.

[Drainage area, 58,550 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 16 to 30	....	....	2,693	160,245	0.05	0.06
May	16,800	2,380	5,455	335,415	0.09	0.10
June	24,800	3,600	10,609	631,279	0.18	0.20
July	30,250	3,865	9,771	600,795	0.17	0.20
August	8,335	2,720	4,855	298,522	0.08	0.09
September	2,580	1,850	2,154	128,172	0.04	0.05
October	3,150	1,750	1,938	119,163	0.03	0.03
November	3,000	1,950	2,236	133,051	0.04	0.05
December	3,150	1,850	2,379	146,279	0.04	0.05

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 254; discharge measurements, page 253; rating table in Paper No. 39, page 449.

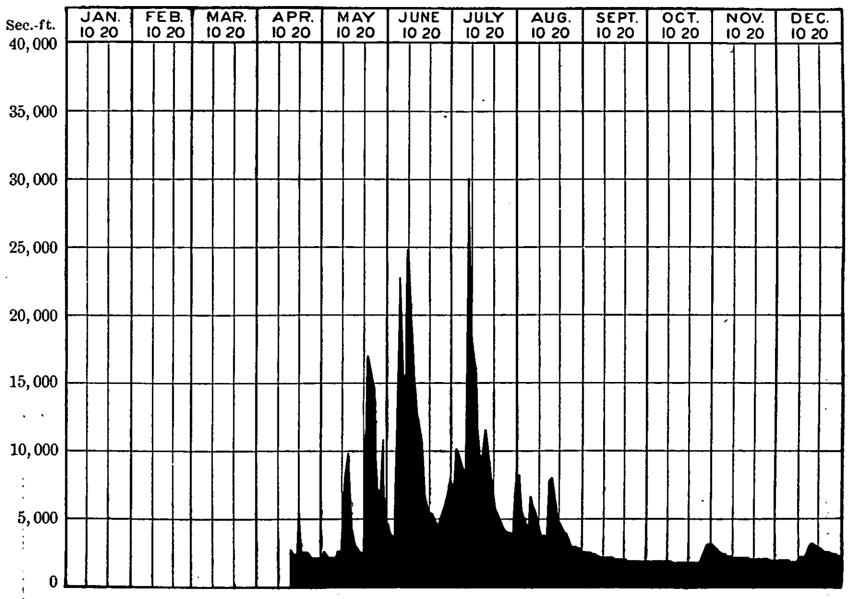


FIG. 139.—Discharge of Kansas River at Lecompton, Kansas, 1899.

ARKANSAS RIVER DRAINAGE.

ARKANSAS RIVER.

The source of this river is in the vicinity of Tennessee Pass, in the central portion of Colorado. It flows southerly for about 70 miles, then easterly for 50 miles to Canyon, receiving a number of tributaries from the mountainous area on either side. At Canyon it suddenly emerges from the Rocky Mountain front, and then flows in an easterly direction, traversing the Great Plains of eastern Colorado, where most of the water is diverted for irrigation. After crossing the Kansas line it continues eastward for about 200 miles, until the center of the State is reached, when it suddenly bends to the south and passes into Indian Territory, then into the State of Arkansas, finally entering the Mississippi about 25 miles above Greenville, Mississippi. Throughout the mountainous area above Canyon the discharge increases, but as soon as the river emerges onto the Great Plains the water is gradually diverted by lines of canals, so that by the time the Kansas line is reached the river is usually dry during the summer. In its mountainous course the river makes a descent from 10,000 feet at Leadville to 5,300 feet at Canyon, a distance of 120 miles.

The principal tributaries of Arkansas River are Lake Creek, which is measured at Twin Lakes, Colorado; Purgatory River, which is measured at Trinidad, Colorado; Verdigris River, which is measured at Liberty, Kansas; and Neosho River, which is measured at Iola, Kansas, and at Fort Gibson, Indian Territory. North Fork of Canadian

River, which is also a tributary of the Arkansas, is measured at Oklahoma, Oklahoma Territory, and at Eufaula, Indian Territory. The main Arkansas River is measured at the following places, in their order downstream: At Granite, Salida, Canyon, Pueblo, Nepesta, Rockyford, Lajunta, Trinidad, at the head gates of Amity canal, and at Granada, all in Colorado; also at Hutchinson, Kansas. The measurements in Colorado are made by A. L. Fellows, those in Kansas by W. G. Russell.

Estimated monthly discharge of Arkansas River at Salida, Colorado.

[Drainage area, 1,160 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 22 to 31	342	294	308	18,938	0.27	0.31
April	632	317	398	23,683	0.34	0.38
May	2,141	426	1,352	83,132	1.17	1.35
June	3,900	1,524	2,639	157,031	2.28	2.54
July	2,094	494	1,301	79,996	1.12	1.29
August	1,334	294	497	30,560	0.43	0.49
September	368	240	281	16,721	0.24	0.27

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 258; rating table in Paper No. 59, page 450.

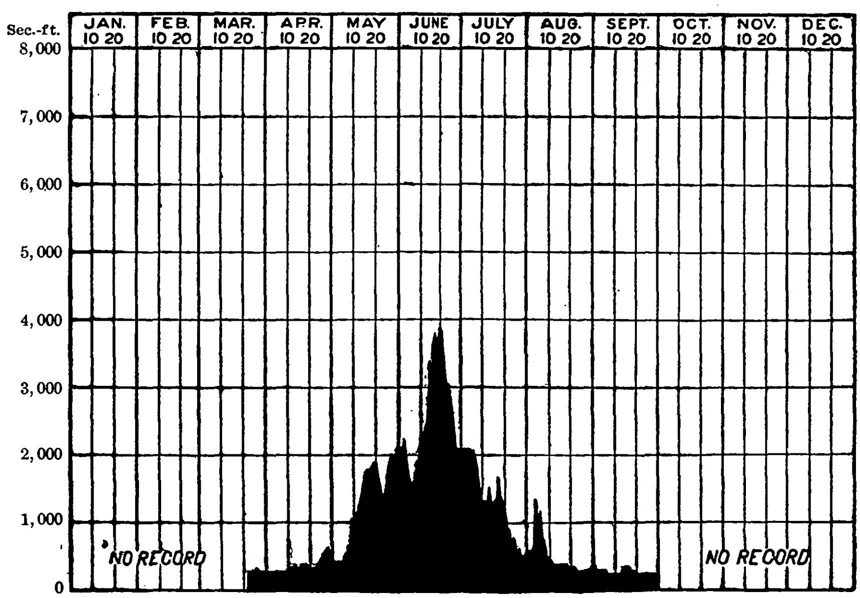


FIG. 140.—Discharge of Arkansas River at Salida, Colorado, 1899.

Estimated monthly discharge of Arkansas River at Canyon, Colorado.

[Drainage area, 3,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			300	18,446	0.10	0.12
February *a*			300	16,661	0.10	0.10
March *a*			600	36,893	0.20	0.23
April	1,057	360	533	31,716	0.17	0.19
May	3,057	476	1,924	118,304	0.63	0.72
June	4,432	2,370	3,496	208,026	1.14	1.27
July	3,432	1,182	2,021	124,267	0.66	0.76
August	2,369	242	711	43,718	0.23	0.26
September	316	186	225	13,388	0.07	0.08
October *a*			200	12,298	0.07	0.08
November *a*			400	23,802	0.13	0.14
December *a*			300	18,446	0.10	0.12

a Approximate.

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 259; rating table in Paper No. 39, page 450.

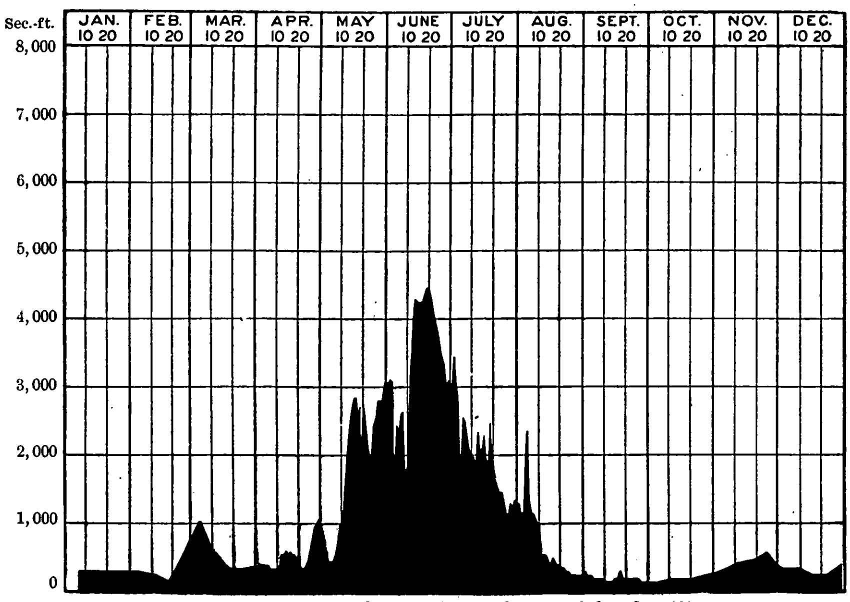


FIG. 141.—Discharge of Arkansas River at Canyon, Colorado, 1899.

Estimated monthly discharge of Arkansas River at Pueblo, Colorado.

[Drainage area, 4,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	527	300	407	25,026	0.0884	0.098
February	1,070	336	603	33,489	0.1311	0.136
March	652	232	406	24,964	0.0883	1.01
April	784	232	418	24,873	0.091	1.01
May	2,855	448	1,683	103,484	0.3658	0.417
June	4,891	1,633	3,384	201,362	1.7356	0.81
July	3,122	1,162	2,043	125,620	0.444	0.49
August	2,492	196	811	49,867	0.176	0.21
September	378	150	238	14,162	0.0517	0.058
October	443	231	303	18,631	0.0659	0.76
November	443	295	374	22,254	0.0813	0.90
December	409	250	327	20,107	0.0711	0.83
The year	4,891	150	916	663,839	0.1992	6.729

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 260; rating tables in Paper No. 39, page 450.

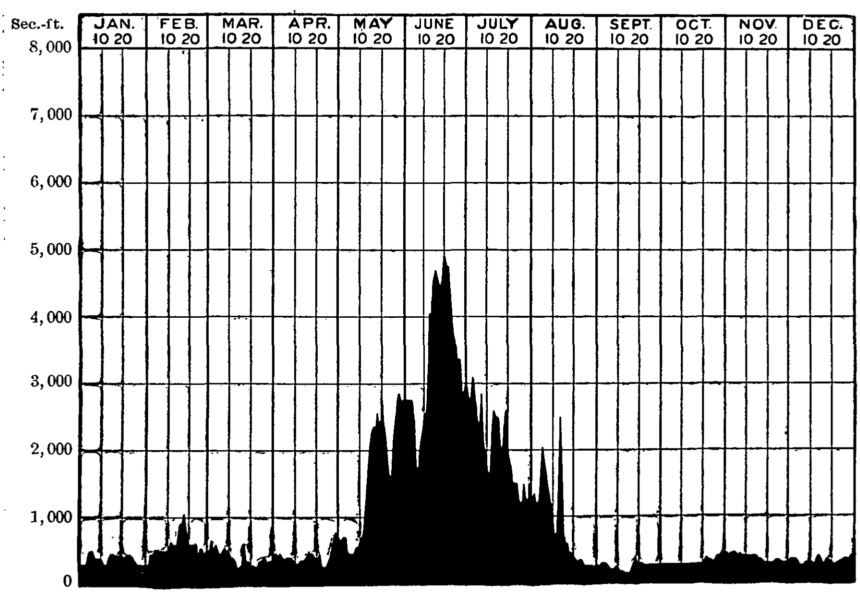


FIG. 142.—Discharge of Arkansas River at Pueblo, Colorado, 1899.

Estimated monthly discharge of Arkansas River at Nepesta, Colorado.

[Drainage area, 9,130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
May	....	350	1,116	68,621	0.12	0.14
June	3,665	918	2,103	125,137	0.23	0.26
July	4,125	136	1,310	80,549	0.14	0.16
August	697	127	311	19,123	0.03	0.03
September	294	160	232	13,805	0.03	0.03
October	511	160	279	17,155	0.03	0.03
November	511	260	366	21,778	0.04	0.04
1899.						
April 21 to 30	314	191	272	16,185	0.03	0.03
May	2,246	259	1,154	70,957	0.13	0.15
June	3,882	1,156	2,622	156,019	0.29	0.32
July	6,066	610	2,651	163,005	0.29	0.33
August	6,974	172	957	58,906	0.10	0.12
September	285	154	200	11,900	0.02	0.02
October	314	172	235	14,450	0.03	0.03
November	2,791	191	350	20,826	0.04	0.04

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, pages 111 and 112; discharge measurements, page 116; rating table, page 117. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 261; rating table in Paper No. 39, page 450.

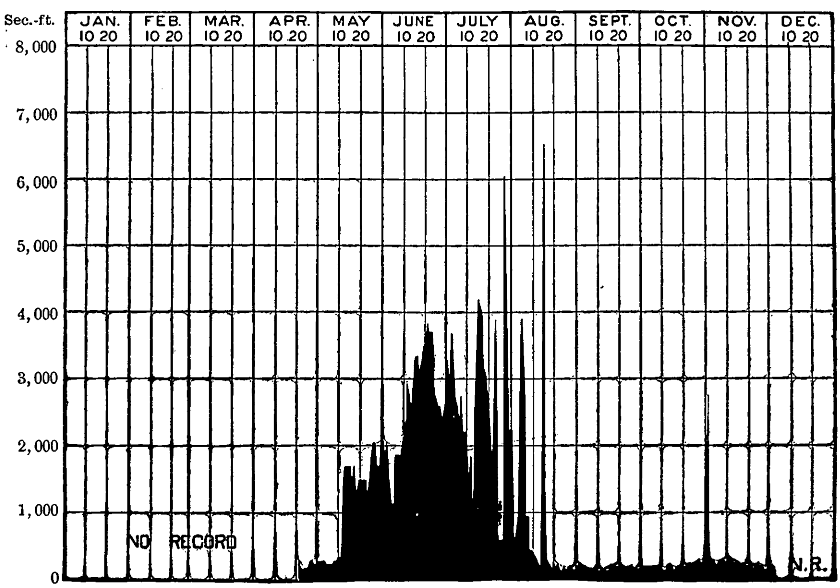


FIG. 143.—Discharge of Arkansas River at Nepesta, Colorado, 1899.

Estimated monthly discharge of Arkansas River at Rockyford, Colorado.

[Drainage area, 11,440 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May 3 to 31	3,363	64	1,147	70,527	0.100	0.120
June	3,206	628	1,834	109,130	0.160	0.180
July	2,034	41	589	36,216	0.052	0.060
August	3,676	20	614	37,754	0.054	0.062
September	108	13	41	2,440	0.004	0.004
October	393	27	143	8,793	0.013	0.015
November	550	41	155	9,223	0.014	0.016
December *a*	....	....	50	3,074	0.044	0.051
1899.						
March 13 to 31	570	140	309	19,000	0.027	0.031
April	520	140	274	16,304	0.024	0.027
May	1,270	140	732	45,009	0.064	0.074
June	2,170	770	1,498	89,137	0.131	0.146
July	3,020	270	1,504	92,478	0.131	0.150
August	3,570	105	686	42,181	0.060	0.069
September	420	95	153	9,104	0.013	0.014
October	300	55	145	8,916	0.013	0.015
November	1,070	105	280	16,661	0.024	0.027
December 1 to 9	190	115	148	9,100	0.013	0.015

a Approximate. For monthly discharge for 1898 see Twentieth Annual Report, Part IV, page 338.

NOTE.—Gage heights and discharge measurements for 1897 are given in Water-Supply and Irrigation Paper No. 16, page 122. Gage heights for 1898 are given in Water-Supply Paper No. 28, page 112; discharge measurements, page 116; rating table, page 117. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 262; rating table in Paper No. 39, page 450.

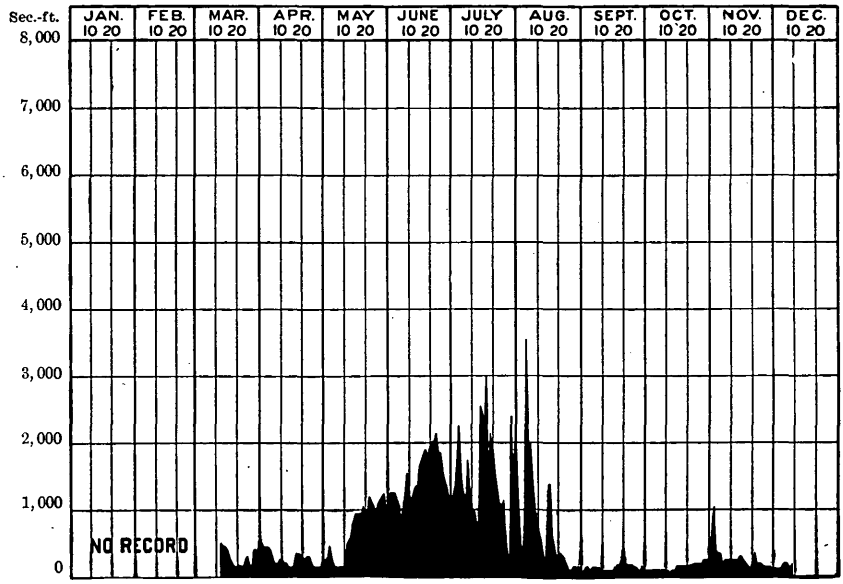


FIG. 144.—Discharge of Arkansas River at Rockyford, Colorado, 1899.

Estimated monthly discharge of Purgatory River at Trinidad, Colorado.

[Drainage area, 742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	193	32	82	4,879	0.11	0.12
May	230	52	110	6,764	0.15	0.17
June	492	4	71	4,225	0.10	0.11
July	2,362	16	443	27,239	0.60	0.69

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 263; rating table in Paper No. 39, page 450.

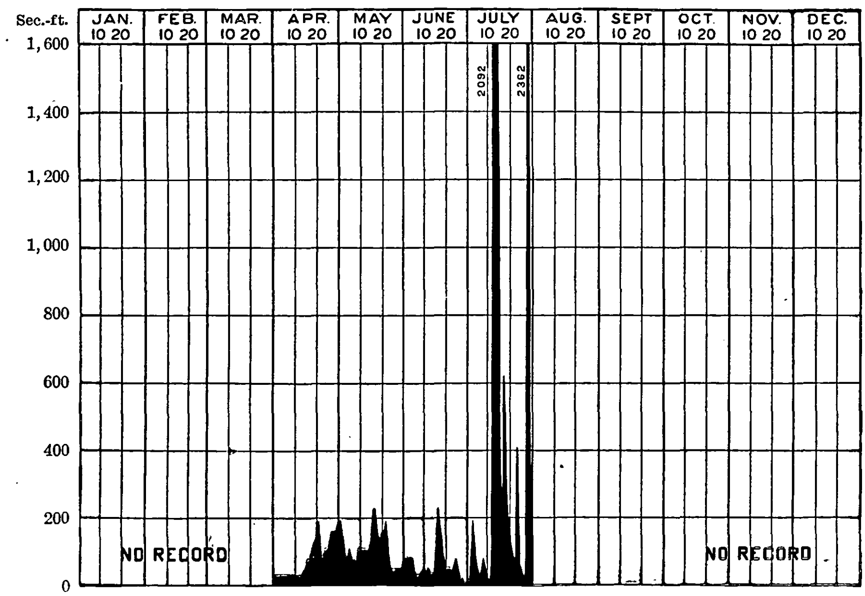


FIG. 145.—Discharge of Purgatory River at Trinidad, Colorado, 1899.

Estimated monthly discharge of Arkansas River at Hutchinson, Kansas.

[Drainage area, 34,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	300	115	209	12,851	0.006	0.007
February	475	220	303	16,828	0.009	0.009
March	1,660	342	881	54,171	0.026	0.030
April	385	70	211	12,555	0.006	0.007
May	102	40	66	4,058	0.002	0.002
June	4,055	46	958	57,005	0.028	0.031
July	4,755	145	1,078	66,284	0.032	0.037
August	3,450	90	900	55,339	0.026	0.030
September	90	40	59	3,511	0.002	0.002
October	145	30	53	3,259	0.002	0.002
November	115	70	87	5,177	0.003	0.003
December	220	115	163	10,023	0.005	0.006
The year	4,755	30	414	301,061	0.012	0.166

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 265; rating table in Paper No. 39, page 450.

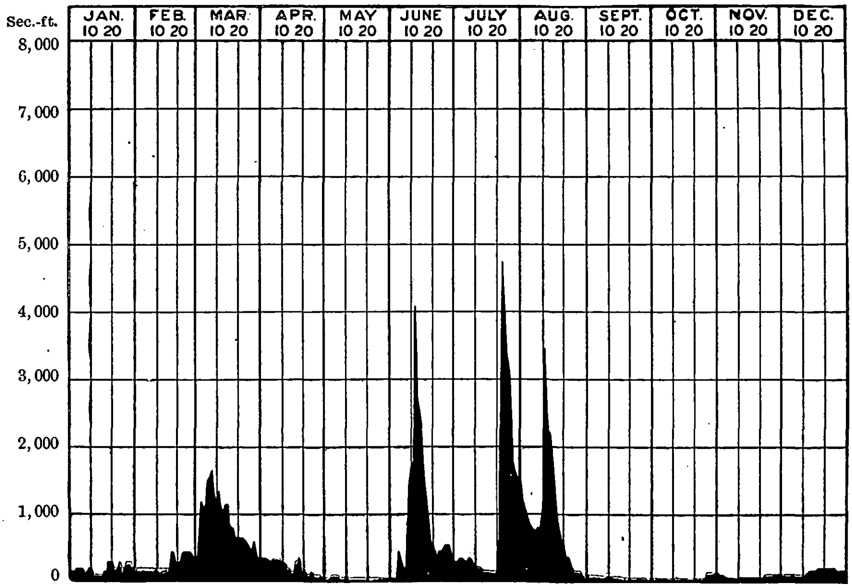


FIG. 146.—Discharge of Arkansas River at Hutchinson, Kansas, 1899.

Estimated monthly discharge of Verdigris River at Liberty, Kansas.

[Drainage area, 3,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	660	210	319	19,615	0.104	0.120
February	2,652	68	342	18,994	0.112	0.116
March	3,062	303	997	61,303	0.325	0.374
April	6,424	400	1,244	74,023	0.406	0.453
May	9,253	256	1,631	100,286	0.532	0.613
June	21,440	190	3,893	231,650	1.269	1.410
July	29,876	154	4,433	272,574	1.445	1.663
August	1,800	20	234	14,388	0.076	0.087
September	20	5	16	952	0.005	0.006
October	20	2	7	430	0.002	0.002
November	14	9	12	714	0.004	0.004
December	28	14	18	1,107	0.006	0.007
The year	29,876	2	1,096	796,036	0.357	4.855

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 266; rating table in Paper No. 39, page 450.

TWIN LAKES RESERVOIR.

The possibilities of the storage of a portion of the headwaters of Arkansas River in Twin Lakes, near Granite, Colorado, have been fully discussed in previous reports of the Survey, notably in the Tenth Annual Report, Part II, page 97; in the Eleventh Annual Report, Part II, page 135; in the Thirteenth Annual Report, Part III, page 365; in

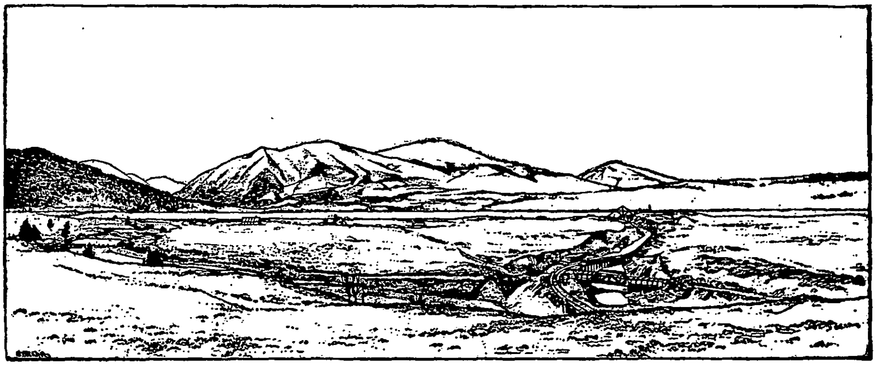


FIG. 147.—Sketch showing original outlet and artificial channel from Twin Lakes, Colorado.

the Nineteenth Annual Report, Part IV, page 352; and in the Twentieth Annual Report, Part IV, page 323.

The following table of the discharge of Lake Creek has been obtained from Mr. O. O. McReynolds, chief engineer of the company which has been converting Twin Lakes into a storage reservoir:

Estimated monthly discharge of Lake Creek at Twin Lakes, Colorado.

[Drainage area, 109 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
June 21 to 30			847	50,519	7.79	8.69
July	667	370	454	27,915	4.17	4.81
August	588	230	381	23,427	3.50	4.04
September 1 to 11			194	11,543	1.78	1.99

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 257; discharge measurements, page 256.

Within the last two years the Twin Lakes Land and Water Company has constructed a dam in a cut leading from the lake to the natural outlet. The plan as it has been worked out contemplates a reservoir with a storage capacity of between 12,000 and 18,000 acre-feet, and an available head of 25 feet, 16 feet of which will be below the old normal level

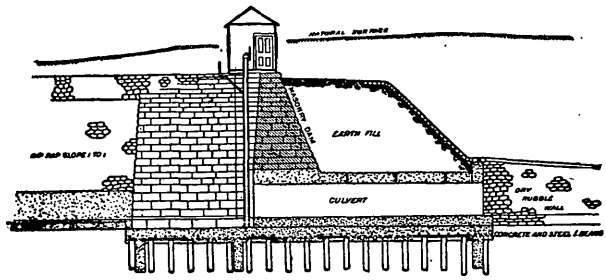


FIG. 148.—Longitudinal section through gates, dam, and culvert of Twin Lakes reservoir, Colorado.

of the lakes and 9 feet above that level. No arrangement has yet been made for conveying water from the Tennessee Fork of the Arkansas, as was proposed in previous discussions of this project. It will, moreover, be observed that the plans now nearly completed do not contemplate the erection of as high a dam as was proposed in earlier years, the present design being on a smaller scale than that suggested in previous reports, and more particularly described in the Thirteenth Annual Report. Part III.

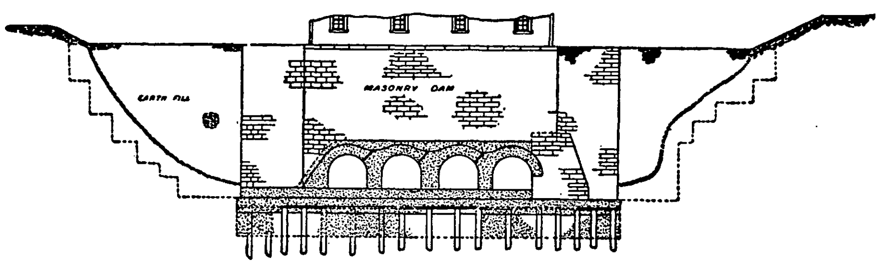


FIG. 149.—Cross section below masonry dam of Twin Lakes reservoir, Colorado.

The present plan is, briefly, as follows: A cut with a maximum depth of 35 feet from the lake to a point about 2,000 feet below; at the deepest part of this cut a masonry dam of tough sandstone is to be placed. (See fig. 148.) As the formation through which the cut is made, and which has hitherto formed the great natural dam impounding Twin Lakes, consists of a terminal moraine made up of a very fine grit, with loose bowlders occasionally embedded, it was impossible to lay the foundations upon bed rock, and the superstructure is therefore laid upon a bed of concrete, as the plans will show. All filling is done with the finest silt obtainable from the excavations of the cut. The natural outlet is dammed by earth embankment, carefully riprapped to a height of about 25 feet. It is intended that the water to be stored in this reservoir shall be used in irrigating large tracts of land from 25 to 60 miles east of Pueblo, Colorado. A beet-sugar factory is already being built upon this land near Ordway.

Pl. XV, *A*, is a view of the dam of Twin Lakes reservoir. The canyon in the background marks the course of Lake Creek as it leaves the mountains, just before reaching the upper of the Twin Lakes. Through this canyon the entire reservoir supply comes. The peaks in the background are Mount Elbert, 14,421 feet high, and Mount Massive, 14,424 feet high. These are the two highest peaks in Colorado.

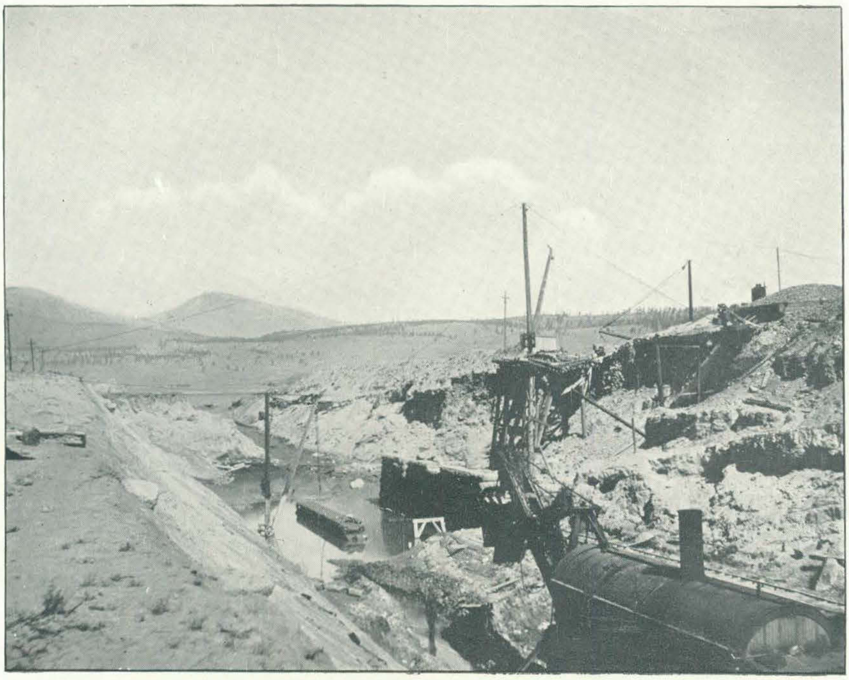
IRRIGATION SYSTEM OF THE GREAT PLAINS WATER COMPANY IN THE ARKANSAS VALLEY, COLORADO.[1]

In the Twentieth Annual Report, Part IV, page 323, brief mention was made of the storage system in process of construction by The Great Plains Water Company. This system has now been practically completed and part of it is in operation. Water is taken from the Arkansas River a few miles northwest of the town of Lajunta, Colorado, and is carried away from the river through the Fort Lyon canal. This canal is 113 miles long, and at its head has a capacity of over 2,000 second-feet. The head gate and dam are so constructed that all of the water in the Arkansas can, if desired, be taken during low stages of the river, and as much as the ditch will safely carry can be taken when the water is high. All the water of the river is therefore carried through this canal when practicable during the winter months, while during the flood stages a very large volume is carried to the reservoirs far down the canal.

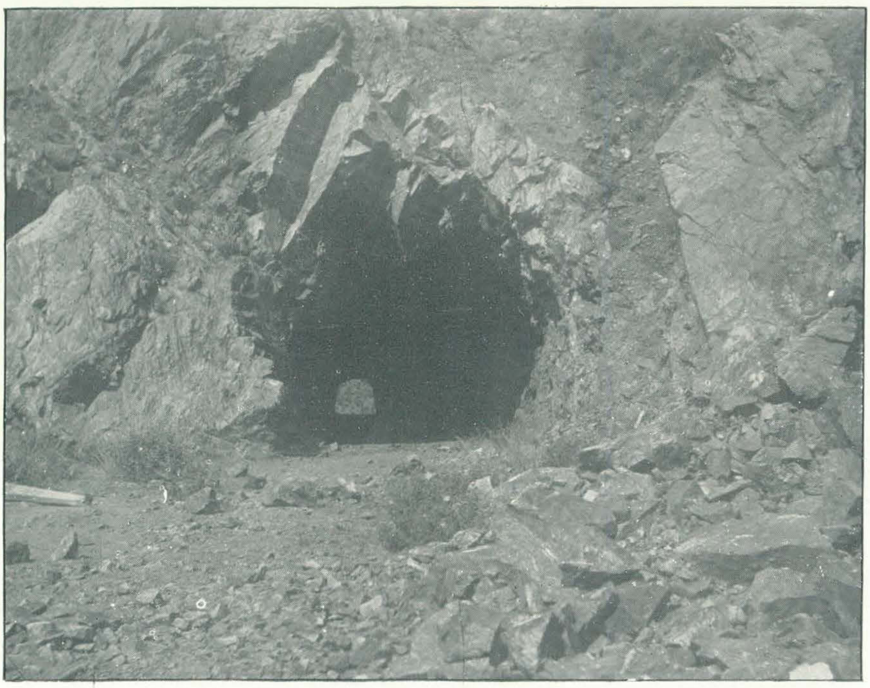
As may be seen from the accompanying map of this system (fig. 150), the Fort Lyon canal crosses Horse Creek at a point 20 miles below the head gate. A flume with a very heavy grade has been constructed across this creek, carrying 1,400 second-feet of water. The heavy fall has, however, resulted in giving more or less trouble during very cold weather, through the formation of anchor and mush ice in the small lake at the lower end of the flume, causing overflow and breaks, and a change of some kind will probably be made.

Just after crossing Gageby Arroya, about 40 miles from the head, the canal divides into two parts—Fort Lyon canal proper, which furnishes water directly to consumers, and Kicking Bird canal (Pl. XVI, *B*), which has a capacity of 1,000 second-feet and carries to the reservoirs the surplus water of Fort Lyon canal. These reservoirs are situated in Kiowa and Prowers counties, from 10 to 20 miles north of

[1] From report of A. L. Fellows.



A. DAM OF TWIN LAKES RESERVOIR, COLORADO.



B. LOOKING UP TUNNEL NO. 1, STATE CANAL NO. 1, NEAR CANYON, COLORADO.

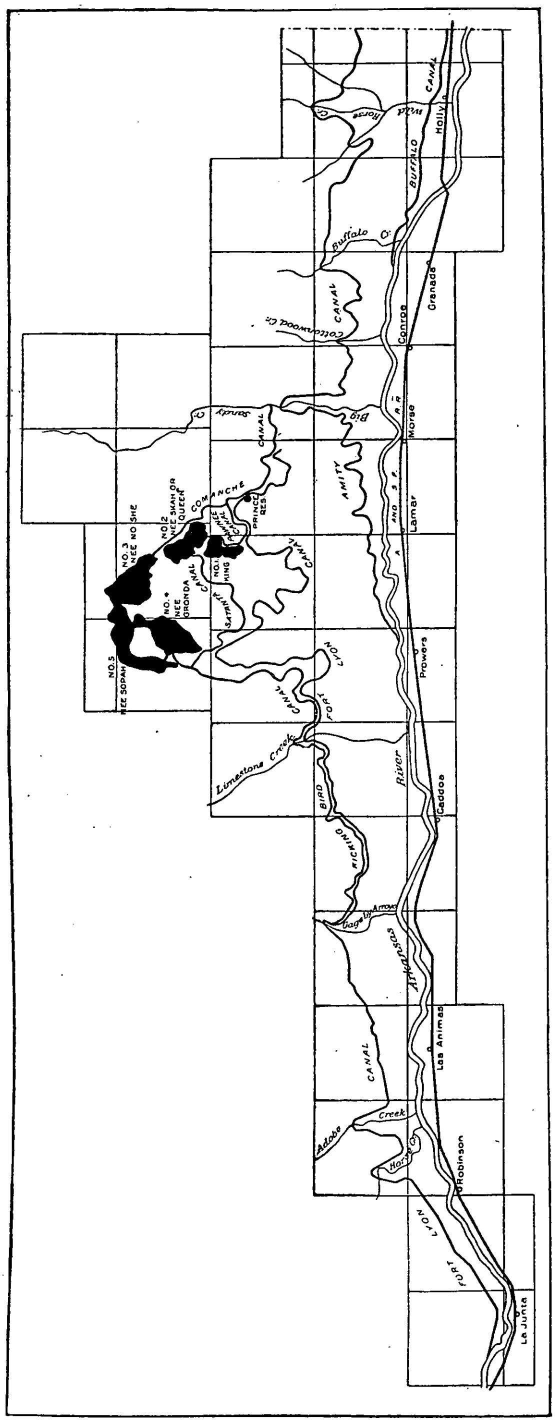


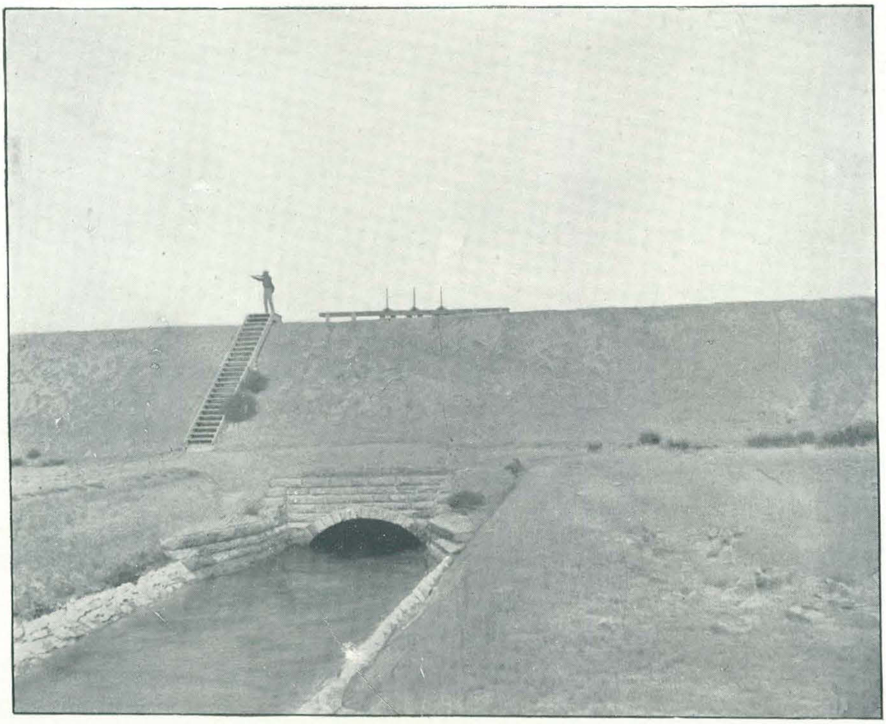
FIG. 150.—Irrigation system of The Great Plains Water Company, Colorado.

Lamar, Colorado. The following data regarding them are furnished by Mr. Thomas Berry, engineer in charge:

	Acre-feet.
Nee Sopah (black water):	
Available capacity	23,600
Unavailable capacity	10,910
Total	34,510
Nee Gronda (big water):	
Available capacity	57,204
Unavailable capacity	39,860
Total	97,064
Nee Noshe (standing water):	
Available capacity	62,052
Unavailable capacity	21,465
Total	84,517
Nee Skah (white water), also called Queen:	
Available capacity	32,557
Unavailable capacity	9,939
Total	42,496
King:	
Available capacity	18,279

While the three first-named reservoirs are connected to one another by channels, Nee Noshe reservoir is now being operated separately. That this might be done, the Lone Wolf canal was constructed (1899) around the high-water mark of Nee Gronda reservoir, beginning at a point about a mile from the lower end of Kicking Bird canal and extending to the channel connecting Nee Gronda and Nee Noshe reservoirs, and a fill was constructed across this channel just above the mouth of Lone Wolf canal. It is proposed to impound 23 feet of water in Nee Noshe and Nee Gronda reservoirs and 13 feet of water in Nee Sopah reservoir. The 23-foot contour of Nee Noshe is the high-water mark of the three reservoirs. The dam of Nee Noshe reservoir is 4,000 feet long and 9 feet high at the outlet valves. It is 25 feet wide on top, with the water slope 1 in 4 and the outer slope 1 in 1½. This embankment commands the three upper reservoirs. (Fig. 150.)

Water is supplied to Nee Skah reservoir through the Satanta canal, 12½ miles long, which leaves Kicking Bird canal at a point about 2 miles from its lower end. This reservoir, commonly called the Queen, was the only one used during 1899, one irrigation being furnished Amity canal from this source. Its dam (Pl. XVI, *A*) is of earth, as are all the others, and is 2,800 feet long and 16 feet high at the outlet. It is 16 feet wide on top and has an inner slope of 1 in 2½ and an outer slope of 1 in 1½. All of the dams are covered with rock riprapping from 18 to 24 inches thick.



A. QUEEN RESERVOIR DAM, NORTH OF LAMAR, COLORADO.

B. KICKING BIRD CANAL, NORTH OF LAMAR, COLORADO.

When filled, the five reservoirs will have a water surface of nearly 14,000 acres, or nearly 23 square miles. The maximum depth will be about 92 feet, but owing to the fact that the basins are almost entirely of natural formation and the artificial embankments are nowhere more than a few feet in height, there can be little danger of serious breaks. About 25,000 acres can be irrigated during the year 1900 from Queen reservoir. Water can either be used directly from the reservoirs for irrigation or can be turned out for the use of other canals controlled by The Great Plains Water Company, as the Amity and Buffalo canals. More than $2,000,000 have been expended upon the system and the results will be awaited with much interest.

NEOSHO RIVER.[1]

A partial description of this river was given in the Twentieth Annual Report, Part IV, pages 345 to 347. The watershed of the stream is a long, narrow strip of land lying east of the watershed of Verdigris River[2] and west of the watershed of Osage and White rivers. Near Emporia its width is 20 miles; at Humboldt, 8 miles south of the point of discharge measurement, its width is 25 miles. The surface slopes gently toward the river. The soil is very productive. The rainfall over the whole watershed varies from 30 to 40 inches per annum. That at Emporia from January, 1896, to December 31, 1899, is given on pages 245 and 246. This city is located near the center of the watershed above the gaging station, and its rainfall will be used in comparing rainfall and run-off.

The gaging station is located at a point about 150 miles from the source, at a carriage bridge about 1 mile west of Iola, Kansas. The gage is fastened to the flume of a mill about 90 feet above the bridge. The bridge, dam, and gage are shown in Pl. XVII, *A*. The width of the river just above the dam is about 220 feet; above the bridge it narrows to 190 feet. The bed at the bridge is stony, the stone having been loosened from the dam by driftwood and carried downstream by the current. During very low water the current at the bridge is sluggish; during extremely high water it is very swift. The gage was put in August 2, 1895. From that time to the present (August, 1899) readings have been taken twice a day and twenty-three discharge measurements have been made. These are given on the following page.

[1] From report of E. C. Murphy, civil engineer.

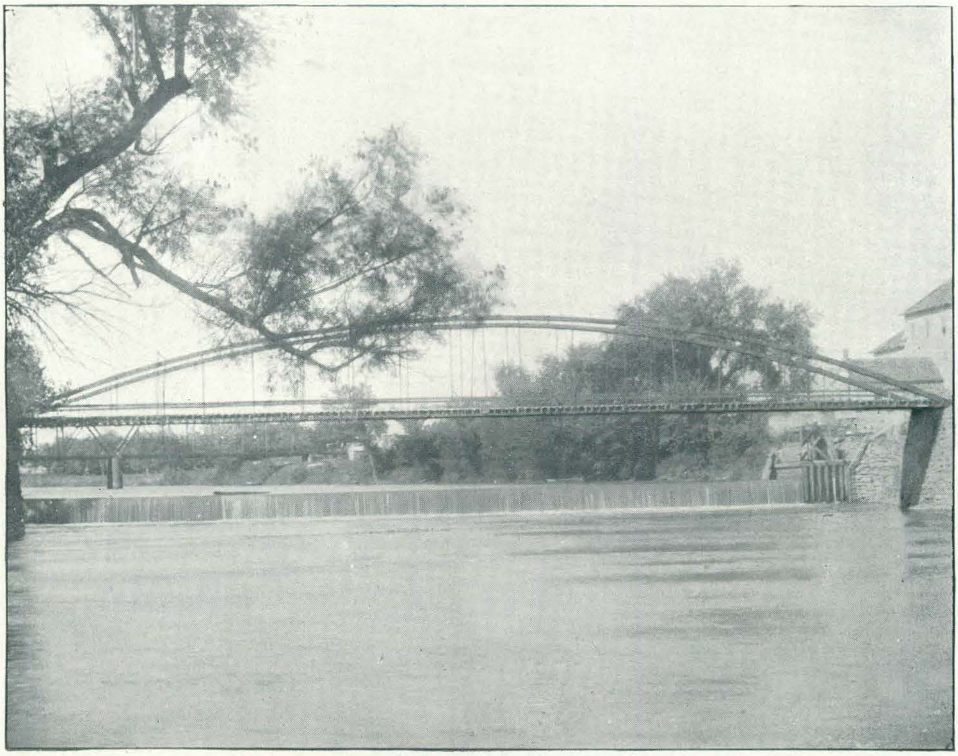
[2] The estimated daily discharge of Verdigris River for 1899 is given on page 237.

Discharge measurements of Neosho River at Iola, Kansas.

Date.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1895.		*Feet.*	*Square feet.*	*Feet per sec.*	*Second-feet.*
July 30	19	2.75	448	0.57	257
August 3	19	3.10	531	.98	521
September 6	17	2.80	453	.79	358
November 15	17	2.40	474	.56	267
1896.					
April 14	10	3.40	680	.97	664
May 26	10	16.80	3,112	11.20	*a* 34,722
July 8	10	3.50	704	1.23	863
October 14	17	2.25	....	....	*b* 73
1897.					
March 19	17	3.15	647	.87	566
April 1	19	4.60	931	2.20	2,049
April 2	19	4.35	883	1.95	1,752
May 1	19	3.28	660	.83	544
June 28	19	4.75	983	2.27	2,226
December 1	....	1.80	....	....	*c* 1
1898.					
March 24	19	2.80	628	.64	400
May 19	19	5.50	1,189	2.86	3,427
May 20	19	10.60	2,166	5.18	11,213
July 11	19	2.85	252	.59	386
1899.					
May 18	19	2.70	490	.49	242
June 5	19	18.00	3,397	....	23,575
July 5	19	8.20	1,545	....	6,313
July 8	19	16.70	3,160	....	21,834
October 11	55	2.30	478	.66	316

a Discharge found from surface floats; should be given little weight.
b Measurement made a little below station.
c Estimated.

A rating table was prepared in 1897 from the measurements made to that time, and the monthly discharges were computed and published in the Nineteenth Annual Report, Part IV, page 362. The high-water measurements of 1898 and 1899 made it possible to prepare a more accurate rating table. This is given on the next page, the monthly discharge for 1898 and 1899 being computed from it.



A. DAM AND GAGE ON NEOSHO RIVER NEAR IOLA, KANSAS.

B. NEOSHO RIVER BRIDGE AT CHETOPA, KANSAS.

Rating table for Neosho River from observations made from 1895 to 1899 at the rating station at Iola, Kansas, by E. C. Murphy.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.00	50	3.60	865	5.50	3,310	11.00	12,200
2.20	110	3.80	1,050	6.00	4,100	12.00	13,850
2.40	180	4.00	1,250	6.50	4,900	13.00	15,500
2.60	260	4.20	1,465	7.00	5,700	14.00	17,150
2.80	350	4.40	1,700	7.50	6,500	15.00	18,800
3.00	450	4.60	1,960	8.00	7,325	16.00	20,450
3.20	565	4.80	2,250	9.00	8,950	17.00	22,100
3.40	700	5.00	2,550	10.00	10,575	18.00	23,750

Estimated monthly discharge of Neosho River at Iola, Kansas.

[Drainage area, 3,670 square miles.]

Month.	Discharge in second-feet.			Total in acre feet.	Run-off.		Rainfall in inches. *a*
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.	
1896.							
January	275	100	125	7,686	0.03	0.03	0.30
February	275	75	114	6,557	0.03	0.03	0.40
March	125	20	61	3,751	0.02	0.02	0.65
April	15,025	50	2,708	161,137	0.74	0.82	6.05
May	45,560	160	10,273	631,666	2.80	3.23	6.20
June	5,408	250	905	53,851	0.25	0.28	3.20
July	7,890	125	1,278	78,581	0.35	0.40	3.75
August	300	10	58	3,566	0.02	0.02	3.50
September	10	0	6	357	0.002	0.002	1.90
October	225	0	11	676	0.003	0.003	3.55
November	2,290	5	245	14,578	0.07	0.07	1.50
December	445	20	88	5,411	0.02	0.02	0.04
The year	45,560	0	1,322	967,817	0.36	4.925	31.04
1897.							
January	920	105	531	32,650	0.145	0.167	1.25
February	3,970	395	1,689	93,802	0.460	0.479	1.70
March	4,840	340	960	59,030	0.262	0.302	1.15
April	2,183	395	894	53,197	0.244	0.272	3.10
May	665	170	379	23,305	0.103	0.119	1.50
June	1,445	75	363	21,600	0.099	0.110	3.00
July	422	87	163	10,023	0.044	0.051	0.70
August	87	50	72	4,427	0.020	0.023	3.50
September	62	1	9	536	0.002	0.002	2.50
October	1	0	1	62	0.000	0.000	1.80
November	1	1	1	60	0.000	0.000	T.
December	1	1	1	62	0.000	0.000	0.75
The year	4,840	0	422	298,754	0.115	1.525	20.95

a At Emporia, Kansas.

Estimated monthly discharge of Neosho River at Iola, Kansas—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.		Rainfall in inches. *a*
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.	
1898.							
January	50	1	7	430	0.002	0.002	2.05
February	5,060	1	466	25,881	0.127	0.146	2.00
March	7,077	80	692	42,550	0.188	0.218	2.00
April	5,460	220	753	44,807	0.205	0.237	5.40
May	26,225	1,250	8,855	544,476	2.413	2.785	7.24
June	27,875	1,250	5,360	318,941	1.461	1.686	4.00
July	1,050	180	392	24,103	0.107	0.123	3.71
August	1,825	110	543	33,388	0.148	0.171	2.36
September	5,220	110	678	40,344	0.185	0.213	3.50
October	3,620	50	395	24,288	0.108	0.124	3.16
November	3,695	145	482	28,681	0.131	0.152	0.30
December	16,077	305	2,311	142,099	0.629	0.727	2.60
The year	27,875	1	1,745	1,269,988	0.475	6.584	38.32
1899.							
January	450	305	357	21,951	0.10	0.12	0.25
February	4,020	220	617	34,266	0.17	0.18	0.75
March	12,290	780	2,138	131,461	0.58	0.67	2.53
April	1,825	505	887	52,780	0.24	0.27	0.85
May	5,620	282	1,094	67,268	0.30	0.35	2.50
June	22,191	350	4,168	248,013	1.14	1.27	5.45
July	21,365	305	3,443	211,703	0.94	1.08	7.90
August	630	220	308	18,938	0.08	0.09	4.85
September	305	180	200	11,901	0.05	0.06	4.10
October	145	50	98	6,026	0.03	0.03	0.50
November	50	50	50	2,975	0.01	0.01	0.60
December	110	50	75	4,612	0.02	0.02	1.82 *b*
The year	22,191	50	1,120	811,894	0.31	4.15	32.10

a At Emporia, Kansas. *b* At Burlington, Kansas.

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 115; discharge measurements, page 116; rating table, page 117. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 267; rating table in Paper No. 39, page 450.

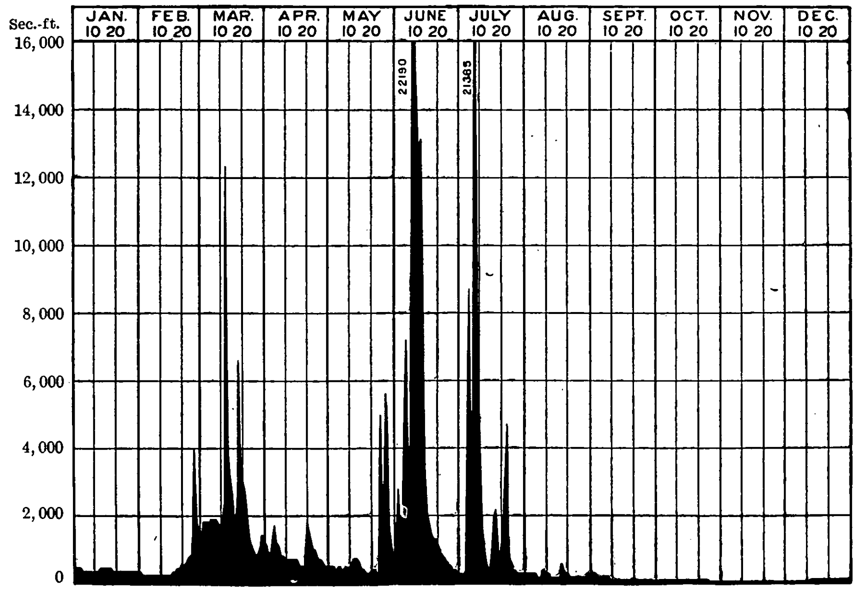


FIG. 151.—Discharge of Neosho River at Iola, Kansas, 1899.

Percentage of rainfall which appears as run-off at Iola, Kansas.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1896..	10	8	3	13	52	9	11	1	0	0	5	50
1897..	14	27	26	9	8	4	7	1	0	0	0	0
1898..	0	7	11	4	39	42	3	7	6	4	50	28
1899..	44	25	22	33	15	24	12	2	1	6	2	1

Computation of flood discharges.—The velocity at the gaging station increases rapidly with the depth, or gage reading, and there is much driftwood brought down, so that it is difficult to obtain velocities, except at the surface, for gage readings above about 10 feet. For higher readings the discharge must be found from surface velocities and from soundings taken directly before or after the flood.

The formula for finding the mean velocity from the greatest surface velocity is $V_m = K V_s$, V_m being the mean velocity of the cross section, V_s the greatest surface velocity, and K a constant whose value is commonly given as 0.83. With a view to finding the value of K for this particular place, there are given the gage readings, the areas, the greatest surface velocities, the discharges, and the value of K for the discharge measurements made in 1897, 1898, and 1899, where the bottom and surface velocities were measured with the Price current meter. K is found by dividing the measured discharge by the product of the area and velocity. These values of K are platted, using gage readings as ordinates and values of K as abscissas, and a smooth curve drawn so as to give an average value for each gage reading.

From this data it appears that the value of K decreases from about 0.83 for a gage reading of 2.70 feet to 0.7 for a gage reading of 7 or 8 feet. It is probably nearly constant for the higher readings. In com-

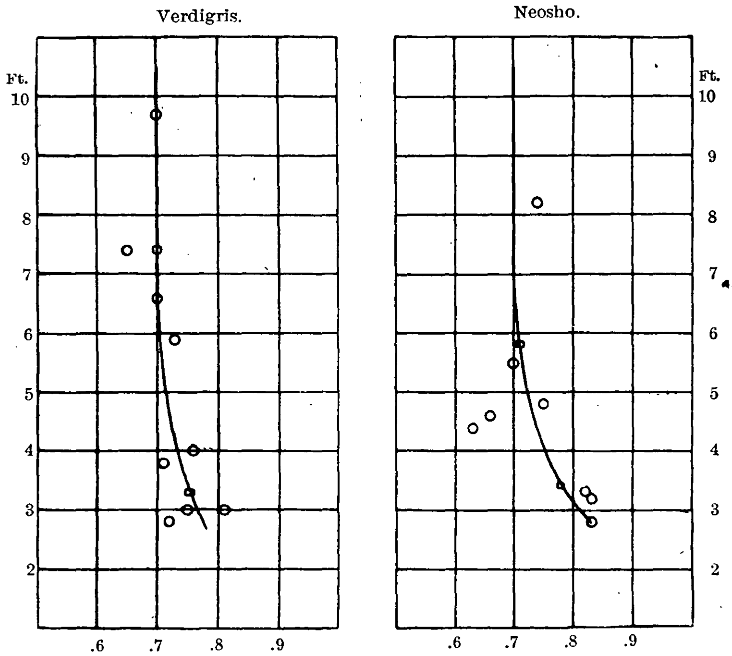


Fig. 152.—Diagram showing relation of mean to surface velocity in flood of Verdigris and Neosho rivers, Kansas.

puting the flood discharges 0.7 has been used as the value of K. Fig. 152 shows how K varies with the gage readings for the gaging station on Verdigris River near Liberty, Kansas.

Values of K for station on Neosho River near Iola, Kansas, computed from gage readings.

Gage height.	Area.	Greatest surface velocity.	Discharge.	Value of K.
Feet.	*Square feet.*	*Feet per second.*	*Second-feet.*	
2.80	628	1.27	662	0.83
3.2	647	1.35	725	0.83
3.3	660	1.01	544	0.82
4.4	880	3.15	1,752	0.63
4.75	980	3.45	2,556	0.75
4.6	931	3.33	2,049	0.66
5.5	1,189	3.81	3,198	0.70
8.2	1,545	5.75	6,628	0.74

Available power.—The dam just above the gaging station is shown in Pl. XVII, *A*. It is 216 feet long and gives a head of 8 feet for a gage reading of 2 to 3 feet. This head decreases as the gage height increases until the reading is 9 to 10 feet, when the effective head is about 2 feet; that is, the water below the dam rises faster than the water above it, so that the effective head is constantly decreasing. For gage readings above 10 feet the mill can not run, on account of backwater, and for gage readings below 2 feet there is not enough water to run it. The number of days, therefore, that the mill is necessarily idle is the sum of the days when the gage reads above 10 feet and below 2 feet.

Summary of gage readings at Neosho River station near Iola, Kansas, for 1896.

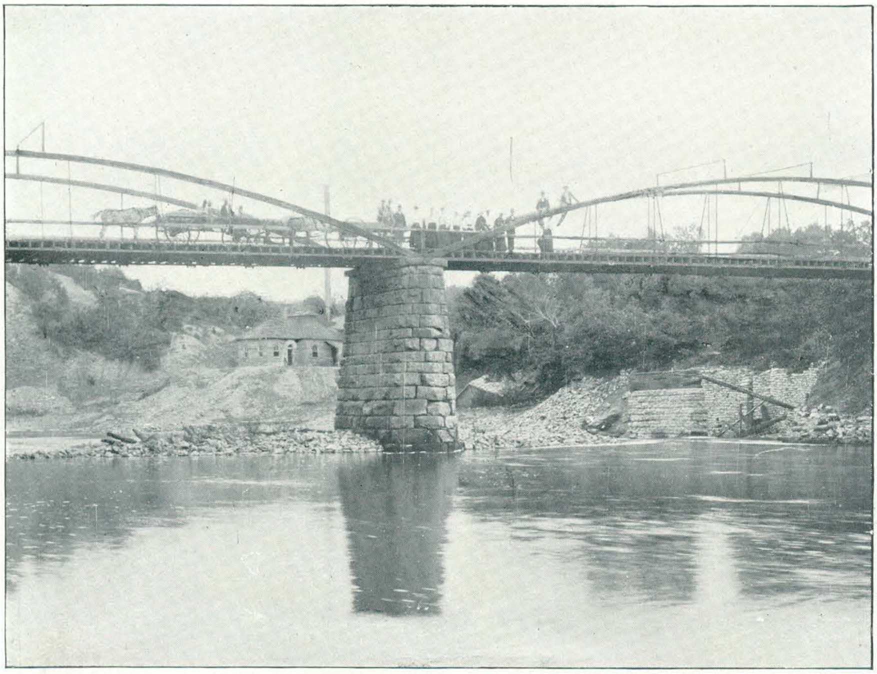
Month.	From 0 to 1.95 feet.	From 2 to 2.95 feet.	From 3 to 3.95 feet.	From 4 to 4.95 feet.	From 5 to 5.95 feet.	From 6 to 6.95 feet.	From 7 to 7.95 feet.	From 8 to 8.95 feet.	From 9 to 9.95 feet.	From 10 feet up.
	Days.	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*
January	0	31	0	0	0	0	0	0	0	0
February	0	28	0	0	0	0	0	0	0	0
March	0	31	0	0	0	0	0	0	0	0
April	0	9	11	3	0	2	1	1	2	1
May	0	5	8	1	5	2	1	0	1	8
June	0	4	20	5	0	1	0	0	0	0
July	0	8	14	5	2	0	2	0	0	0
August	0	30	1	0	0	0	0	0	0	0
September	0	30	0	0	0	0	0	0	0	0
October	0	31	0	0	0	0	0	0	0	0
November	0	24	4	2	0	0	0	0	0	0
December	0	29	2	0	0	0	0	0	0	0
Total days.	0	260	60	16	7	5	4	1	3	9
Mean discharge, second-feet	....	220	780	1,825	3,310	4,900	6,500	8,150	9,775	....
Effective head, feet	....	8.0	7.5	7.0	6.25	5.5	4.5	3.5	2.5	....
Mean horse-power	....	200	665	1,452	2,352	3,064	3,326	3,243	2,778	....
Horsepower available	....	52,000	39,900	23,232	16,464	15,320	13,304	3,243	8,334	....

Summary of gage readings at Neosho River station near Iola, Kansas, for 1897.

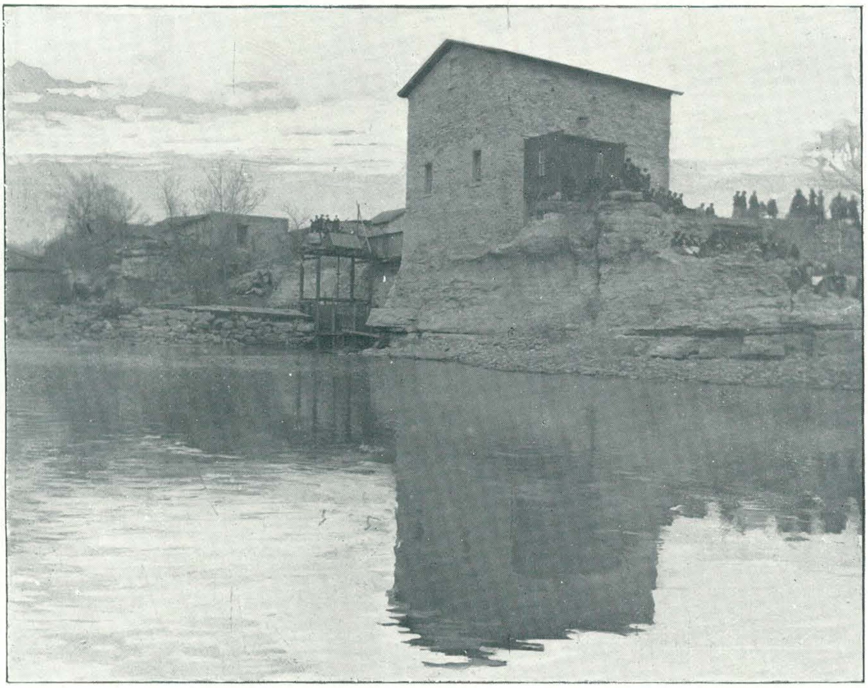
Month.	From 0 to 1.95 feet.	From 2 to 2.95 feet.	From 3 to 3.95 feet.	From 4 to 4.95 feet.	From 5 to 5.95 feet.	From 6 to 6.95 feet.	From 7 to 7.95 feet.	From 8 to 8.95 feet.	From 9 to 9.95 feet.	From 10 feet up.
	Days.	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*
January	0	11	20	0	0	0	0	0	0	0
February	0	2	12	7	7	0	0	0	0	0
March	0	8	16	4	2	1	0	0	0	0
April	0	2	22	6	0	0	0	0	0	0
May	0	18	13	0	0	0	0	0	0	0
June	0	23	6	1	0	0	0	0	0	0
July	0	31	0	0	0	0	0	0	0	0
August	0	31	0	0	0	0	0	0	0	0
September	26	4	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0	0
Total days	118	130	89	18	9	1	0	0	0	0
Mean discharge, second-feet	....	220	780	1,825	3,310	4,900	....	....	....	....
Effective head, feet	....	8.0	7.5	7.0	6.25	5.5	....	....	....	....
Mean horsepower	....	200	665	1,452	2,352	3,064	....	....	....	....
Horsepower available	....	26,000	59,185	26,136	21,168	3,064	....	....	....	....

Summary of gage readings at Neosho River station near Iola, Kansas, for 1898.

Month.	From 0 to 1.95 feet.	From 2 to 2.95 feet.	From 3 to 3.95 feet.	From 4 to 4.95 feet.	From 5 to 5.95 feet.	From 6 to 6.95 feet.	From 7 to 7.95 feet.	From 8 to 8.95 feet.	From 9 to 9.95 feet.	From 10 feet up.
	Days.	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*	*Days.*
January	28	3	0	0	0	0	0	0	0	0
February	9	16	0	2	0	1	0	0	0	0
March	0	14	15	1	0	0	1	0	0	0
April	0	18	7	4	0	1	0	0	0	0
May	0	0	0	8	4	5	1	2	1	10
June	0	0	0	8	13	0	4	1	2	2
July	0	25	6	0	0	0	0	0	0	0
August	0	17	11	3	0	0	0	0	0	0
September	0	20	7	1	1	1	0	0	0	0
October	0	26	3	0	2	0	0	0	0	0
November	0	23	3	1	1	0	0	0	0	0
December	0	18	4	3	1	0	1	2	0	2
Total days	37	180	58	31	22	8	7	5	3	14
Mean discharge, second-feet	....	220	780	1,825	3,310	4,900	6,500	8,150	9,775	....
Effective head, feet	....	8.0	7.5	7.0	6.25	5.5	4.5	3.5	2.5	....
Mean horsepower	....	200	665	1,452	2,352	3,064	3,326	3,243	2,778	....
Horsepower available	....	36,000	38,570	45,012	51,744	24,512	23,282	16,215	8,334	....



A. RUINS OF DAM ON NEOSHO RIVER AT OSWEGO, KANSAS.



B. DAM ON NEOSHO RIVER AT HUMBOLDT, KANSAS.

It will be seen that in 1896 there was water enough to run the mill every day of the year, but the gage read 10 feet or more during 9 days; hence the mill was necessarily idle during those days. The foregoing table gives also the mean discharge, in second-feet, for the gage reading at the head of each column; thus 780 is the discharge for a gage reading of 3.5 feet. The table also gives the effective head, the mean horsepower, and the available horsepower. The mean horsepower is found by multiplying the mean discharge by the effective head, then by 62.5, and dividing the product by 550. The available horsepower is found by multiplying the mean horsepower by the total number of days when the gage was as indicated at the head of the column. The total available horsepower for the year 1896 was 171,799. If this sum be divided by 365 we have 471, the mean horsepower for the year. The maximum horsepower utilized by the mill is only 75.

It will be seen that during 1897 the gage did not read above 7 feet, and that there were 118 days that the mill could not run on account of lack of water—nearly one-third of a year that the mill required steam power to operate it. The mean horsepower for the year was 371.

In the table for 1898 it will be seen that the gage read less than 2 feet on 37 days and 10 feet or more on 14 days, making 51 days that the mill was necessarily shut down. The mean horsepower for the year was 668. By computing the discharge for the 14 days when the gage read 10 feet or more and comparing it with the total discharge for the year, we find that 43 per cent of the total yearly discharge passed down on these 14 days and could not be utilized by this dam.

The value of Neosho River as a source of power is evident from these tables. It will be seen that in order to have constant power it is necessary to have a steam plant, as the water power may fail during three or four months of the year. It should be said that people who have lived near the river for many years claim that the river was low, practically dry, for a longer period during the year 1897 than during any other year within their recollection.

The power of the Neosho proper has been utilized in at least ten places; at the present time it is utilized in eight places. From Emporia to the mouth of the river there is a fall of some 550 feet. At the present time not more than 60 feet of this fall are utilized. The dams, with the exception of the one at Hartford, Kansas, were built in the seventies. None have been built within the last fifteen years. Two mills that have burned have not been rebuilt, and their dams have been neglected. It is evident that the power of the river is not considered so valuable as it was in the seventies. This is due in part to a better knowledge of the characteristics of the river—its occasional long periods of very small discharge and its large flood discharge. The dams are located between Neosho Rapids and the southern border of Kansas. They are described further on, in their order up the river.

The dam farthest down the river is located about 2½ miles south of Chetopa, Kansas. Here an island divides the river into two channels. The dam is across the main channel; the other channel is used as a mill race. The dam, which was built in 1875, is of brush and stone. Its length is 300 feet, its height 2 feet. The water is taken to the mill through the race, which is 40 feet wide and a half mile long. There is a fall of 4 feet in the race. This, with the 2-foot head of the dam, gives a working head of 6 feet. One 48-inch Leffel turbine working under this head furnishes the power. The capacity of the mill, as given by the owner, Mr. John Bartlett, is 30 barrels of flour, 10 barrels of corn meal, and 3 tons of chop a day. The character of the river at Chetopa is illustrated in Pl. XVII, *B*. The bridge shown has a main span of 224 feet.

The next place on the river where the water has been utilized is near Oswego, Kansas. Here, in the early seventies, a mill and a timber crib dam 200 feet long and 7 feet high were built. The mill was burned about ten years ago and has never been rebuilt. The dam has been allowed to deteriorate. A view of it is shown in Pl. XVIII, *A*.

Between 1868 and 1870 a mill and dam were built near Erie, Kansas. The dam is 220 feet long and 7 feet high, and is of timber and stone. Power is furnished by two 40-inch Stillwell and Bierce turbines. The dam is said to back the water 10 miles and to furnish power to run the turbines ten months of the year on an average.

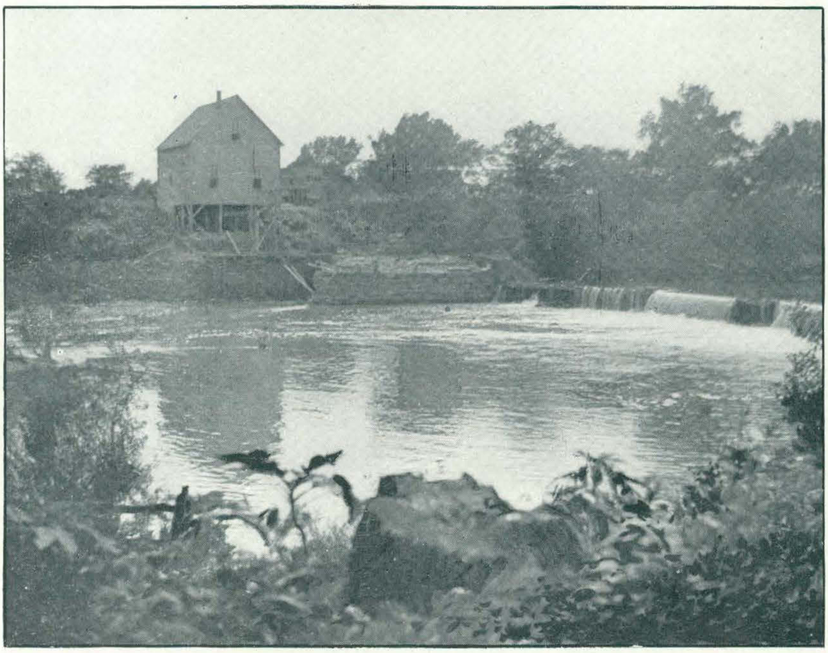
There was formerly a mill and dam near Austin, Kansas. The mill was burned, however, in 1897 and has not been rebuilt. The dam is gradually being carried away by the water.

The mill flume and a portion of the dam at Humboldt, Kansas, are shown in Pl. XVIII, *B*. The dam was built in 1875, of large stone without mortar. Its length is 280 feet, and it gives a head of 8 feet. The power is furnished by two turbines. The dam backs the water about 4½ miles, and is said to furnish power to run the mill ten months of the year on an average.

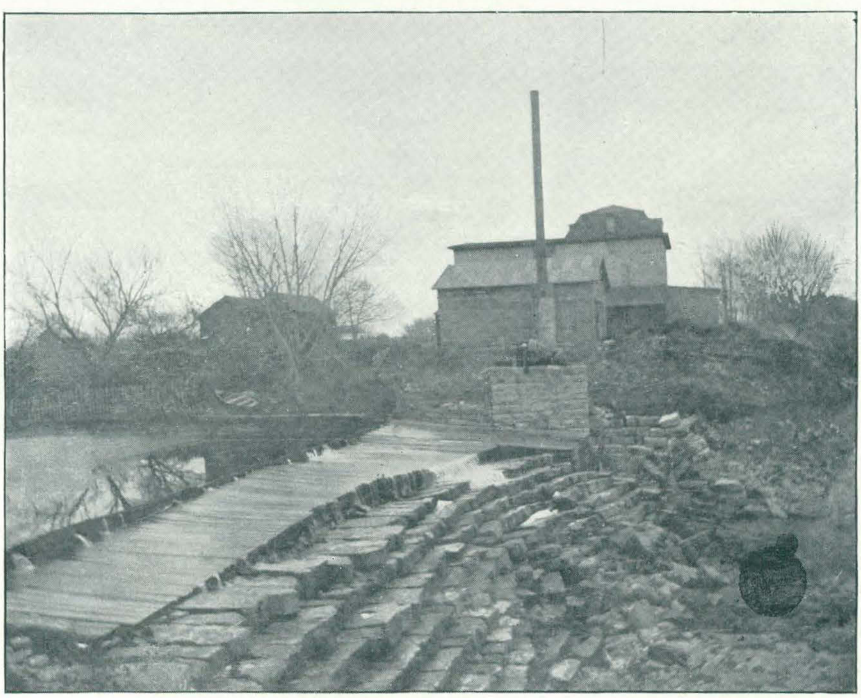
The dam near Iola, Kansas, is at the gaging station, and is shown in Pl. XVII, *A*. It was built in 1879, of timber cribs filled with stone and planked on the upstream face. Its length is 216 feet, and it gives a head of 8 feet. This dam was built to replace a low dam about 2 miles up the river. The power is furnished by one 61-inch Leffel turbine. There is a steam engine for furnishing power when the river will not supply it.

The dam at Leroy, Kansas, was built in 1868, of hewn logs and stone. It has a length of 240 feet, and gives a head of about 4 feet. The power is supplied by two Leffel turbines, one 42-inch and one 48-inch.

The dam near Hartford, Kansas, is shown in Pl. XIX, *A*. It was



A. DAM AND MILL ON NEOSHO RIVER AT HARTFORD, KANSAS.



B. DAM ON COTTONWOOD RIVER NEAR MARION, KANSAS.

built in 1885, of timber cribs filled with stone and planked on the upstream face. The length of the dam is 200 feet, and it gives a head of about 4 to 5 feet. The power is furnished by one 48-inch Leffel turbine.

The dam and mill at Burlington, Kansas, are the best on the river. They are owned by the Excelsior Water Mill Company, having been built in 1871. The dam is made of timber cribs filled with rock and planked on the upstream face. Its length is 315 feet, and it gives a head of 10 feet. The mill is situated a half mile from the dam. The water passes to it through a race 20 feet wide. The power is furnished by three Leffel turbines, two 35-inch and one 30-inch. The dam is said to back the water about 5 miles and to supply power about eleven months of the year on an average. There is a steam engine for furnishing power when water is short. The capacity of the mill is said to be 500 barrels of flour per day.

There is a dam near Council Grove, Kansas, owned by the Council Grove Water Company and used to store water for the city. It was built in 1877, of logs and stone, and has a height of 5 feet. Some years ago there was a dam and mill with one water wheel about a half mile down the river from the Council Grove dam, but the mill was burned and has not been rebuilt.

Cottonwood River is a better stream for power than Neosho River, its discharge being more permanent. The mills along it can often run when those along the Neosho can not for lack of water. The mill at Emporia is usually run by water a greater number of days during the year than is the mill at Burlington. The first dam at Emporia, on the Cottonwood, was built in 1860, of wood. The present dam is of stone masonry. It has a length of 110 feet and gives a head of 9 feet. The leakage through it is small, and it backs the water 12 to 14 miles, so that it acts as a storage reservoir. The power is furnished by five turbines, four 48-inch and one 32-inch. On an average of one week a year the mill can not run on account of backwater.

The dam at Cottonwood Falls (shown in Pl. XXX, *B*, of the Twentieth Annual Report, Part IV, p. 308), was built in 1882. It is of stone masonry, has a length of 170 feet, and gives a head of 7 feet. The power is furnished by four turbines, three 40-inch and one 26½-inch. The dam backs the water about 7 miles, and leaks very little. The dam at Florence, Kansas, was built in 1873. It is of stone masonry, 120 feet long and 12 feet high. The power is furnished by two turbines, one 36-inch and one 46-inch.

The dam near Marion, Kansas (Pl. XIX, *B*), was built in 1886, of piling, cribbing, and rock. It has a length of 115 feet and a height of 14 to 15 feet. The power is furnished by one 20-inch Victor turbine. There is no water to run the mill during about six months of the year.

WESTERN GULF DRAINAGE.

TRINITY RIVER.

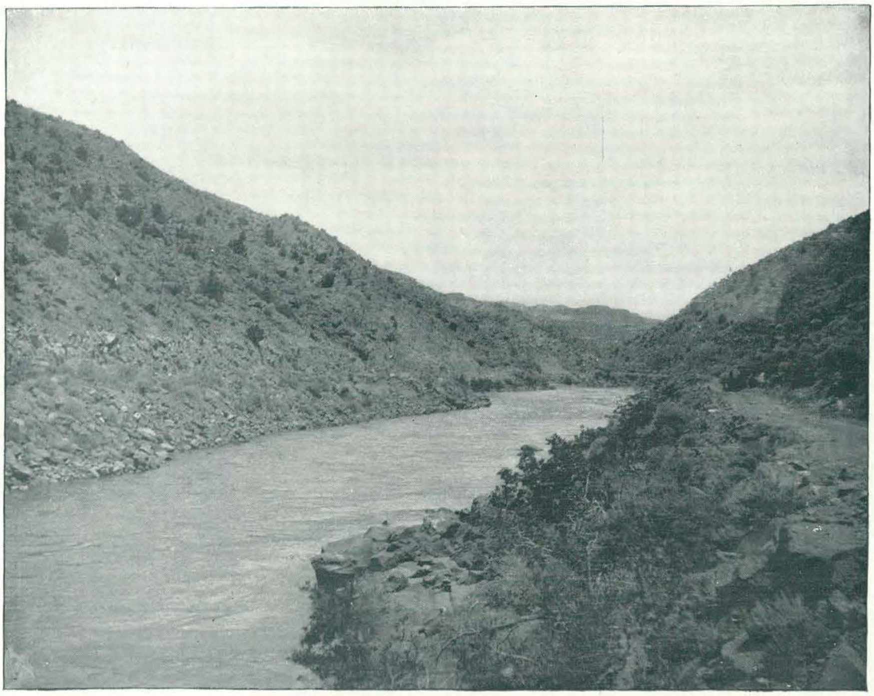
This river rises in Montague and Cooke counties, in northern Texas, the headwater streams draining the area within a few miles of Red River, on the north. The general course of the river is southeasterly. It empties into the Gulf of Mexico at Galveston. The entire basin is located in Texas. The station, established October 1, 1898, is located at the Turtle Creek pumping station of the city of Dallas, Texas. At this point a gage height of 53.1 feet indicates no flow. The discharge here often ceases for several months, as during 1899, but there is always water in the river at and below Dallas. The banks of the stream are comparatively high and prominent, and at usual stages the water moves with very small velocity. The daily gage heights and measurements made during 1899 are given in Water-Supply Paper No. 37, page 271.

BRAZOS RIVER.

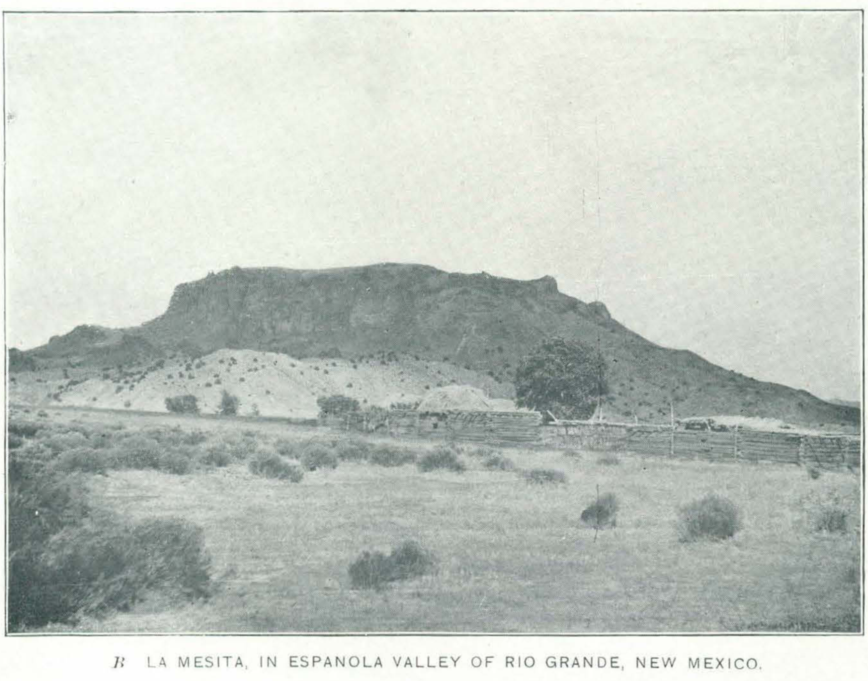
The Brazos has its source in the Staked Plains region of western Texas, and flows in a southeasterly direction, emptying into the Gulf of Mexico south of the mouth of Trinity River. Its drainage basin is entirely within the State of Texas. A gaging station is maintained at Waco, established September 14, 1898. Measurements are made by Thomas U. Taylor. The gage consists of a 6-inch by 8-inch pine stick bolted to an inclined iron bar 3 inches by 3 inches embedded in the limestone rock on the south bank under the highway suspension bridge. The gage is inclined at a slope of 5 vertical to 27 horizontal. The highest point of the gage is 4.2 feet, the gage heights above that being taken from the suspension bridge by a wire gage. Flood heights have been marked on the walls of a laundry just east of the gage, which are, from present datum, as follows:

	Feet.
April 26, 1890	31.43
May 22, 1884	32.03
May 31, 1887	32.13
March 29, 1897	32.93
July 1, 1889	33.43
July 30, 1899	34.38
May 28, 1885	34.63

The channel at Waco has good banks on both sides, that on the southeast being of limestone. The bed of the stream being of sand it shifts constantly. The depth of the sand to rock in the main channel at the suspension bridge is 15 feet, and at the railroad bridges of the Missouri, Kansas and Texas Railway, two blocks southeast, it is 22 feet. The main channel of the river under the suspension bridge is confined to the southwest side, and at the railroad bridges below it shifts to the northeast side. On account of the shifting nature of the



A. EMBUDO CANYON OF RIO GRANDE, NEW MEXICO.



B LA MESITA, IN ESPANOLA VALLEY OF RIO GRANDE, NEW MEXICO.

bed it was impossible to place a gage on any of the piers of the railroad bridges, as at low water they are often left high and dry on a sand bank. The present gage was placed after a study of the local conditions in connection with the history of the stream. The daily gage readings and the results of occasional measurements of volume of flow are given in Water-Supply Paper No. 37, page 272.

COLORADO RIVER.

The Colorado drains a large area in central Texas. It rises in the extreme western portion of the State, within a few miles of the western boundary of New Mexico, and flows in a general southeasterly direction, emptying into the Gulf of Mexico in Matagorda County. Its headwater tributaries drain the country immediately south of Brazos River. Llano River is a tributary of Colorado River, emptying into it 85 miles above Austin. Besides the Llano, Colorado River receives the waters of the Concho, the San Saba, the Pecan Bayou, the Pedernales, and various large springs, two of the latter, Mormon and Bartons, being near Austin. The gage is located at the foot of Congress avenue, Austin, and is marked on a vertical 4-inch by 4-inch post. In addition to this, the pier is marked in bold figures throughout its whole height for flood observation. The daily heights and measurements of discharge are given in Water-Supply Paper No. 37, page 274.

RIO GRANDE.

The Rio Grande has its source in the Continental Divide, in southern Colorado. Its general course is easterly through its mountainous collecting area until San Luis Park is reached, when it gradually takes a southeasterly course, and just before crossing the State line into New Mexico bends to the southward and continues in that direction through the latter State. There are gaging stations on the river at Del Norte, Los Mogotes, and Cenicero, in Colorado; at Embudo, Rio Grande, and San Marcial, in New Mexico; and at El Paso, Texas. The measurements in Colorado are made by A. L. Fellows, those in Mexico by P. E. Harroun, and those at El Paso by T. M. Courchesne, under the direction of W. W. Follett, chief engineer of the International (Water) Boundary Commission. Pl. XX, *A*, is a view of Embudo Canyon of Rio Grande.

Estimated monthly discharge of Rio Grande at Del Norte, Colorado.

[Drainage area, 1,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	1,030	280	618	36,774	0.44	0.49
May	2,315	537	1,377	84,668	0.98	1.13
June	1,509	753	1,091	64,919	0.78	0.87
July	1,302	537	703	43,226	0.50	0.58
August	1,207	280	597	36,708	0.43	0.49
September	753	280	370	22,017	0.26	0.29

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 278; rating table in Paper No. 39, page 450.

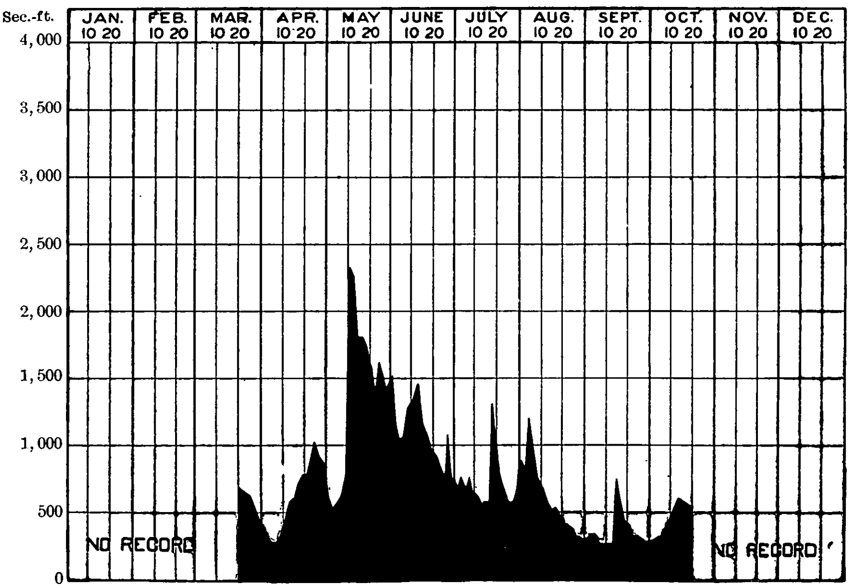


FIG. 153.—Discharge of Rio Grande at Del Norte, Colorado, 1899.

Estimated monthly discharge of Rio Grande at Cenicero, Colorado.

[Drainage area, 7,695 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
July	170	12	42	2,582	0.005	0.006
August	129	20	53	3,259	0.007	0.008
September	423	31	102	6,069	0.013	0.015
October	170	65	117	7,194	0.015	0.017
November	297	170	259	15,412	0.034	0.038
December	381	170	318	19,553	0.041	0.047

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 280; discharge measurements, page 279; rating table in Paper No. 39, page 450.

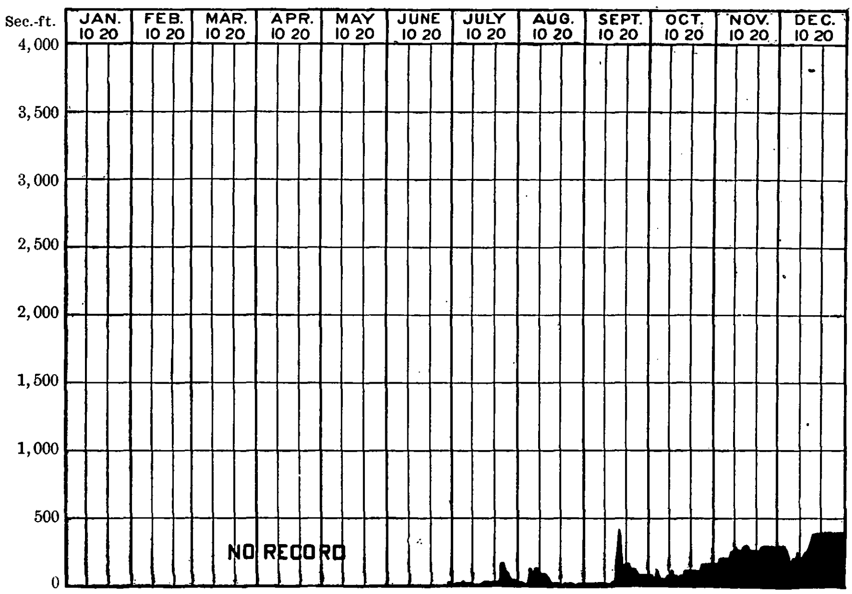


FIG. 154.—Discharge of Rio Grande at Cenicero, Colorado, 1899.

Estimated monthly discharge of Rio Grande at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	560	375	470	28, 899	0. 07	0. 08
February	560	420	481	26, 713	0. 07	0. 07
March	1, 030	465	761	46, 792	0. 11	0. 13
April	1, 550	660	1, 090	64, 859	0. 16	0. 18
May	1, 400	610	956	58, 782	0. 14	0. 16
June	560	65	249	14, 817	0. 04	0. 04
July	660	185	297	18, 262	0. 04	0. 05
August	290	185	236	14, 511	0. 03	0. 03
September	685	185	309	18, 387	0. 04	0. 04
October	420	290	356	21, 890	0. 05	0. 06
November	660	420	535	31, 835	0. 08	0. 09
December	610	420	478	29, 391	0. 07	0. 08
The year	1, 550	65	518	375, 138	0. 07	1. 01

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 281; discharge measurements, page 280; rating table in Paper No. 39, page 451.

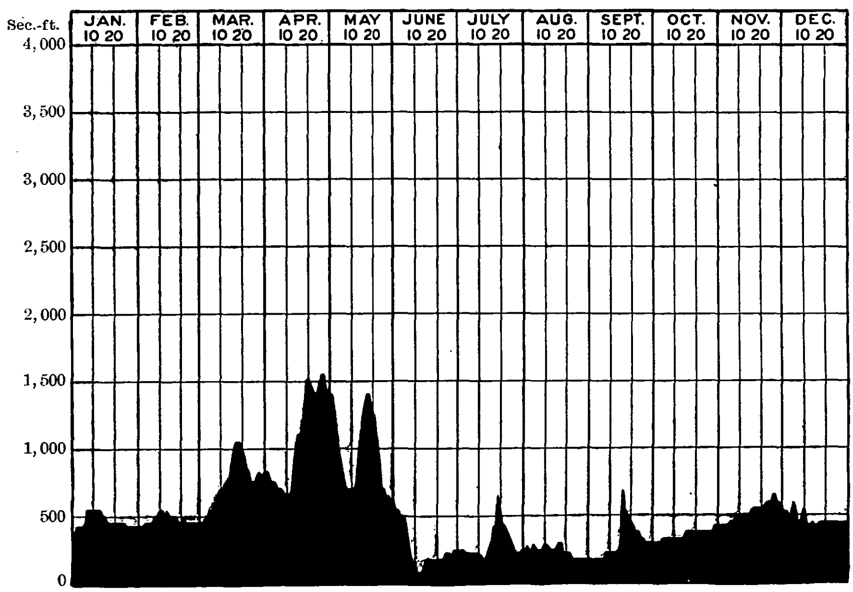


FIG. 155.—Discharge of Rio Grande at Embudo, New Mexico, 1899.

Estimated monthly discharge of Rio Grande at Rio Grande, New Mexico.

[Drainage area, 11,250 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	610	295	423	26,009	0.04	0.05
February	890	485	641	35,599	0.06	0.06
March	1,990	775	1,320	81,164	0.12	0.14
April	5,620	935	2,965	176,430	0.26	0.30
May	3,550	810	1,914	117,687	0.17	0.20
June	740	190	399	23,742	0.04	0.04
July	4,450	135	596	36,647	0.05	0.06
August	2,160	100	361	22,197	0.03	0.03
September	8,260	95	893	53,137	0.08	0.09
October	560	310	432	26,563	0.04	0.05
November	980	535	756	44,985	0.07	0.08
December	775	360	621	38,184	0.06	0.07
The year	8,260	95	943	682,344	0.08	1.17

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 127; discharge measurements, page 129; rating table, page 130. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 282; rating table in Paper No. 39, page 451.

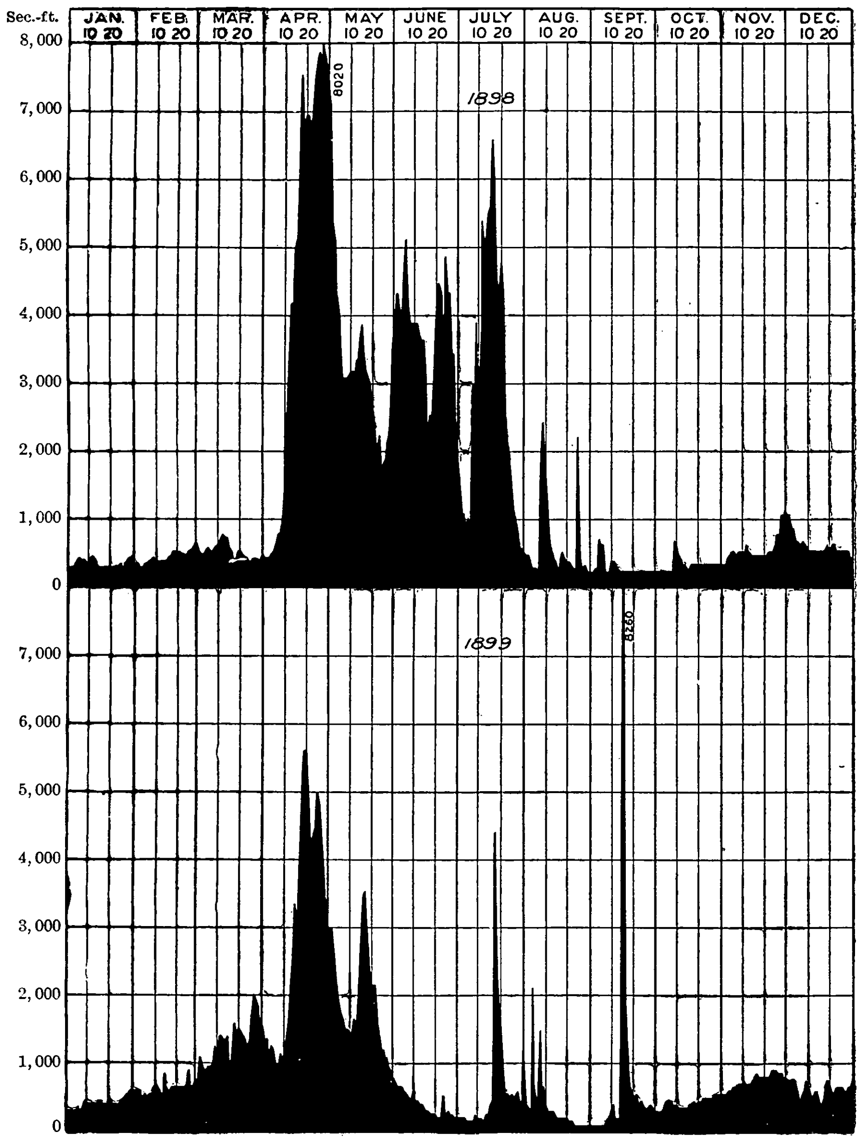


FIG. 156.—Discharge of Rio Grande at Rio Grande, New Mexico, 1898 and 1899.

Estimated monthly discharge of Rio Grande at San Marcial, New Mexico.

[Drainage area, 28,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	580	400	453	27,854	0.02	0.02
February	670	75	443	24,603	0.02	0.02
March	620	350	448	27,546	0.02	0.02
April	2,220	160	909	54,089	0.03	0.03
May	1,610	156	570	35,048	0.02	0.02
June	130	0	16	952	0	0
July	4,655	0	462	28,407	0.02	0.02
August	1,295	0	104	6,395	0.004	0.005
September	690	0	49	2,916	0.002	0.002
October	60	0	11	676	0	0
November	252	72	160	9,521	0.006	0.007
December	690	246	355	21,828	0.012	0.014
The year	4,655	0	332	239,835	0.013	0.158

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 283.

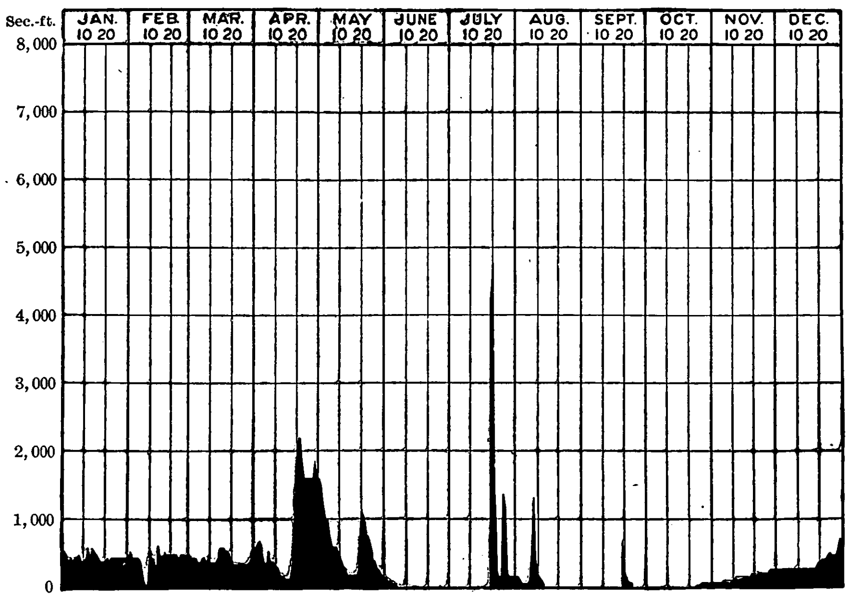


FIG. 157.—Discharge of Rio Grande at San Marcial, New Mexico, 1899.

Estimated monthly discharge of Rio Grande at El Paso, Texas.

[Drainage area, 30,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January	703	207	490	30,129	0.016	0.018
February	965	320	606	33,655	0.020	0.021
March	620	99	326	20,044	0.011	0.013
April	4,750	15	1,646	97,944	0.055	0.061
May	5,800	530	2,280	140,192	0.076	0.087
June	3,080	522	1,875	111,570	0.063	0.070
July	9,900	1,210	3,192	196,269	0.106	0.122
August	1,550	100	508	31,236	0.017	0.020
September	170	3	38	2,262	0.001	0.001
October	3	2	3	160	0.001	0.001
November	2	2	2	119	0.001	0.001
December	200	2	93	5,718	0.003	0.003
The year	9,900	2	922	669,298	0.031	0.418
1899.						
January	290	130	210	12,912	0.007	0.008
February	300	130	204	11,330	0.007	0.007
March	220	40	115	7,071	0.004	0.005
April	730	10	148	8,807	0.005	0.006
May	690	10	168	10,330	0.006	0.007
June	0	0	0	0	0	0
July	1,900	0	318	19,553	0.011	0.013
August	120	0	7	430	0.0002	0.0002
September	0	0	0	0	0	0
October	0	0	2	123	0.0001	0.0001
November	0	0	2	119	0.0001	0.0001
December	110	0	46	2,828	0.002	0.002
The year	1,900	0	102	73,503	0.0035	0.0484

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 128: discharge measurements, page 120. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 37, page 284.

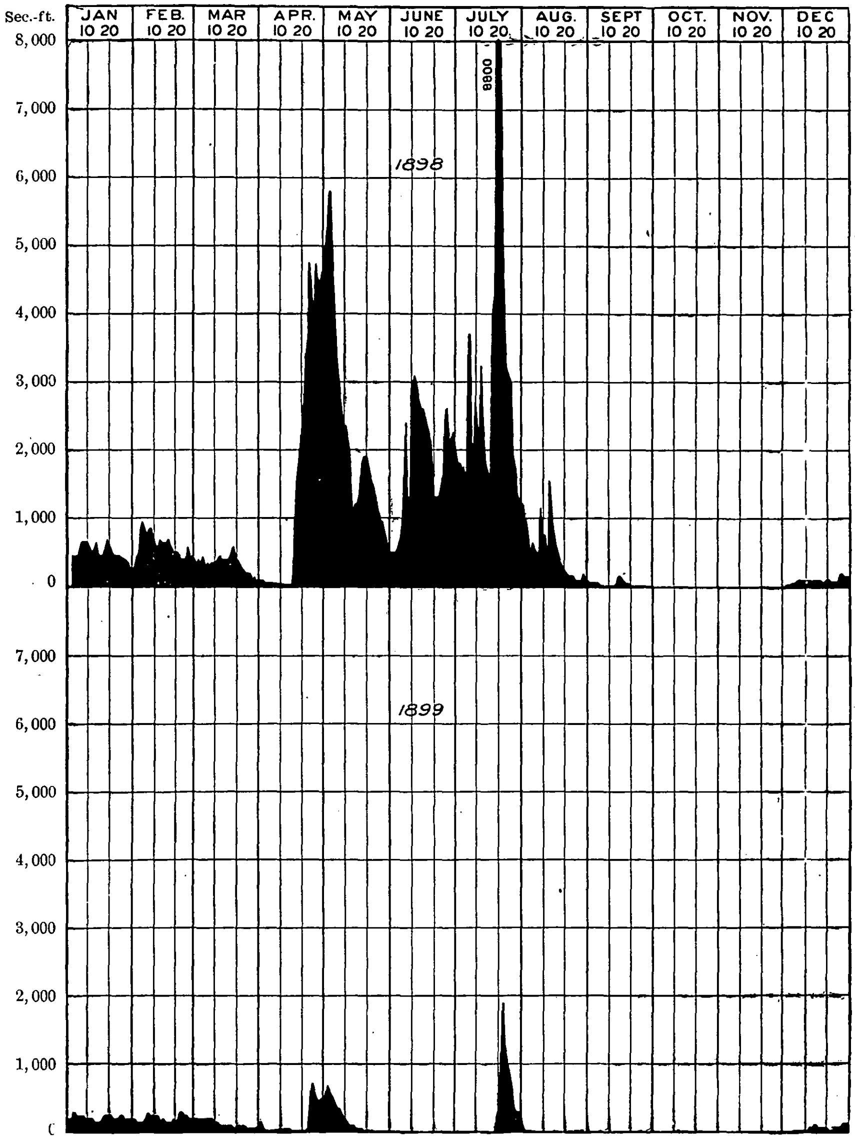


FIG. 158.—Discharge of Rio Grande at El Paso, Texas, 1898 and 1899.

SUBIRRIGATION IN SAN LUIS VALLEY, COLORADO.[1]

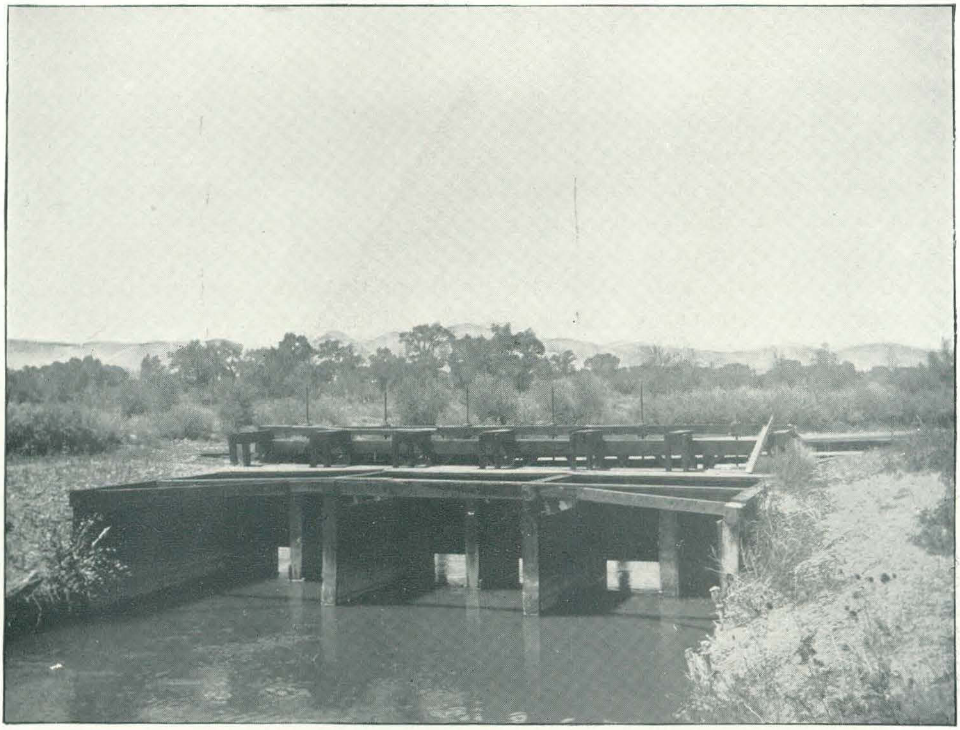
On the headwaters of Rio Grande, in the vicinity of Monte Vista, Colorado, but lying mostly to the north and east of that town, is a large tract of land, very fertile when water is applied to it, which is known as the "subirrigating belt." The cultivatable area in this tract is variously estimated at from 400 to 600 or 800 square miles. It is, to the eye at least, as level as a floor, but in reality it has a fall to the

[1] From report of A. L. Fellows.

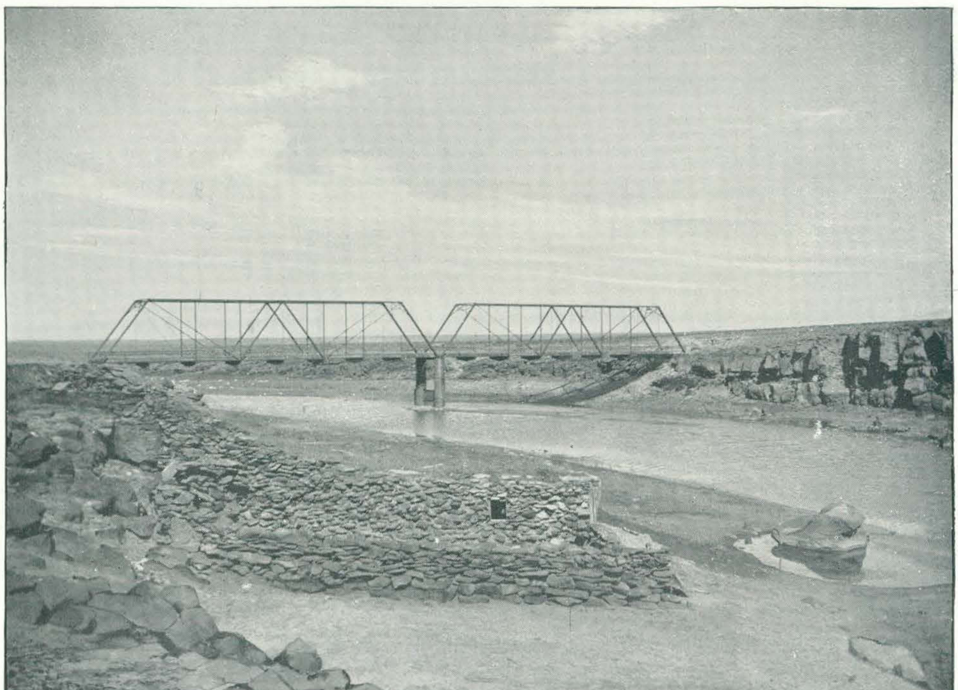
east and northeast of from 2 to 7 or 8 feet to the mile. It is particularly remarkable for the quality which it possesses of freely subirrigating, or permitting the water running along the upper side of each section or quarter section to percolate through the soil in such a way that no personal attention from the farmers is required. Indeed, the farmers have complained that their chief objection to the country is the extreme monotony of the life there; that there is nothing to do during the growing season excepting to watch the crops mature! Consequently, many of them go into the mountains and prospect, or spend the summer picking berries or fishing, or in other recreations.

Irrigation is by means of a lateral running from the main ditch across the upper or more elevated side of each ranch, with possibly three or four laterals running parallel to it through other parts of the land. The water having been turned into these laterals percolates through the soil to such an extent that all parts of the ranch are thoroughly irrigated, and at the same time the ground does not become heavy nor soggy, although the surface is continually kept moist enough to feel damp to the hand and to permit evaporation. A view of the head gate of San Luis canal is shown in Pl. XXI, *A*. The duty of water used in the ditches covering this belt has never been thoroughly ascertained, but it would seem certain that it is much greater than under other methods, such as flooding, or by means of marks (made by a drag or marker), as there is practically little water going to waste. The superintendent of the Rio Grande canal is authority for the statement that the water goes probably two or three times as far as under other methods.

The soil, the nature of which, of course, permits this subirrigation, is a rather sandy loam of fairly even depth. There is, however, a considerable diversity of opinion among those who should be well informed upon the subject as to the nature of the subsoil, some asserting that a hardpan exists at a depth of from a few inches to 7 or 8 feet, and that this hardpan prevents the water from sinking to great depths, but holds it so that it is drawn to the surface by saturation and capillary action. This theory seems to be borne out by the fact that where the soil is deep the subirrigation is slow, while it is more rapid in places where the soil is thin, and, moreover, by the fact that this belt has gradually extended westward into the deeper soil. Another evidence tending to the same conclusion is that the surface of the soil where the loam is thin soon becomes covered with a coating of alkali, which has not yet appeared where the surface loam is thick. The question arises whether this whole tract is not in danger of becoming alkaline, thus destroying it for purposes of crop raising. Some fear that it may, from the fact that the alkali seems to be spreading from the eastern limit of the belt, which is already and probably always has been strongly alkaline, toward the west, where the salts have never been noticed. Others, again, believe that the



A. HEAD GATE OF SAN LUIS CANAL, SAN LUIS VALLEY, COLORADO.



B. STATE BRIDGE ACROSS RIO GRANDE NEAR COLORADO STATE LINE.

salts are carried off through the gravel which lies upon the hardpan. This is a point well worthy of study and careful watching.

There are upon the headwaters of the Rio Grande many fine reservoir sites that could be utilized, and it is unfortunate that, owing to legal complications, these sites are not available. This is the more unfortunate from the fact that during the time that water would be stored in Colorado sufficient water comes in from the side streams to supply the land to the south of that State. It has been stated that if all the water that could possibly be stored in Colorado were actually held there, the shortage in New Mexico and Mexico would be no greater than it is at present. It is to be hoped that the matter will be speedily settled, so that the water may be used to the greatest advantage, which means by storage in Colorado.

There are still vast tracts of land in the San Luis Valley which could be cultivated if there were water for irrigation. Much of the land already under cultivation becomes short of water late in the season, whereas if it were supplied by water stored in reservoirs crops would be assured and the land become so much the more valuable. In 1899, for example, hundreds of thousands of dollars were lost in that section through inability to obtain water for a few days' irrigation. The principal town in San Luis Valley is Alamosa, Colorado, a view of which is shown in Pl. XXII, *B*. Pl. XXII, *A*, shows an artesian well at Alamosa.

RESERVOIR SURVEYS IN NEW MEXICO.

Surveys of reservoir sites at important localities, mainly in northern New Mexico, were made during 1899 by Philip E. Harroun. The following facts have been taken from the unpublished report submitted by Mr. Harroun.

ESPANOLA VALLEY RESERVOIR SITE.

This reservoir site is situated at the lower or southern end of the Espanola Valley of the Rio Grande, and is wholly within the Indian pueblos of San Ildefonso and Santa Clara, New Mexico. The elevation of the site is from 5,470 to 5,550 feet above sea level, and the area covered, at the 5,550-foot contour, is 5,437 acres. Of this acreage there are 494 acres under irrigation and cultivation, divided as follows:

	Acres.
San Ildefonso Indians	223
Santa Clara Indians	37
Mexicans	108
Hobart ranch	126
Total	494

The remainder of the area is waste land, some parts being covered with a scanty growth of low cottonwoods, the rest being sidehill slopes hardly fit for grazing.

The improvements on the site are as follows: The tracks of the

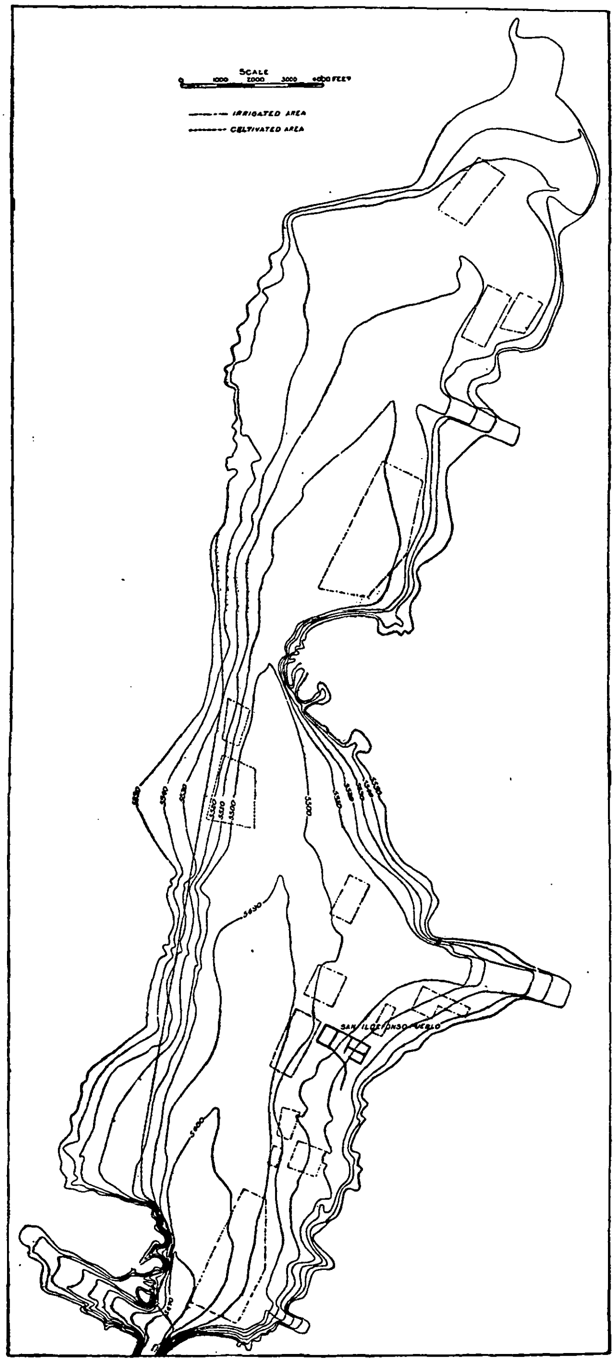
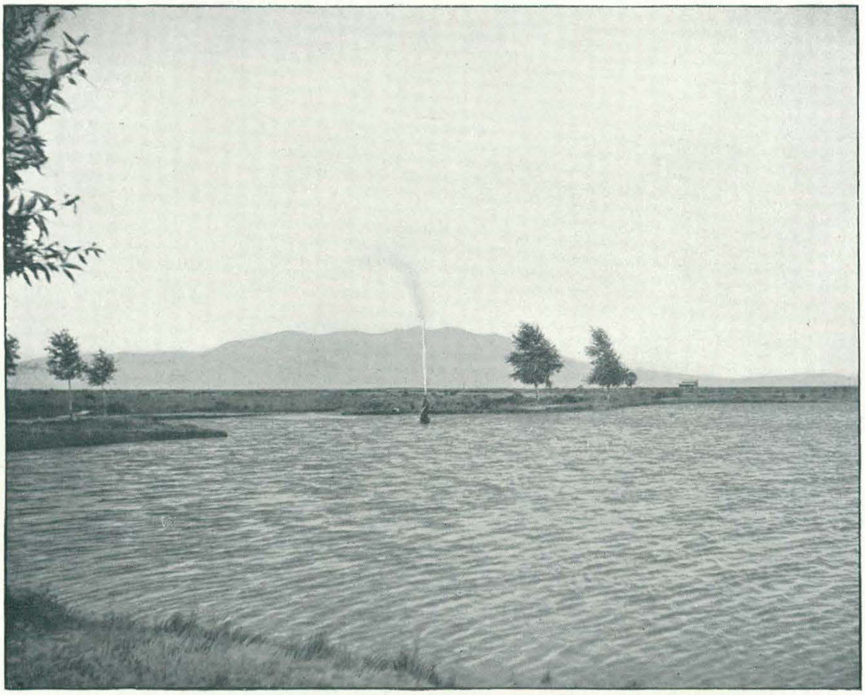


FIG. 159.—Reservoir site in Espanola Valley, New Mexico.



A. ARTESIAN WELL AT ALAMOSA, COLORADO.

B. ALAMOSA, COLORADO.

Denver and Rio Grande Railway (a narrow-gage road), which cross the lower half of the site on the western side of the river; the pueblo of San Ildefonso, which lies between the 5,500-foot and the 5,530-foot contours and would be wholly submerged; a few adobe houses belonging to Mexicans, and two houses on the Hobart ranch.

The dam site is located at the upper end of Whiterock Canyon (fig. 160), a short distance below the bridge of the Denver and Rio Grande Railway. The formation at the site is peculiar, consisting, as it does, of clay beds in which are embedded irregular basaltic blocks ranging in size from 5 cubic feet to 4 cubic yards. The accompanying view (Pl. XX, *A*) shows the formation plainly. It extends an indefinite distance below the river surface, and until a more careful examination

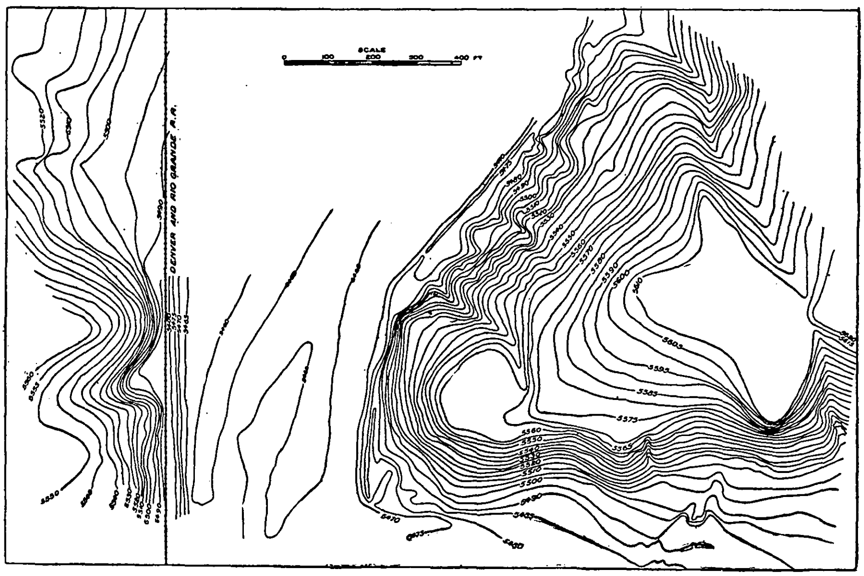


FIG. 160.—Dam site of Espanola Valley reservoir, New Mexico.

of the underlying strata shows to the contrary, may be accepted as that on which any dam must be built.

A spillway can be constructed beyond the west end of the dam, where the two ravines head, as shown in the contour map of the dam site (fig. 160).

The Espanola site is unquestionably a fine one, and is of the utmost importance. It controls the entire situation, so far as the Albuquerque Valley of the Rio Grande is concerned, for at this point must be collected and stored the waters which are to be used for irrigation between Cochiti pueblo and La Joya.

The records of the station at the town of Rio Grande (also called Water Tank) compared with those at Embudo and Del Norte indicate that most of the flow of the Rio Grande passing this point is run-off from the New Mexico drainage, and hence will not be affected by the construction of storage works and other improvements in Colorado, but will remain a permanent quantity and may be relied on as a constant supply for this reservoir.

The disadvantages of the location are the uncertainty as to the foundation on which the dam is to be placed, the fact that the Denver and Rio Grande Railway runs across the site and would have to be changed, and the fact that the pueblo of San Ildefonso would be submerged.

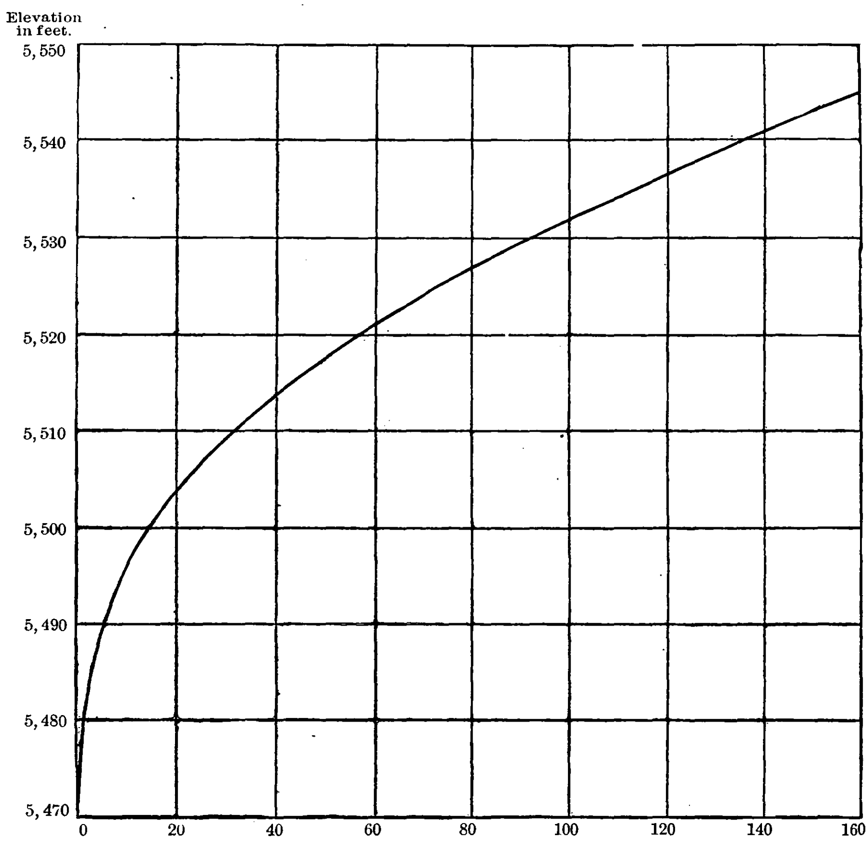


FIG. 161.—Capacity curve of Espanola Valley reservoir, New Mexico, showing capacity in thousand acre-feet, with water surface at various contours.

The first objection could be removed by a thorough investigation—by soundings, to ascertain the character of the substrata. The second objection would necessitate the removal of the tracks of the Denver and Rio Grande Railway outside and above the 5,550-foot contour, and although the time was too short to investigate this matter fully, it is thought that this could be done at a comparatively small expense. The third objection—the submergence of the pueblo—could be properly handled only by the Government.

This reservoir site must ultimately be utilized, in order to accomplish the greatest good for the greatest number, and it seems that in order to do this the Government will have to acquire title to the reservation, moving the Indians to other lands to be granted them in lieu thereof.

Another matter of importance is the fact that the silt problem here is of less consequence than at any other point on the entire river in either New Mexico or Texas. Although the Chama is a rather muddy stream, most of the silt brought down by it is during the violent floods of the rainy season; at other times there is comparatively little.

Area and capacity of Espanola Valley reservoir.

Contour.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
5,470	49.85	....
5,480	173.35	1,116
5,490	627.99	5,123
5,500	1,260.38	14,565
5,510	2,164.55	31,690
5,520	2,974.35	57,385
5,530	4,102.08	92,767
5,540	4,639.83	136,476
5,550	5,437.13	186,861

SANTA FE RESERVOIR SITE.

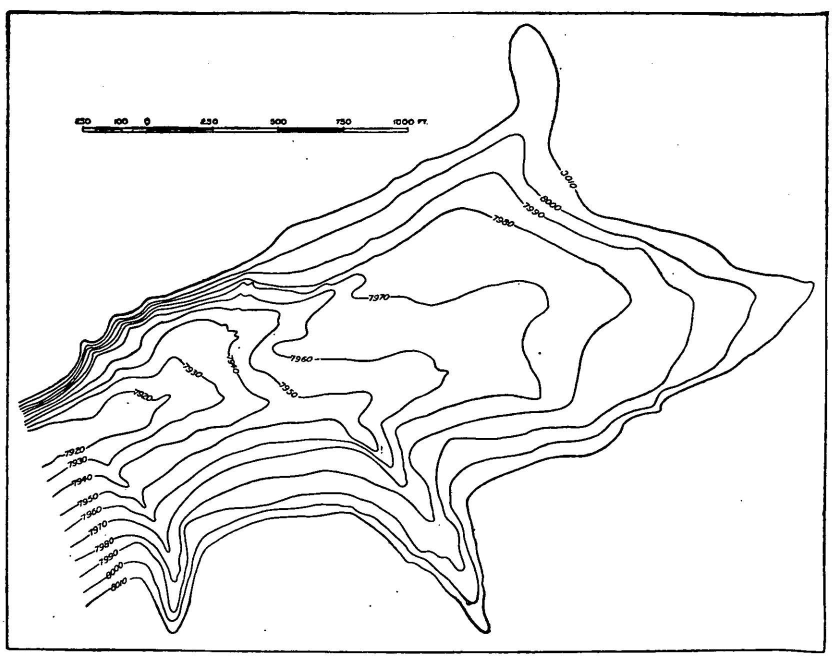


FIG. 162.—Reservoir site on Santa Fe Creek, New Mexico.

This reservoir site is on Santa Fe Creek, about 8 miles east of the city of Santa Fe. Its elevation is from 7,920 to 8,010 feet above sea level, its area, on the 8,010-contour, 68 acres, of which about 15 acres are spasmodically cultivated by a Mexican family. There are no other improvements on the site.

As will be seen from an inspection of the topographic map, fig. 162, the slope of the valley is great, rising 1 foot in 30 feet from the dam

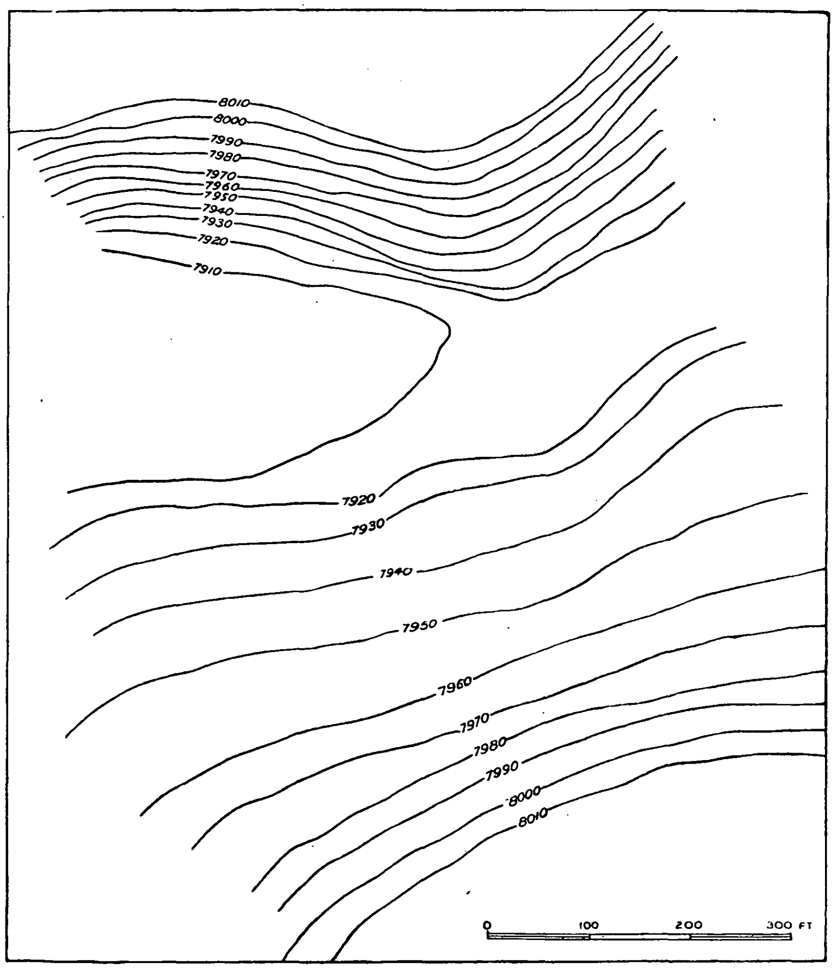
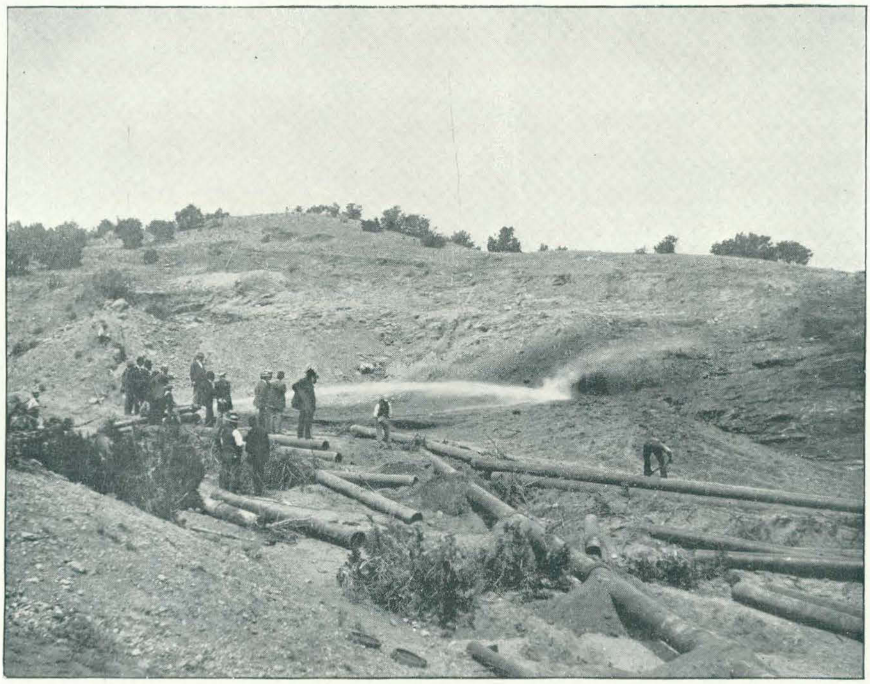


FIG. 163.—Dam site on Santa Fe Creek, New Mexico.

site up, and affording an exceedingly small impounding capacity for any given height of dam. The proposed location of the dam is at the narrowest part of the canyon, where bed rock (porphyry) is exposed on each side.

The Santa Fe site, viewed from the standpoint of the capitalist, is without recommendation, in that its construction would involve the



A. DAM BUILDING, HYDRAULIC PROCESS, AT SANTA FE, NEW MEXICO, SHOWING "HYDRAULIC GIANT" IN USE.

B. DAM BUILDING, HYDRAULIC PROCESS, AT SANTA FE, NEW MEXICO, SHOWING OUTLET PIPE.

expenditure of a sum of money far in excess of that which would be justified by any possible financial return. There are, however, 10,000 people dependent for their daily bread on the waters of this stream, and to-day they are indigently poor, not because there is insufficient water to supply their needs, but because this water is not stored and

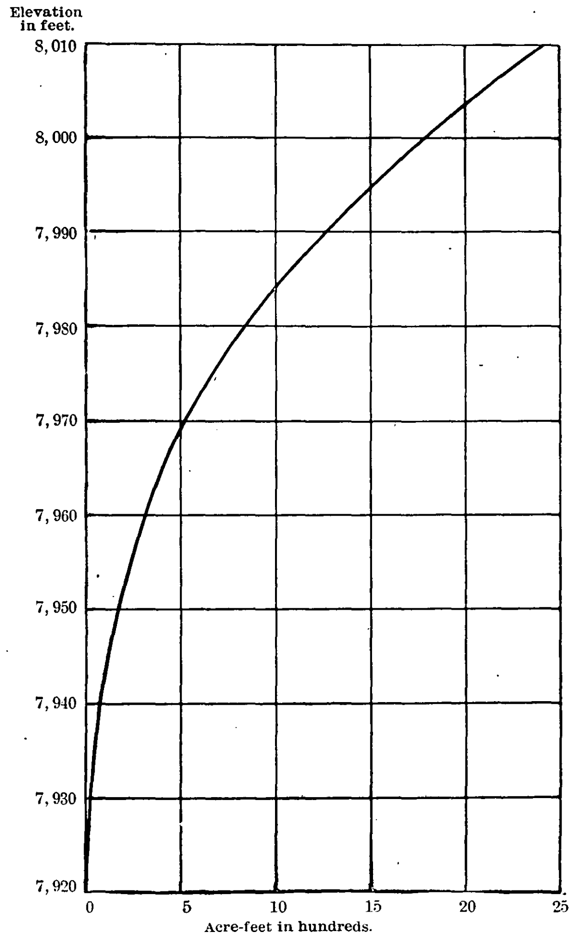


FIG. 164.—Capacity curve of Santa Fe reservoir, New Mexico, showing capacity in hundred acre-feet, with water surface at various contours.

applied to the land when it is most needed. The worst of it is that without governmental aid they can hope for no relief, for capitalists will not undertake the construction of the reservoir. There would not be commensurate return for them, but the Government would reap a large indirect return in increased tax receipts and in trade from a prosperous community.

Area and capacity of Santa Fe reservoir.

Contour.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
7,920	1.45	....
7,930	3.57	25
7,940	6.43	75
7,950	11.16	163
7,960	16.99	304
7,970	26.32	520
7,980	37.45	839
7,990	48.63	1,269
8,000	56.25	1,793
8,010	68.02	2,414

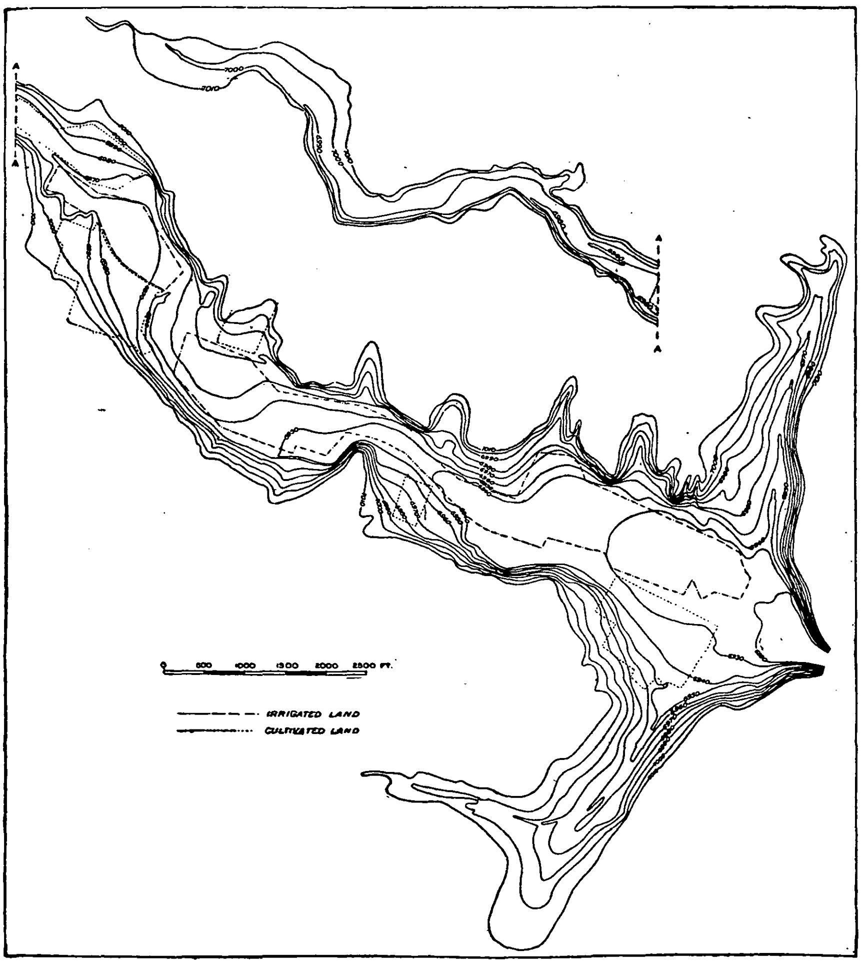


FIG. 165.—Reservoir site near Lacueva, New Mexico.

LACUEVA RESERVOIR SITE.

This reservoir site is situated in a narrow gap on Mora River, about one-eighth of a mile above Lacueva, New Mexico. Its elevation is from 6,920 feet to 7,010 feet above sea level. It covers 764 acres at the 7,010-foot contour. Of this area 134 acres are irrigated, 83 acres are cultivated without irrigation, depending wholly upon rains, and the remainder, 547 acres, is waste and grazing land.

The improvements on the site consist of the irrigated and cultivated lands mentioned and thirteen adobe houses belonging to Mexicans.

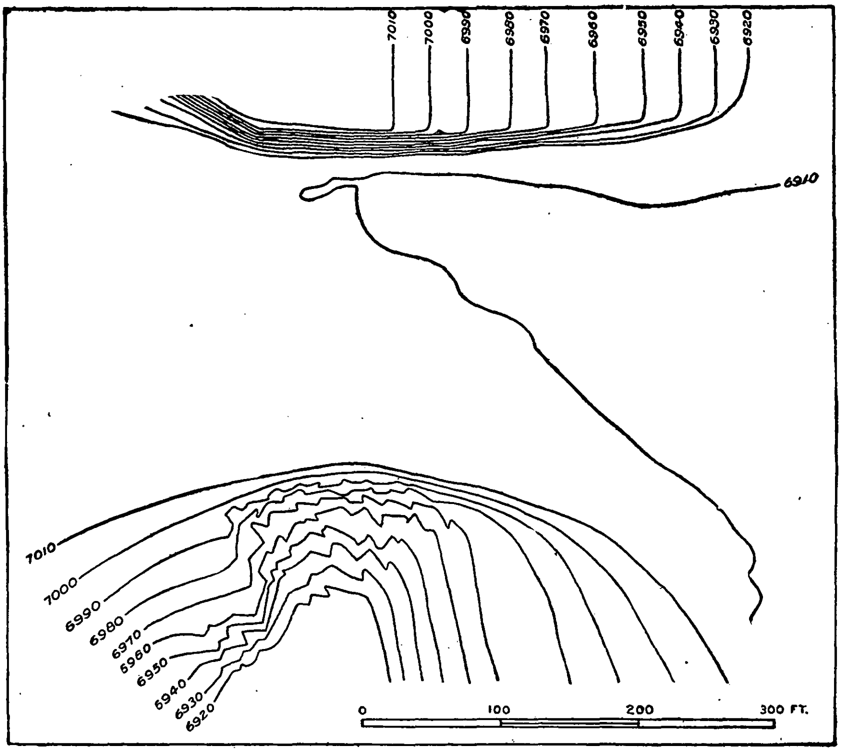


FIG. 166.—Dam site near Lacueva, New Mexico.

The dam site is at a narrow gap, where porphyritic ledges are entirely exposed on either side. No soundings for bed rock in the bottom could be had, but it is very probable that bed rock is but a short distance below the surface.

This site is a good one in every sense of the word, but that section of the country is not at this time particularly in need of the reservoir, for the inhabitants do not suffer from scarcity of water. The site is on the Mora grant, and all the lands are private property, so that when the need of the reservoir is felt there is no question that private capitalists will come forward and furnish the money necessary for its construction.

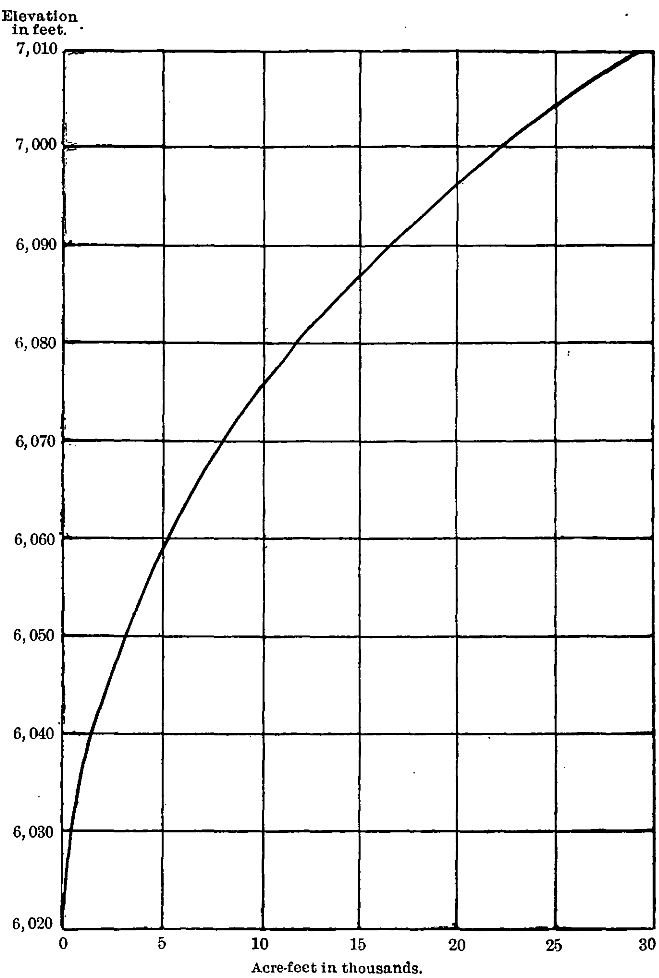


FIG. 167.—Capacity curve of Lacueva reservoir, New Mexico, showing capacity in thousand acre-feet, with water surface at various contours.

Area and capacity of Lacueva reservoir.

Contour.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
6,920	11.91	....
6,930	62.22	371
6,940	140.11	1,383
6,950	186.03	3,014
6,960	237.98	5,134
6,970	314.21	7,895
6,980	428.89	11,610
6,990	524.66	16,378
7,000	629.05	22,146
7,010	764.28	29,113

SAN FELIPE RESERVOIR SITE.

This reservoir site is situated on the Rio Grande, about a half mile above the pueblo of San Felipe, New Mexico. The elevation of the site is from 5,130 feet to 5,170 feet above sea level. It covers 1,511 acres at the 5,170-foot contour. Of this area but 200 acres are under ditch and in cultivation, the balance being a valueless sandy waste. The entire site is on the San Felipe Indian Reservation.

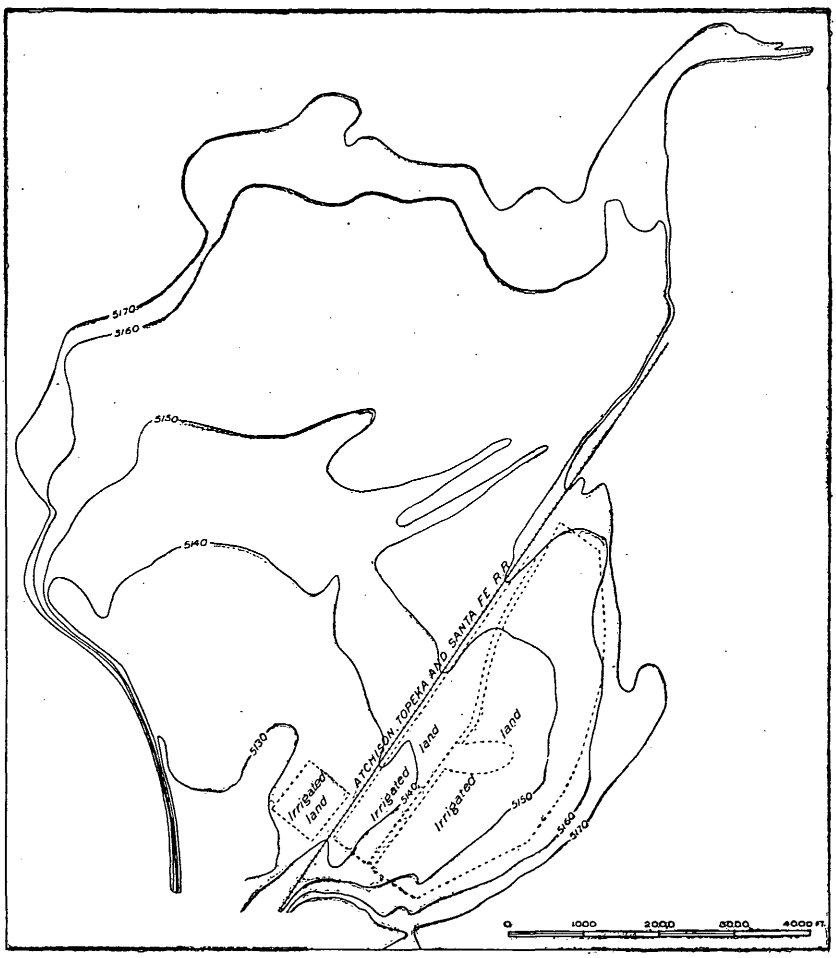


FIG. 168.—Reservoir site near San Felipe, New Mexico.

The improvements on the site consist of the cultivated lands mentioned and the tracks of the Atchison, Topeka and Santa Fe Railway on the east side of the river, as shown on the map, fig. 168.

The dam site has little to recommend it. It is over 1,600 feet long to the west of the butte, with about 750 feet in addition required to the east, where the spillway should be placed. The formation here is similar to that at the Espanola site, but there is a less proportion of rock with the clay, and in places there is a tendency to quicksand. The formation is much less stable than that at the Espanola site.

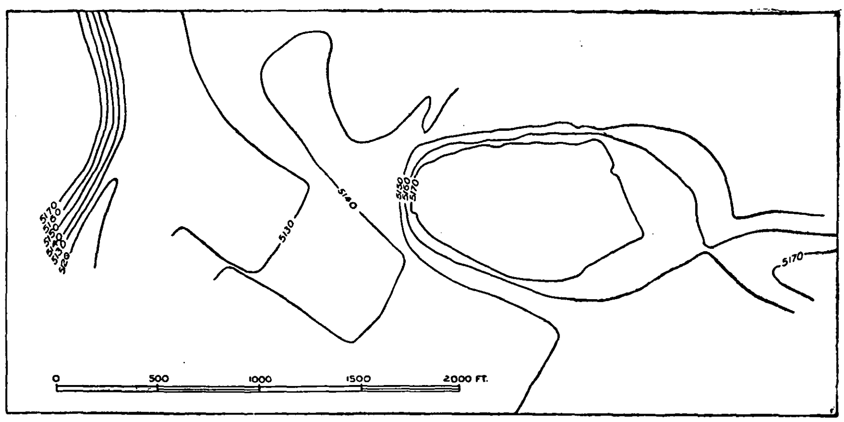


FIG. 169.—Dam site near San Felipe, New Mexico.

This site is a part of the Rio Grande reservoir problem. It is probable that the Espanola reservoir could be constructed so as to take care of all the surplus water at this point, leaving the San Felipe reservoir to serve as an auxiliary in the storage of the excessive flood waters and the run-off from the drainage below Whiterock Canyon and above San Felipe, notably the surplus waters from Santa Fe Creek and the Galisteo.

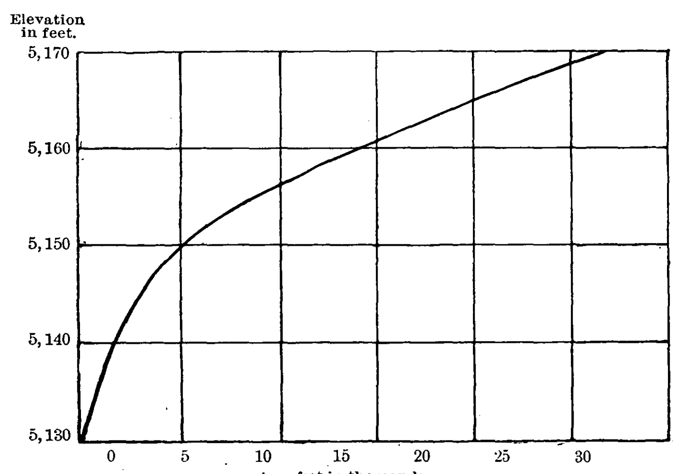
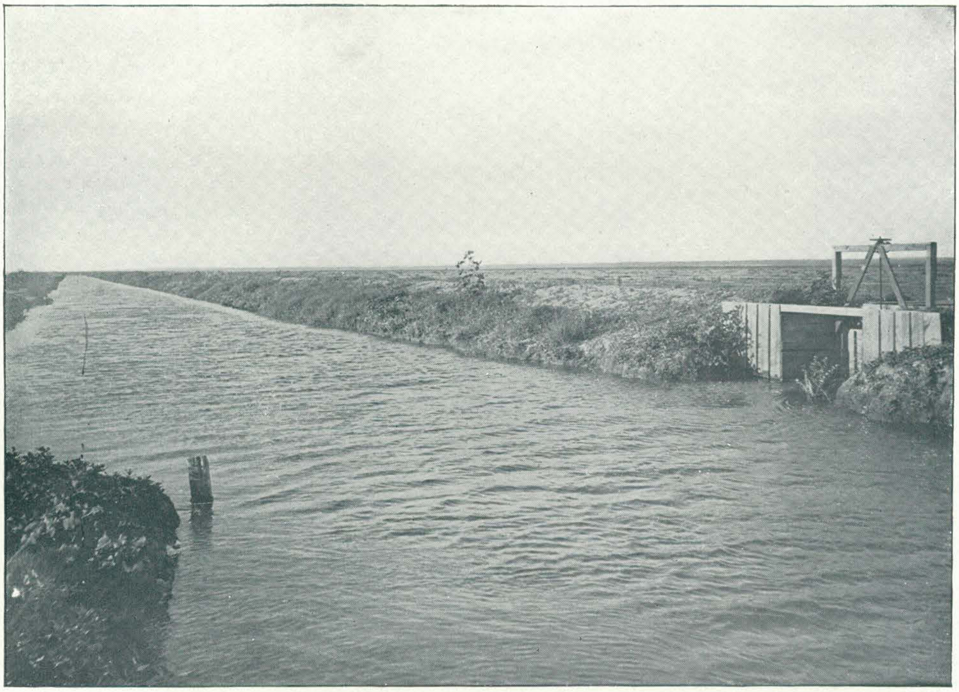
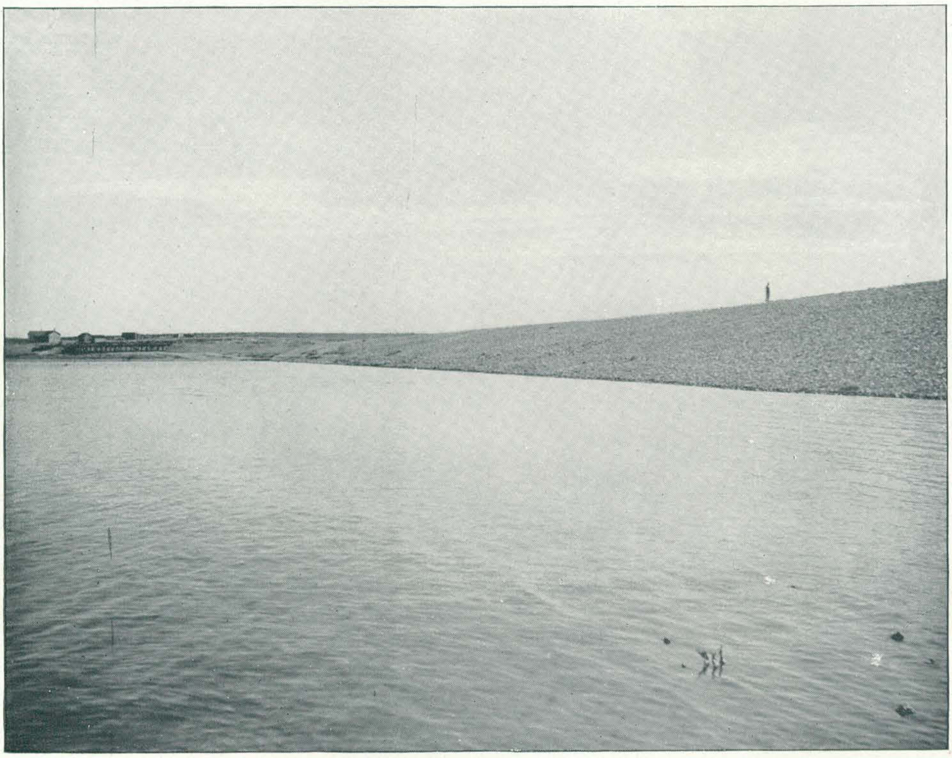


FIG. 170.—Capacity curve of reservoir near San Felipe, New Mexico, showing capacity in thousand acre-feet with water surface at various contours.



A. MAIN CANAL AND HEAD GATE NEAR HAGERMAN, NEW MEXICO.



B. SEVENRIVERS DAM, PECOS VALLEY, NEW MEXICO, LOOKING EAST.

Area and capacity of San Felipe reservoir.

Contour.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
5,130	47.50	....
5,140	275.48	1,615
5,150	606.29	6,024
5,160	1,013.33	14,122
5,170	1,510.79	26,743

RIO PECOS.

This river rises on the eastern slope of the Santa Fe Range in northern New Mexico. Its course is southerly through a typical mountainous and canyon country until it reaches Fort Sumner, when the character of the topography changes. The river then takes a more southerly course, and the country changes from a rolling to an almost flat area. A number of extensive irrigation enterprises have been completed within the last few years, a large area in the vicinity of Roswell and Eddy, New Mexico, also in Texas, being now irrigated. The summer flow of the river is largely dependent upon numerous springs which occur in the limestone in the vicinity of Roswell and below. Owing to the many diversions for irrigating purposes, the river would be dry in the summer where it crosses into Texas were it not for the water which is gradually returned to it through seepage. This water is, however, unfortunately impregnated to a considerable extent with alkali, which renders it undesirable for irrigating purposes. The river enters the Rio Grande near latitude 29° 40′ north and longitude 101° 20′ west. It is about 800 miles long. The gaging station is at Pecos, Texas. It was established January 1, 1898. Pl. XXIV, *A*, is a view of the main canal and head gate on Rio Pecos, near Hagerman, New Mexico. Pl. XXIV, *B*, is a view of Sevenrivers dam, Pecos Valley, New Mexico, looking east.

COLORADO RIVER DRAINAGE.

COLORADO RIVER.

The great Colorado River of the West is formed by the junction of the Grand and the Green, which drain portions of Wyoming, Colorado, and Utah. It passes through canyons of immense depth and grandeur, finally emerging into the desert regions of southern Arizona and California, through which it flows into the Gulf of California. Its drainage basin consists for the most part of elevated plateaus, in which the river and its principal tributaries have cut narrow gorges of extraordinary depth. Water can not be diverted or even pumped for irrigation upon these high lands, so that, except possibly for water power, the main stream has little economic importance. The upper tributaries, however, before they reach their canyons, can be diverted to serve adjacent lands, and considerable progress toward their utilization has already been made. The principal tributaries below the junction of the Grand and Green are the San Juan, coming from the west and draining southern Colorado and northern New Mexico, and the Gila, flowing through southern Arizona.

Colorado River is navigable for light-draft steamers from Yuma to The Needles, and to even higher points in times of flood. In its lower course its waters have little other economic importance, as already stated, although it is possible that at some future time a portion may be diverted for the irrigation of lands in the Salton Desert, west of Yuma.

GUNNISON RIVER.

This river, the principal tributary of the Grand, rises on the western slope of the Continental Divide, in south-central Colorado, and flows in a general westerly direction into Grand River at Grand Junction, Colorado. Its principal tributary is Uncompahgre River, which enters it at Delta, Colorado. There is a gaging station on the Uncompahgre at Fort Crawford, Colorado, established June 25, 1895, and one on Grand River at Grand Junction, Colorado, established in May, 1897. The measurements at both stations are made by A. L. Fellows. Pl. XXV, *A*, is a view of Black Canyon of Gunnison River, Colorado. Pl. XXV, *B*, a view at Grand Junction, Colorado, looking down the left channel of Grand River.

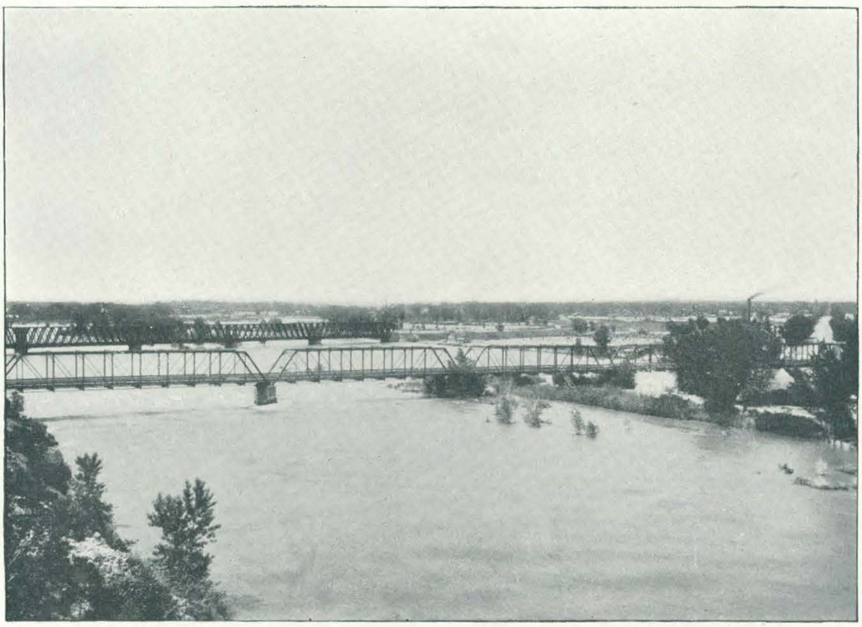
Estimated monthly discharge of Gunnison River at Grand Junction, Colorado.

[Drainage area, 7,935 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	8,792	968	3,550	211,240	0.45	0.50
May	16,750	3,902	10,296	633,080	1.30	1.50
June	16,752	8,078	12,380	736,662	1.56	1.74
July	8,430	2,246	4,349	267,410	0.55	0.63
August	4,562	908	1,921	118,118	0.24	0.28
September	1,000	758	875	52,066	0.11	0.12

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 298; rating table in Paper No. 39, page 451.

A. BLACK CANYON OF GUNNISON RIVER, COLORADO.



B. LOOKING DOWN LEFT CHANNEL OF GRAND RIVER AT GRAND JUNCTION, COLORADO.

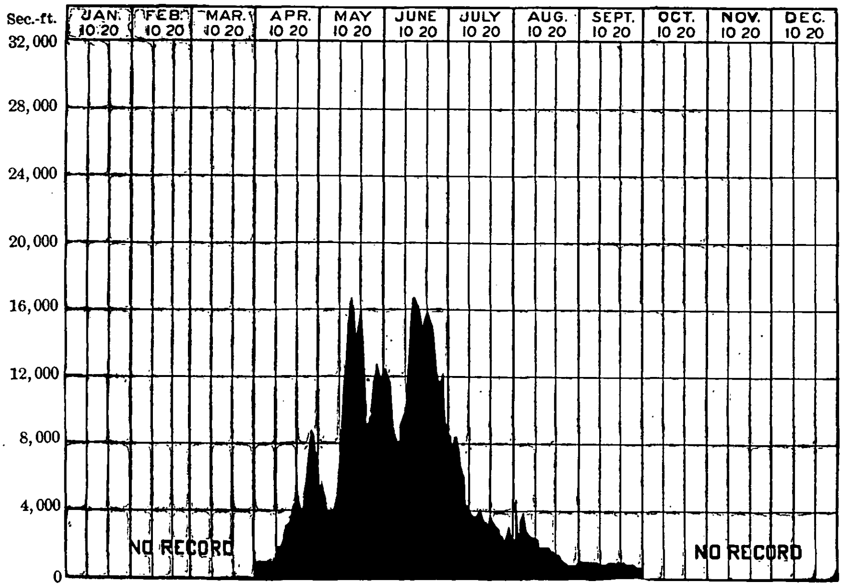


FIG. 171.—Discharge of Gunnison River at Grand Junction, Colorado, 1899.

Estimated monthly discharge of Uncompahgre River at Fort Crawford, Colorado.

[Drainage area, 497 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	481	102	265	15,769	0.53	1.59
May	915	240	534	32,834	1.07	1.23
June	1,163	259	709	42,188	1.43	1.60
July	450	150	252	15,495	0.51	0.59
August	512	19	138	8,485	0.28	0.32
September	137	4	41	2,440	0.08	0.09

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 297; rating table in Paper No. 39, page 451.

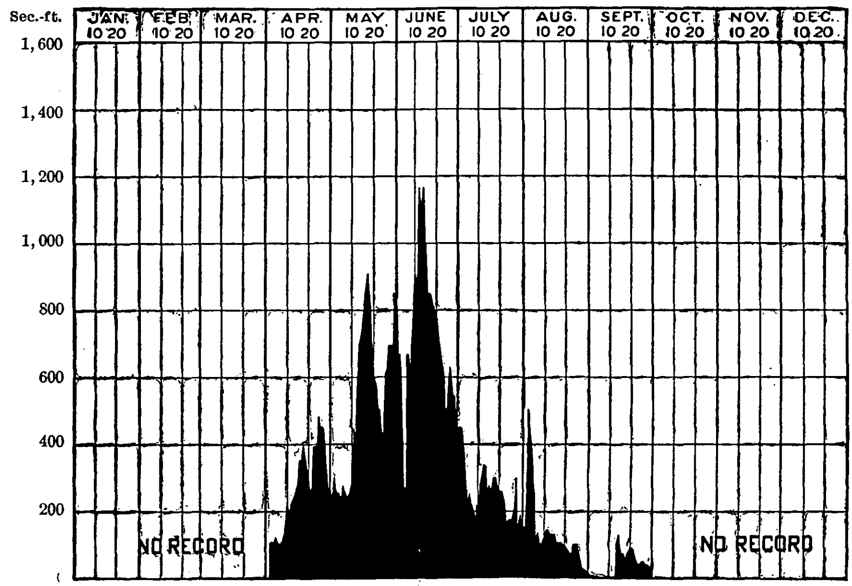


FIG. 172.—Discharge of Uncompahgre River at Fort Crawford, Colorado, 1899.

GRAND RIVER.

This river has its source on the western slope of the Continental Divide in north-central Colorado, near the headwaters of North Platte, South Platte, and Arkansas rivers. It flows in a general southwesterly direction, passing out of the State of Utah into Wyoming. Sixty miles below the crossing of the Rio Grande Western Railway in Utah, Green River joins Grand River, to form the Colorado. Its principal tributaries are Gunnison and Dolores rivers. Two stations are maintained on Grand River, one at Glenwood Springs, established May 12, 1899, and the other at Grand Junction, Colorado, established October 18, 1894. Measurements at both stations are made by A. L. Fellows.

Estimated monthly discharge of Grand River at Grand Junction, Colorado.

[Drainage area, 8,644 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March			1,799	110,616	0.21	0.24
April			3,940	234,446	0.46	0.52
May			19,375	1,191,322	2.24	2.59
June			31,306	1,862,836	3.62	3.99
July			14,070	865,130	1.63	1.88
August			4,577	281,429	0.53	0.61
September			2,164	128,886	0.25	0.28

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 295; rating tables in Paper No. 39, page 451.

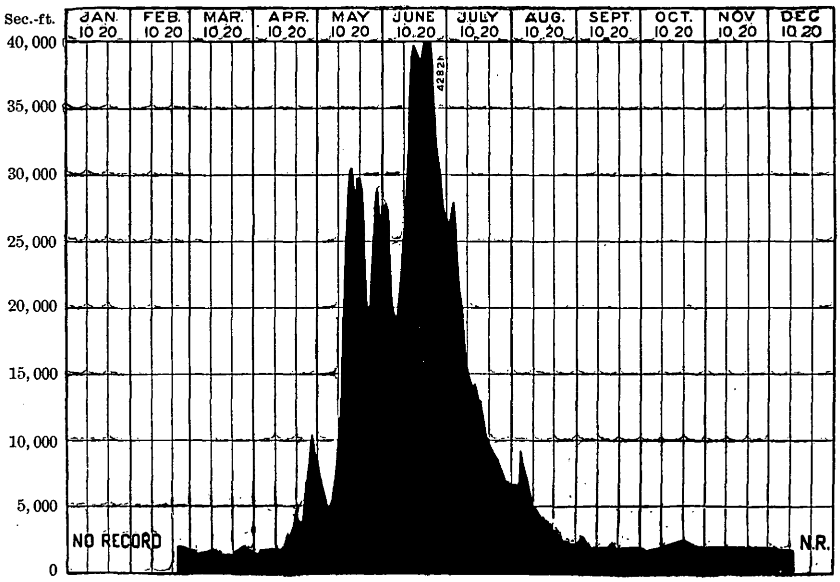


FIG. 173.—Discharge of Grand River at Grand Junction, Colorado, 1899.

DOLORES RIVER.

This river, one of the principal tributaries of the Grand, has its source in the La Plata and San Miguel mountains, in which the highest peak, Mount Wilson, attains an elevation of 14,280 feet. It flows in a general northwesterly direction, and joins Grand River soon after entering Utah. In the vicinity of Dolores, Colorado, where the gaging station is located, considerable irrigation is practiced, both from small ditches and from one or two large systems. San Miguel River enters Dolores River in the western part of Montrose County, Colorado. There is a station on the San Miguel at Fallcreek, Colorado, established in June, 1895. Measurements at both stations are made by A. L. Fellows.

Estimated monthly discharge of Dolores River at Dolores, Colorado.

[Drainage area, 524 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 22 to 31	....	....	37	2,275	0.07	0.08
April	885	37	437	26,003	0.83	0.92
May	1,461	118	785	48,268	1.50	1.73
June	810	220	499	29,693	0.95	1.05
July	412	100	207	12,728	0.40	0.46
August	736	30	204	12,543	0.39	0.45
September	82	23	33	1,964	0.06	0.07
October	343	23	93	5,718	0.18	0.21
November	82	37	49	2,916	0.09	0.10
December	220	30	151	9,285	0.29	0.33

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 306; discharge measurements, page 305; rating table in Paper No. 39, page 451.

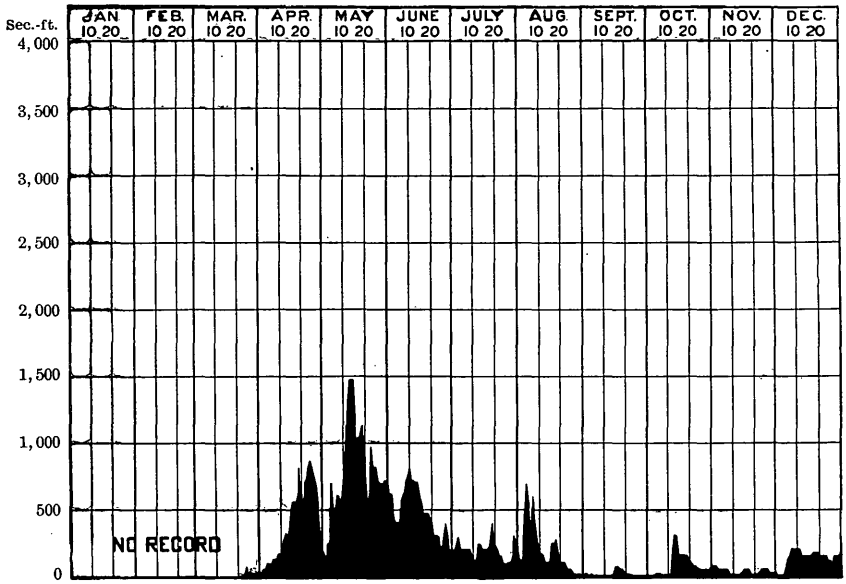


FIG. 174.—Discharge of Dolores River at Dolores, Colorado, 1899.

Estimated monthly discharge of San Miguel River at Fallcreek, Colorado.

[Drainage area, 327 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	299	25	134	7,974	0.41	0.46
May	934	126	414	25,456	1.27	1.46
June	995	249	538	32,013	1.65	1.84
July	387	176	238	14,634	0.73	0.84
August	387	105	195	11,990	0.60	0.69
September	138	64	101	6,002	0.31	0.35

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 307; discharge measurements, page 306; rating table in Paper No. 39, page 451.

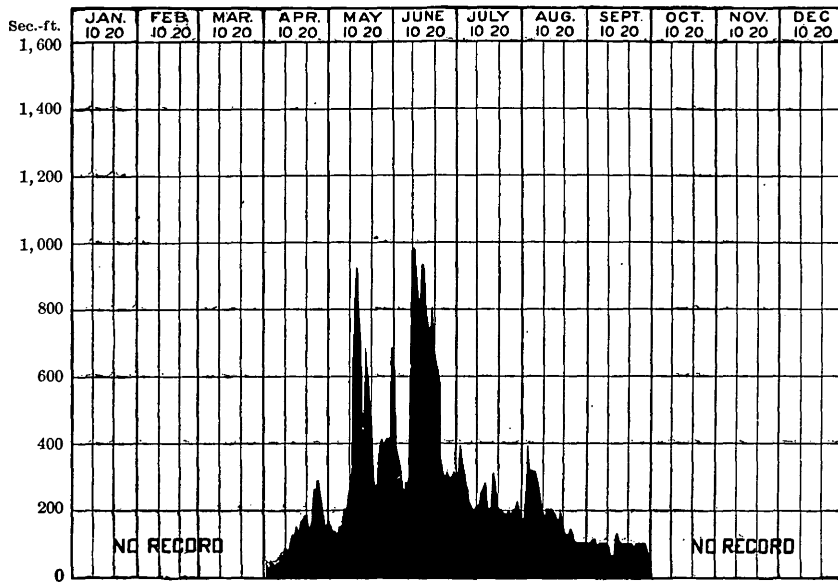


FIG. 175.—Discharge of San Miguel River at Fallcreek, Colorado, 1899.

MANCOS RIVER.

This river is an important tributary of the San Juan, draining the southwestern corner of Colorado. The lower portion of its course is through the Southern Ute Indian Reservation. It enters San Juan River near the adjoining corners of Utah, Colorado, New Mexico, and Arizona. The primary object in establishing a station on this river was to obtain data relative to the amount of water that can be stored for the water supply of the Southern Ute Indian Reservation. The results of this investigation, made by Mr. G. H. Matthes, may be found in the Twentieth Annual Report, Part IV, pages 408 to 434. The station, established April 9, 1898, is at Mancos, Colorado. Measurements are made by A. L. Fellows.

Estimated monthly discharge of Mancos River at Mancos, Colorado.

[Drainage area, 117 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January *a*						
February *a*						
March *b*			50	3,074	0.43	0.49
April	375	123	261	15,531	2.23	2.49
May	270	144	206	12,667	1.76	2.03
June	291	144	213	12,674	1.82	2.03
July	333	2	104	6,395	0.89	1.02
August	12	8	9	553	0.08	0.09
September	12	3	7	399	0.06	0.07
October *b*			5	307	0.04	0.04
November *b*			3	179	0.03	0.03
December *a*						
The year				51,779	0.82	8.29
1899.						
January *a*						
February *a*						
March *b*			90	5,534	0.77	0.89
April	91	5	42	2,499	0.36	0.40
May	144	19	74	4,550	0.63	0.72
June	81	5	33	1,964	0.28	0.31
July	19	3	9	533	0.08	0.09
August	102	8	41	2,521	0.35	0.40
September	123	5	33	1,964	0.28	0.31
October	60	1	22	1,353	0.19	0.22
November *b*			5	298	0.04	0.04
December *a*						
The year				19,268	0.30	3.07

a Frozen. *b* Approximate; no observations were made during these periods.

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 137; discharge measurements, page 142; rating table, page 144. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 38, page 312; rating table in Paper No. 39, page 452.

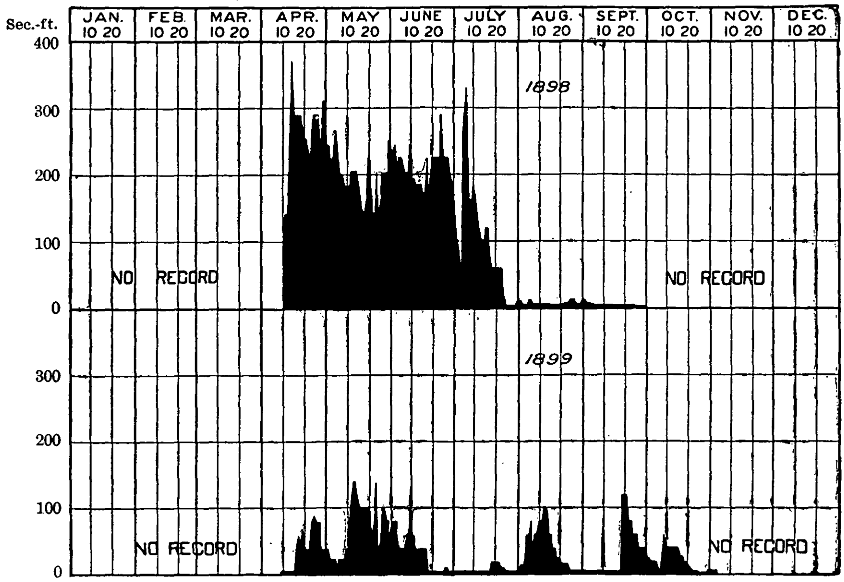


FIG. 176.—Discharge of Mancos River at Mancos, Colorado, 1898 and 1899.

RESERVOIR SITES IN MANCOS CANYON.

During the fall of 1899 an examination of Mancos River, particularly of that portion in the canyon south of Mesa Verde, was made by Mr. Gerard H. Matthes, the work being a continuation of the examination of the water supply available for use upon the Southern Ute Indian Reservation, as described on pages 408 to 434 of the Twentieth Annual Report, Part IV. A plane-table traverse, on a scale of 1 mile to 1 inch, was extended from the upper portion of Mancos Canyon, shown in fig. 177, to its mouth, a distance of 25 miles. Short lines were also extended up the principal side canyons, and the topography was sketched in 100-foot contours.

During the course of this reconnaissance five reservoir sites were selected (figs. 178, 180, 182, 184, and 186) and surveys of them made, on a scale of 1,000 feet to 1 inch, with 10-foot contours. The locations of the proposed dams are indicated on the map of the canyon, fig. 177, and are as follows, taking them in order downstream:

Site No. 1, fig. 179, main canyon at a point 1 mile above the junction of Cliff and Mancos canyons.

Site No. 2, fig. 181, main canyon about a half mile below the junction of Johnson and Mancos canyons.

Site No. 3, fig. 183, main canyon just below the mouth of Grass Canyon.

Site No. 4, fig. 185, main canyon a short distance above the old ruin known as Mosses Tower and about 5 miles above the lower end of the canyon.

Site No. 5, fig. 187, Navajo Canyon just below the junction of its two main tributaries, some 4 miles above its mouth.

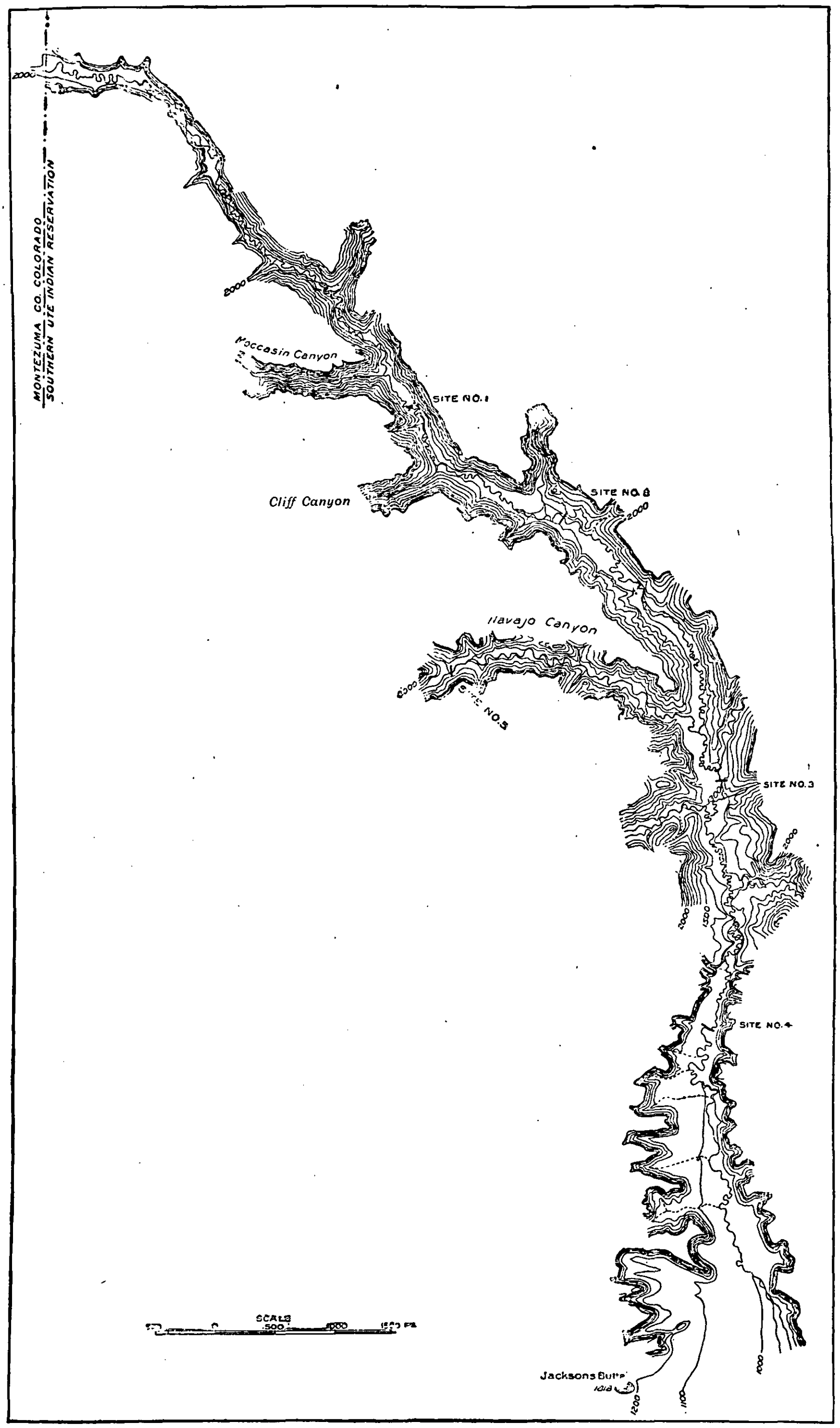


Fig. 177.—Map of Mancos Canyon, Colorado.

Pl. XXVI, *A*, is a view of Mosses Tower and ruins in Mancos Canyon. Pl. XXVI, *B*, shows the Twin Towers, Ruin Canyon.

During the progress of this field work Mr. A. L. Fellows, resident

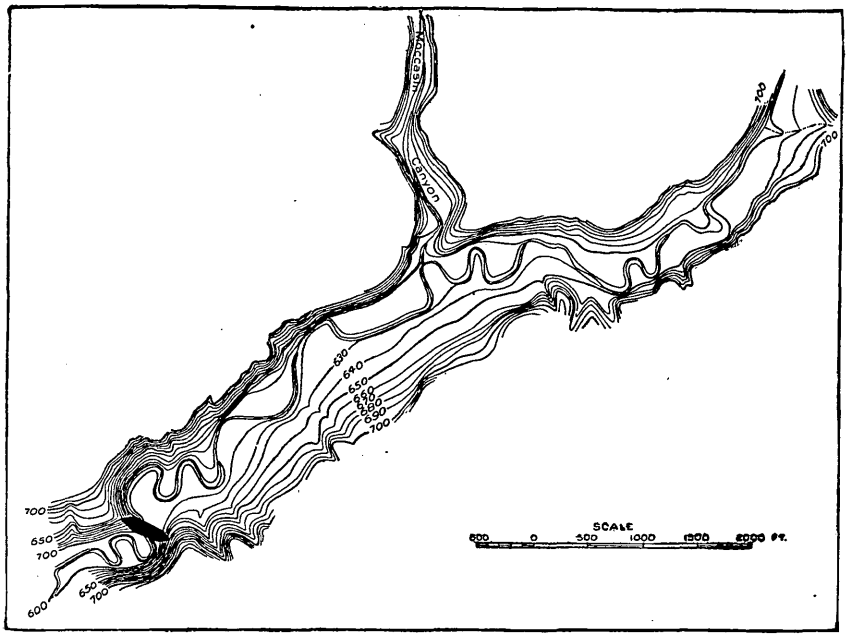


FIG. 178.—Reservoir site No. 1, Mancos Canyon, Colorado.

hydrographer for Colorado, visited many of these localities with Mr. Matthes and examined the proposed reservoir sites. The field operations were brought to a close on October 30, and a detailed report prepared by Mr. Matthes from which the following statements have been taken:

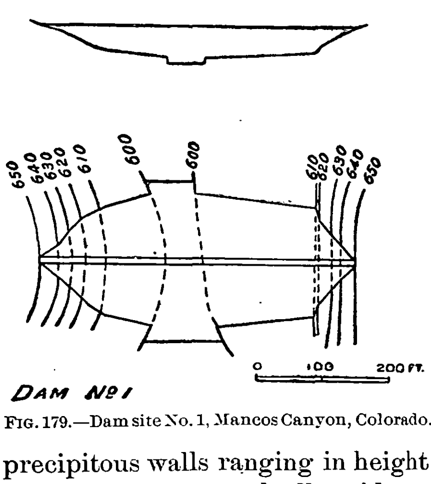


FIG. 179.—Dam site No. 1, Mancos Canyon, Colorado.

Mancos River has its source on the west slope of the LaPlata Mountains, and flows in a southwesterly direction to a point a few miles below the town of Mancos, where it changes its course toward the south and enters a canyon in the high table-land known as Mesa Verde. The total length of this canyon is about 30 miles. Through it the river is encased between precipitous walls ranging in height from 800 to 1,000 feet. Narrow at first, the canyon gradually widens until in its lower portion its width in some places exceeds 1 mile. The formations in which the canyon

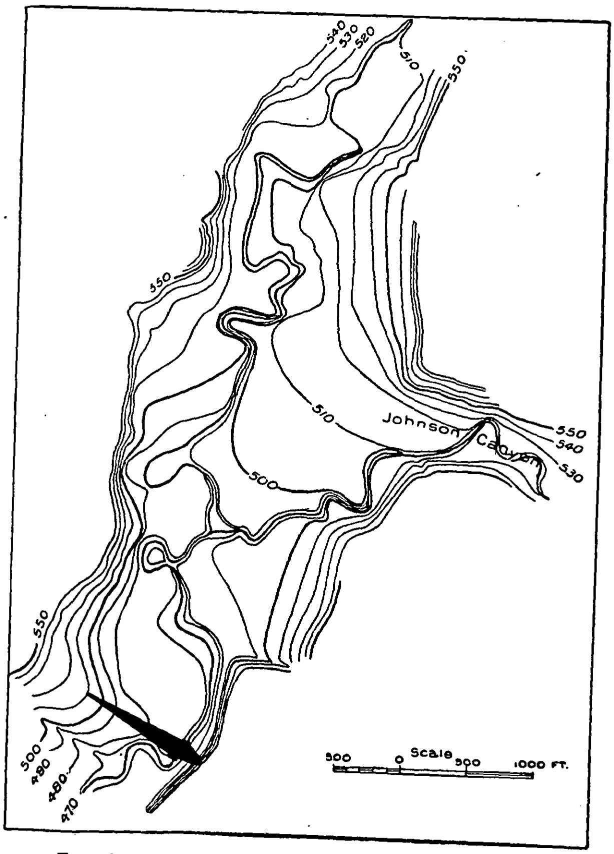


FIG. 180.—Reservoir site No. 2, Mancos Canyon, Colorado.

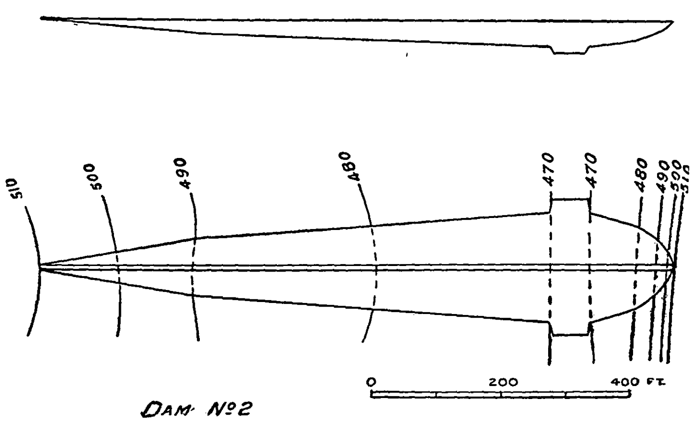


FIG. 181.—Dam site No. 2, Mancos Canyon, Colorado.

and its numerous side canyons are carved are Dakota sandstone and underlying shales, the strata having an apparently uniform south-easterly dip.

Mancos Canyon, though having a total fall of about 1,000 feet from the reservation line down to where it emerges from the mesa, does not

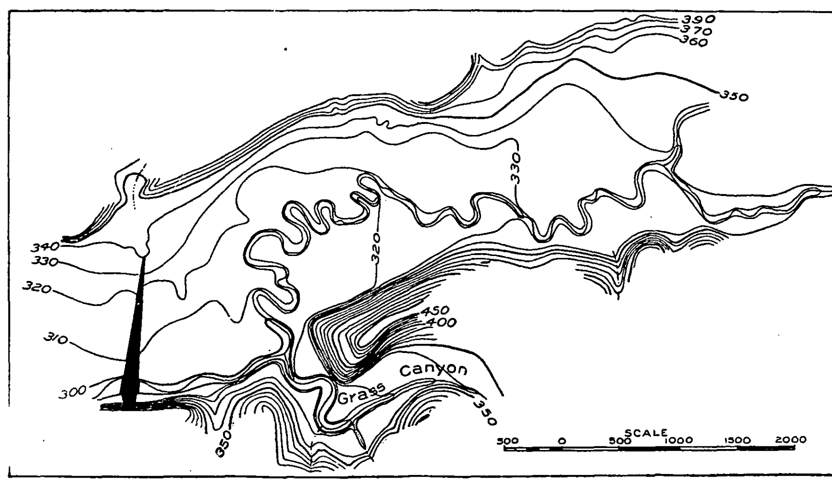


FIG. 182.—Reservoir site No. 3, Mancos Canyon, Colorado.

increase in depth in this distance of 25 miles, owing to the slope of the mesa. Entering the canyon with a southerly course, the river gradually turns toward the southwest, and finally emerges from Mesa Verde flowing in a westerly direction. Thence, to its junction with San Juan River, it flows through the open, slightly undulating country

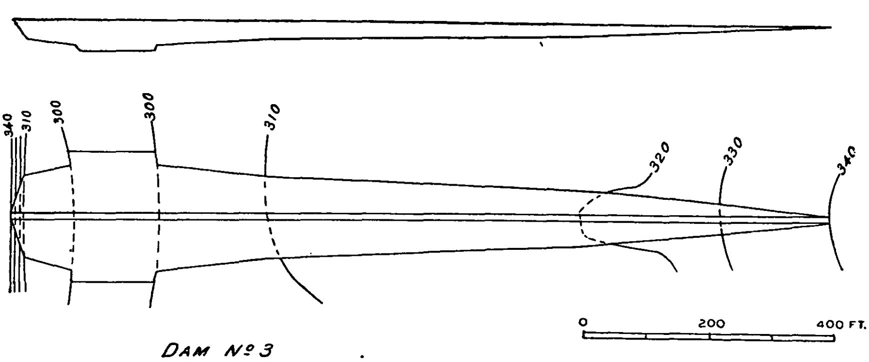
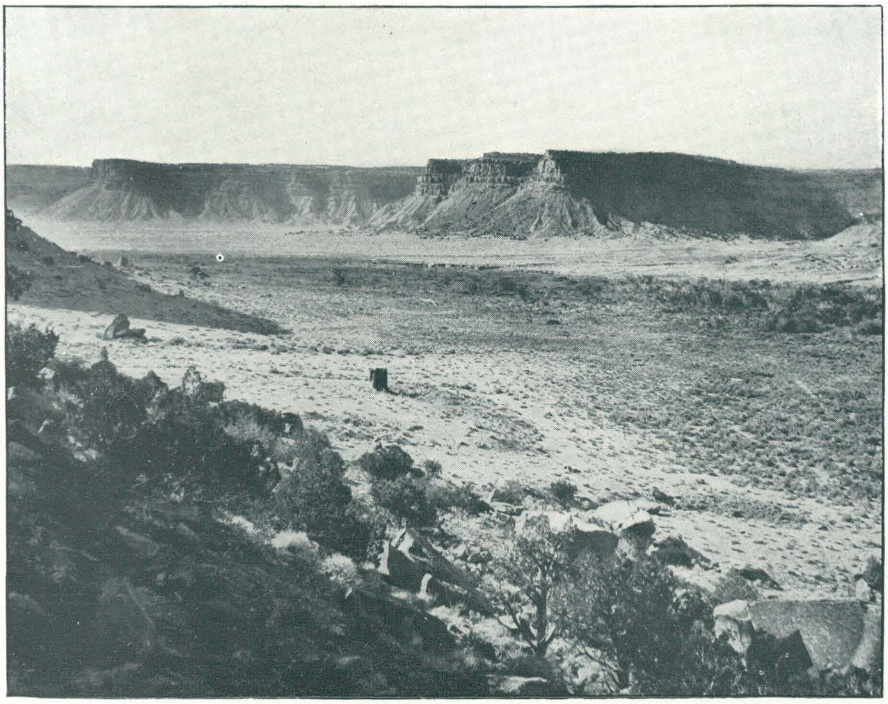


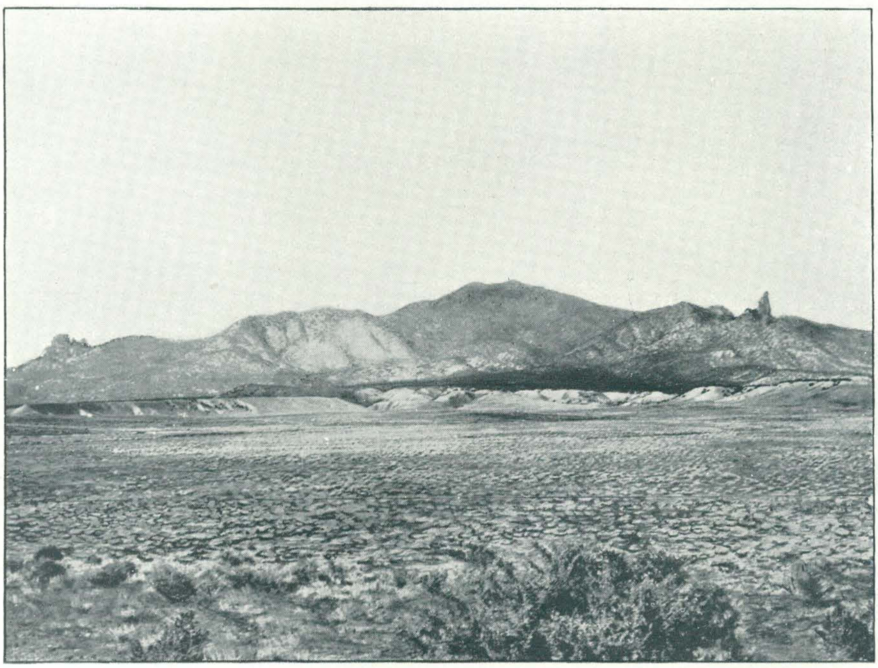
FIG. 183.—Dam site No. 3, Mancos Canyon, Colorado.

characteristic of the southwestern portion of the reservation, its tortuous channel encased by high adobe walls.

In its phenomena of discharge the Mancos is typical of the rivers of the arid West. With the melting of the snow during the spring months large quantities of water rush down its channel, giving it the



A. MANCOS CANYON, COLORADO, MOSSES TOWER IN CENTER, SHOWING ARABLE LANDS.



B. SIERRA EL LATE, COLORADO, LOOKING ACROSS MONTEZUMA VALLEY, SHOWING ARABLE LANDS.

appearance of a turbulent mountain stream. Similarly, after heavy rains the discharge is considerable, and the great erosive power of the stream becomes manifest in the rapidity with which it produces changes in its bed. With the advent of the dry, hot summer the river bed gradually dries from its mouth upward, leaving at intervals pools of

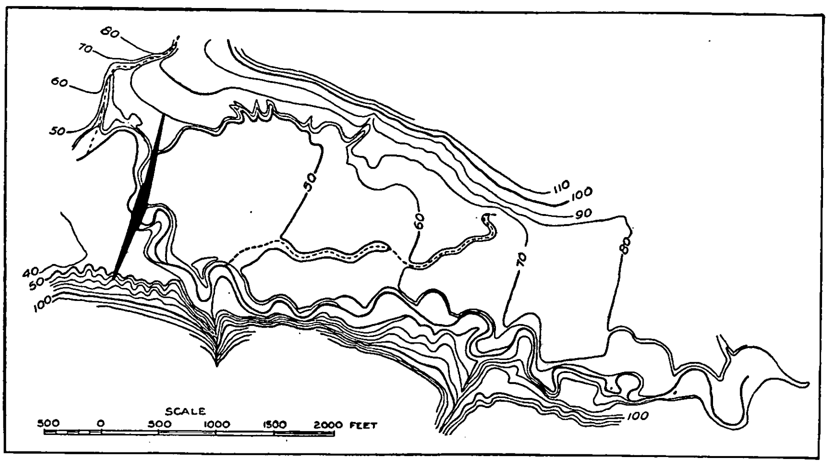


FIG. 184.—Reservoir site No. 4, Mancos Canyon, Colorado.

stagnant, highly alkaline water, flow taking place underground only. This condition extends up the river into the canyon, where the bed for the lower 15 miles is dry during the summer and fall, except for short periods after heavy rainfalls. Along the upper half of the canyon numerous springs in the river bed furnish a small flow, this water con-

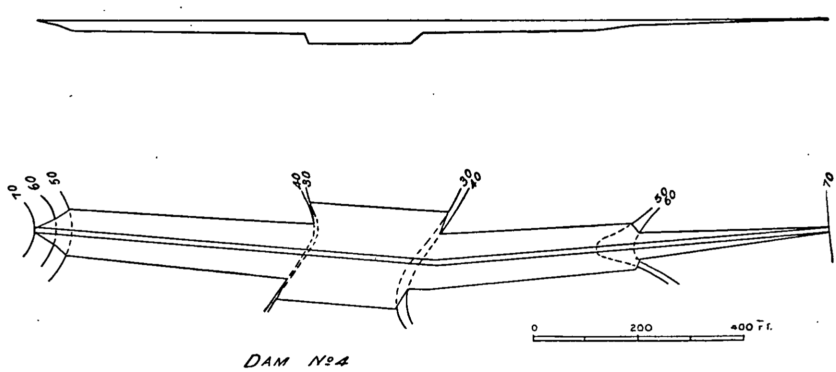


FIG. 185.—Dam site No. 4, Mancos Canyon, Colorado.

stituting in a great measure return seepage from irrigation water diverted from the river by the ranchmen of Mancos and vicinity.

A gage is maintained by the United States Geological Survey at Mancos, observations on which were begun April 9, 1898. The station is described in Water-Supply and Irrigation Paper No. 28, page 131, and in the Twentieth Annual Report, Part IV, page 404. The table and diagram (fig. 176) on pages 285 and 286 show the discharge of the river at this point during the seasons of 1898 and 1899. These records will convey an adequate idea of the flow of the river from the junction of the main forks down to the reservation line. It is true that more or less water is diverted for irrigation purposes, and that some small tributaries empty into the river along this part of its course; but it must be remembered that most of the water so diverted finds its way back into the river as seepage, and that the discharge of the tributaries—the principal of which are Chicken and Mud creeks—is trifling except directly after rainfall. A discharge measurement was made September 13, 1899, just above the head gate of the lowest ranch on the river, about 1 mile above the reservation line, and a flow of 3 second-feet was found. The discharge for that day, computed from the gage height at Mancos, is 5 second-feet.

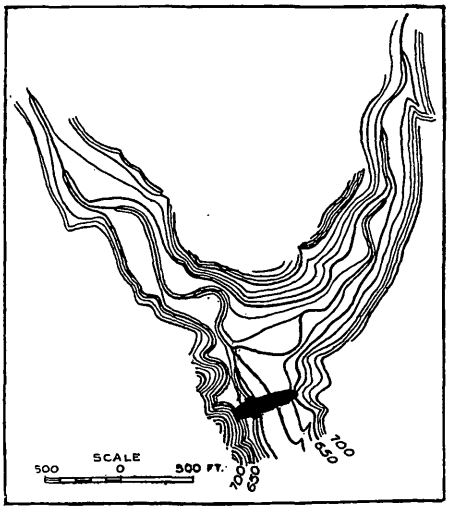


FIG. 186.—Reservoir site No. 5, Mancos Canyon, Colorado.

A number of side canyons lead into the main canyon, the total area drained by them being about 325 square miles. This section, however, is exceedingly arid, and no flow takes place in the canyons except during the season of melting snows or after heavy rains. It was even possible to ascertain that many of them possessed no subsurface flow, bed rock showing in many instances near their mouths. Springs in the Mesa Verde are small and scarce; the few that occur are found in the larger side canyons, such as Cliff and Navajo, and their supply is insignificant.

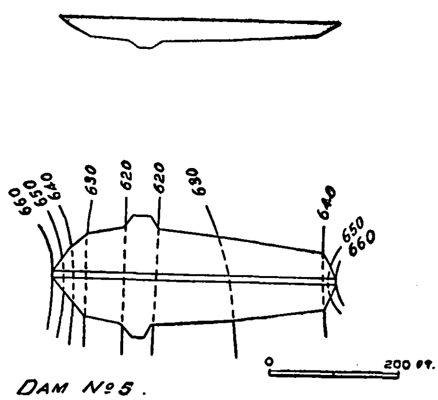


FIG. 187.—Dam site No. 5, Mancos Canyon, Colorado.

With a grade of 40 feet to the mile Mancos Canyon is at first glance not a favorable place for the storage of water by means of low dams, and unusual topographic features had therefore to be looked for.

Of the basins selected for reservoir sites the three lower ones possess the important advantage of having, besides narrow dam sites, great widths in their deepest parts. As will be seen from their locations, the reservoir sites occur in the wide section of the canyon. Many good dam sites were found in the upper, or narrow, portion of the canyon, but owing to the great amount of fall and the narrowness of the gorge none of these sites are worth considering. Next to finding a dam site, width was the principal feature that determined the value of a basin for storage purposes, the combination being one met with only where the local configuration of the canyon bottom offered special advantages.

Reservoir site No. 1 was surveyed for a dam 50 feet high, the top contour of the reservoir coinciding with contour 1,650 of the survey. The dam site is a favorable one, permitting the construction of a dam twice as high, leaving ample provision for a spillway. A survey of the basin led to the conclusion, however, that a dam 50 feet high would be most economical at this point, for the reason that the canyon walls are so precipitous that the reservoir would gain but little in extent by increasing the height of dam, and for the further reason that the canyon grows narrower upstream, both of which facts seem to indicate that the additional storage capacity gained by increasing the height of dam would hardly be commensurate with the increased cost.

Three miles below site No. 1 is site No. 2, for which a dam 40 feet high is estimated on. This would back water 1 mile up the canyon, the top contour of the dam coinciding with contour 1,510 of the survey. Immediately below site No. 2 are found the first good agricultural lands of Mancos Canyon.

At reservoir site No. 3 the height of dam is limited to 40 feet, a higher dam rendering it impossible to provide for a spillway at this point, as will readily be seen from the plan of the site. The reservoir would exceed 1 mile in length, its top contour coinciding with contour 1,340 of the survey. It has the greatest capacity of the sites considered in this investigation, while at the same time its cost per acre-foot is the least. A few miles below this site the canyon contracts, and at one point is but 600 feet wide. It then widens gradually until at its mouth the width exceeds 2 miles.

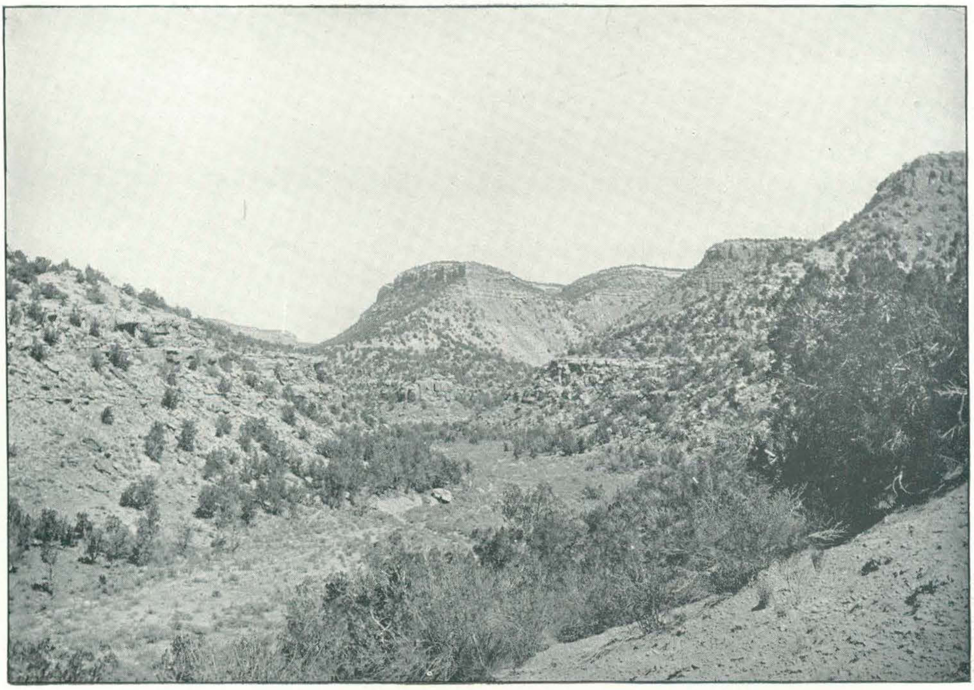
Reservoir site No. 4 is situated below the narrow portion of the canyon referred to, and consequently commands all the good agricultural lands which lie in the wide part of the canyon. The top level coincides with contour 1,170 of the survey.

Reconnaissances made in the principal side canyons met with negative results. With few exceptions these canyons are narrow, and their heavy grades forbid the construction of reservoirs, even where at times a junction of two or more of the smaller canyons creates a basin-like appearance. A further objection to the construction of reservoirs in these side canyons lies in the fact that the water supply would be insufficient, their drainage areas being relatively small and the annual precipitation limited. Navajo Canyon, the widest tributary and possessing by far the greatest drainage area, was carefully inspected. A small site was found at the junction of two of its main forks, and a survey of it made. It will be seen from the appended table (page 295) giving capacities and cost of construction, that this reservoir, No. 5, the site of which is in many respects a favorable one, is not to be recommended owing to its small capacity, caused by too great a fall.

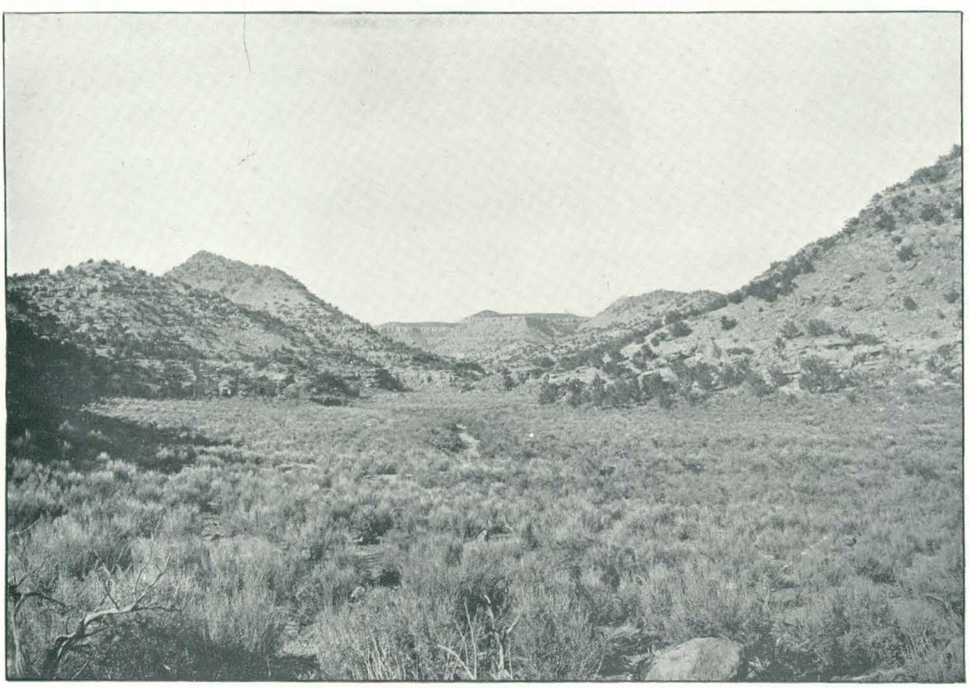
A discouraging feature in regard to dam construction in Mancos Canyon is the notable lack of evidence as to the depth at which bed rock occurs. A short distance above the reservation line there is in the river bottom what appears to be bed rock, and this is exposed also in many of the side canyons. Below the mouth of Cliff Canyon it appears certain that bed rock occurs at a much greater depth than higher up in the main canyon. This belief is further strengthened by the fact that a small flow of water in the upper portion of the canyon, such as may be caused by a summer shower, is lost by seepage in the gravelly bottom of the channel between the mouths of Cliff and Navajo canyons, and disappears, not returning again to the surface of the river bed. Thus, on October 4, after rain had fallen on the day preceding and during the night, a flow which was estimated at 4 second-feet obtained in the main canyon near the mouth of Cliff Canyon. From this point down, however, the flow gradually diminished, until at the junction of Navajo and Mancos canyons the river bed was dry and continued so throughout the canyon. That there existed during this period a subsurface flow was abundantly ascertained when on moving camp, October 5, to a point 7 miles above the lower end of the canyon, in the hope of finding water in that section, an excellent supply was obtained by digging a hole 2 feet deep in a low place in the creek bed.

Persistent rains on October 11, 12, 13, and 14 caused the river to rise considerably, and for several hours its estimated discharge exceeded 100 second-feet. The flow of the river during this period and for two weeks following was continuous throughout the canyon; in no instance was any perceptible diminution due to seepage observed, the sand and gravel underlying the river bed being probably in a condition of complete saturation.

From the foregoing observations it may safely be concluded that reservoirs built in the lower portion of the canyon are likely to lose considerable from seepage, unless dams are built in a manner to counteract this, which could be done by extending them down to bed rock. On the other hand, depth to bed rock being an unknown and presumably a considerable quantity, it will doubtless be found to be better



A. FORKS OF NAVAJO CANYON.



B. NAVAJO CANYON, MESA VERDE, COLORADO.

economy to build surface dams and lose some of the impounded water through seepage than to expend enormous sums upon underground constructions, the cost of which would not be commensurate with the benefits derived from additional storage so gained.

In the following table a rough estimate of the cost of construction of each dam is given, being made on the basis of providing for rock-fill structures 10 feet wide on top, with slopes of 2 to 1, faced with hand-laid dry rubble masonry, the upstream face to be rendered tight by carefully filling the joints with cement grout. In all cases it is intended that the material used in the building of the dam is to be taken out in such manner as to excavate a waste or spillway of sufficient dimensions to protect the dam from freshets and from overflow.

Cost and capacity of reservoirs in Mancos Canyon, Colorado.

No.	Capacity.	Contents of dam.	Cost of construction.	Engineering and contingencies.	Total cost.	Cost per acre-foot.
	Acre-feet.	*Cubic yards.*				
1	2,268	70,870	$71,335	$7,135	$78,470	$34.59
2	2,077	70,820	71,460	7,140	78,600	37.84
3	2,983	89,370	90,175	9,025	99,200	33.26
4	2,242	79,515	80,300	8,050	88,350	39.40
5	520	33,130	33,440	3,360	36,800	70.77

An inspection of the table of discharges computed for Mancos River at the Mancos gaging station shows that the flow during the spring months of the year, when little or no irrigation water is required, is more than ample to fill the proposed reservoirs in the main canyon. Their combined capacity is 9,570 acre-feet; a flow of 100 second-feet during forty-eight days would be sufficient to fill them.

Like all reservoirs built on natural waterways, the life of these reservoirs would be seriously menaced by the large accumulations of débris and sediment which the river carries at times of high water and which would be deposited in them with small prospect of being flushed out again.

It appears from a reconnaissance of the main canyon that it contains a large amount of very excellent land, which, with proper irrigation, could be turned into first-class farms. Further advantages are found in the regular slope of the canyon and in the character of its bottom, which would render it possible to irrigate land within close proximity to the reservoirs and would furnish convenient grades for ditches and roads. The arable land in the lower part of the canyon is estimated at 4,000 acres. (See Pl. XXVII.)

It is believed that in case it should be found profitable to construct reservoirs in Mancos Canyon, enough land could probably be brought under cultivation to settle the majority of the unallotted Utes. This would possess the inestimable advantages of eventually collecting the Indian farms into nearby groups, of making the most economical application possible of the water, and at the same time requiring a minimum length of ditching. It would also tend to unite reservoirs, ditches, and cultivated areas into a single comprehensive system, easily controlled by the Indian agent, farmers, and other employees charged with the supervision and maintenance of such works.

A reconnaissance of the country south of Mesa Verde shows that much of it can be turned into good agricultural land if irrigated by water stored in Mancos Canyon. West of Aztec Springs Creek, however, this would not be practicable, except by putting flumes across the wide arroyo of the creek, which would necessarily entail large expenditures. It appears certain, from this investigation as well as from that carried on the year before, that the country lying south of the Ute Peak group and west of Aztec Springs Creek can only be put under ditch by obtaining a water supply from Montezuma Valley, or, strictly speaking, from Dolores River. Should any reservoir sites exist in that area—the reconnaissances made in 1898 and 1899 do not seem to indicate the existence of any—the providing of a water supply to fill them would be difficult and fraught with great expense, while the many miles of ditching through this open, arid country would mean a loss of water by seepage and evaporation that would destroy whatever economical features the project might otherwise possess.

SUMMARY.

1. Twenty-five miles of Mancos Canyon are in the Southern Ute Indian Reservation. In this distance the canyon has an aggregrate fall of 1,000 feet, or, roughly, 40 feet to the mile.

2. The upper portion of the main canyon and the side canyons are not adapted to the construction of storage reservoirs.

3. Only four feasible reservoir sites were found in the wide portion of the main canyon, their aggregate capacity being 9,570 acre-feet.

4. The average cost per acre-foot of these sites is estimated at $36, on the basis of providing rock-fill dams.

5. The flow of Mancos River during the early part of the year is ample to fill these reservoirs.

6. It appears certain that the reservoirs, if built as suggested, will be exposed to two serious disadvantages: (1) Loss of water by seepage; (2) gradual filling by sediment.

7. The water stored could be immediately applied on land in the canyon and also southwest of Mesa Verde, the agricultural land situated in the canyon alone amounting to 4,000 acres.

8. A large part of Mancos Canyon is well adapted to agricultural purposes, the construction of ditches, and the building of roads.

9. The plan of settling the unallotted Utes in Mancos Canyon offers many advantages of an economic character.

SAN JUAN RIVER.

The San Juan has its source on the western slope of the Continental Divide in southern Colorado, its headwater tributaries adjoining those of the Rio Grande. It flows in a general southwesterly direction, but after it receives the waters of Piedra River and crosses the State line into New Mexico it takes a more westerly course for some distance, then turns northwest, passing very close to the four corners of Utah, Colorado, New Mexico, and Arizona. After flowing for a considerable distance through a canyon country in Utah, it enters Colorado River a short distance above Marble Canyon. Its principal tributaries are Mancos River, Piedra River, Los Pinos River, and Animas River. The gaging station on San Juan River, established June 19, 1895, is at Arboles, Colorado. Piedra River also is measured at Arboles. The station on Los Pinos River, established April 22, 1899, is at Ignacio, Colorado, and the station on Animas River, established June 20, 1895, at Durango, Colorado. Florida River, a tributary of the Animas, is also measured at Durango. Measurements at all of the stations are made by A. L. Fellows.

Estimated monthly discharge of San Juan River at Arboles, Colorado.

[Drainage area, 1,320 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 23 to 30	1,286	569	934	55,577	0.71	0.79
May	1,976	373	917	56,384	0.70	0.81
June	805	248	550	32,727	0.42	0.47
July	1,838	152	523	32,158	0.40	0.46
August	1,700	116	385	23,673	0.29	0.33
September	1,838	96	219	13,031	0.17	0.19

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 308; discharge measurements, page 307; rating table in Paper No. 39, page 451.

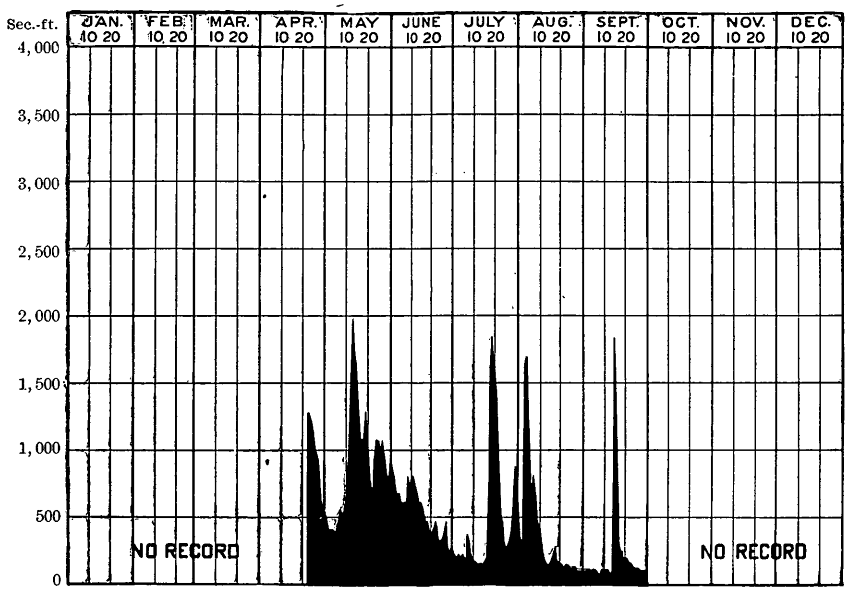


FIG. 188.—Discharge of San Juan River at Arboles, Colorado, 1899.

Estimated monthly discharge of Piedra River at Arboles, Colorado.

[Drainage area, 670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 23 to 30	467	256	380	22,612	0.57	0.63
May	643	138	315	19,369	0.49	0.56
June	256	88	168	9,997	0.25	0.28
July	439	60	141	8,670	0.21	0.24
August	869	38	180	11,068	0.27	0.31
September	138	25	49	2,916	0.07	0.08

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 309; discharge measurements, page 308; rating table in Paper No. 39, page 452.

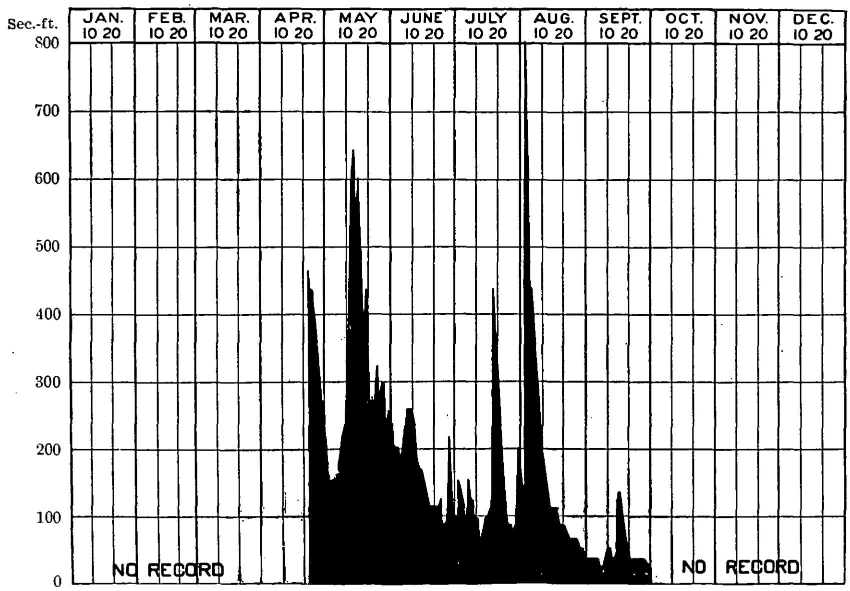


FIG. 189.—Discharge of Piedra River at Arboles, Colorado, 1899.

Estimated monthly discharge of Los Pinos River at Ignacio, Colorado.

[Drainage area, 450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 23 to 30			499	29,693	1.11	1.24
May	947	180	530	32,588	1.18	1.36
June	605	264	469	27,907	1.04	1.16
July	662	124	289	17,770	0.64	0.74
August	1,346	49	349	21,459	0.77	0.89
September	264	36	62	3,689	0.14	0.16
October	292	36	127	78,088	0.28	0.32
November	124	89	103	6,129	0.23	0.26
December 1 to 21	89	49	59	3,628	0.13	0.15

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 310; discharge measurements, page 309; rating table in Paper No. 39, page 452.

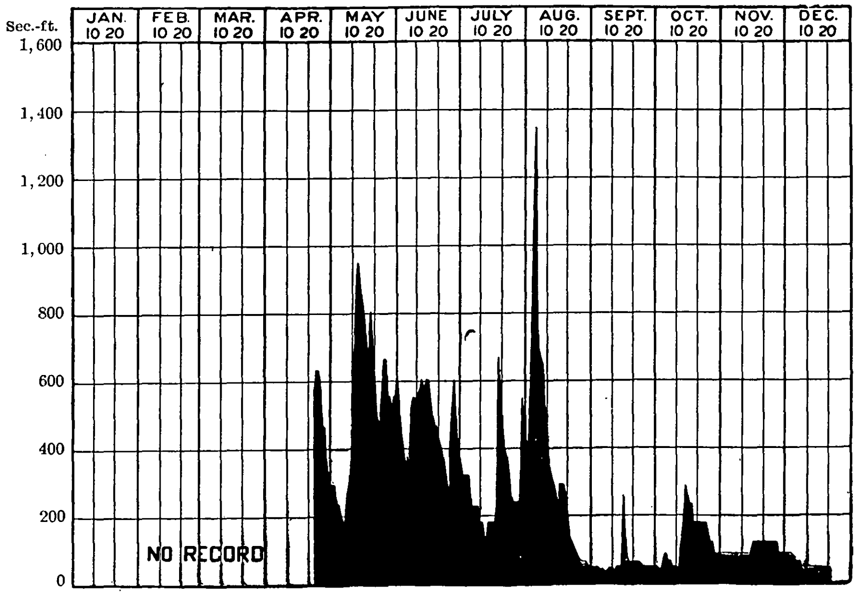


FIG. 190.—Discharge of Los Pinos River at Ignacio, Colorado, 1899.

Estimated monthly discharge of Florida River at Durango, Colorado.

[Drainage area, 136 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
May 21 to 31			139	8,547	1.02	1.18
June	121	12	68	4,046	0.50	0.56
July	211	6	45	2,767	0.33	0.38

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 311; rating table in Paper No. 39, page 452.

Estimated monthly discharge of Animas River at Durango, Colorado.

[Drainage area, 812 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	1,256	138	584	34,750	0.72	0.80
May	3,240	532	1,730	106,374	2.13	2.46
June	2,855	923	1,797	106,929	2.21	2.46
July	1,208	402	668	41,074	0.82	0.94
August	2,049	315	691	42,488	0.85	0.98
September	379	201	276	16,423	0.34	0.38
October	357	201	297	18,262	0.37	0.43
November	315	201	267	15,888	0.33	0.37
December	275	168	212	13,035	0.26	0.30

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 311; discharge measurements, page 310; rating table in Paper No. 39, page 452.

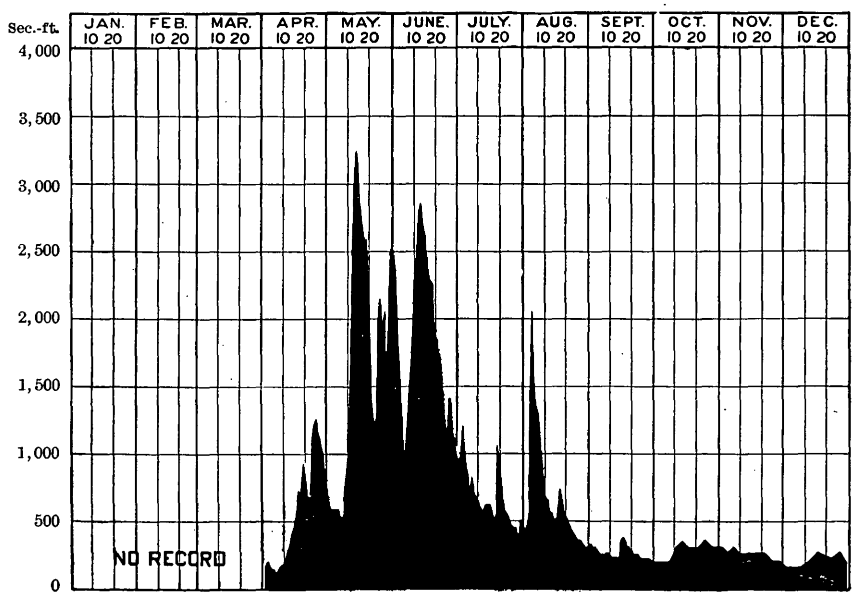


FIG. 191.—Discharge of Animas River at Durango, Colorado, 1899.

GREEN RIVER.

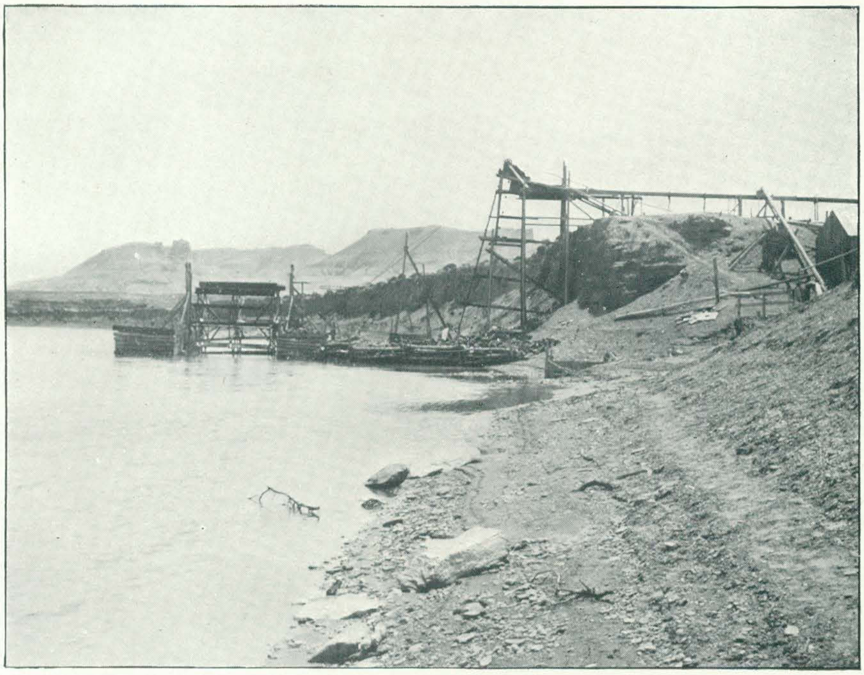
This river has its source in the Wind River and Gros Ventre mountains, in western Wyoming. It flows southerly, receiving a number of important tributaries from either side, and after crossing the State line flows through Utah. Its principal tributaries in Utah are Yampa and White rivers, from the east, and Duchesne River, from the west. Sixty miles below the crossing of the Rio Grande Western Railway in Utah, Green River joins Grand River to form the Colorado. The small streams which form Black Fork, another tributary of Green River, have their source in Utah. The Black Fork flows in a general northeasterly direction until after its junction with Hams Fork, when it turns to the southeast and joins Green River 20 miles below Greenriver, Wyoming. Black Fork is measured at Granger, Wyoming, measurements being made by A. J. Parshall. Pl. XXIX, *B*, is a view of the Black Fork below Granger, Wyoming, the low-water gage being shown at the right. Two stations have been maintained on Green River, one at Greenriver, Wyoming, and the other at Blake, Utah. The former was established May 2, 1895. Measurements are made by A. J. Parshall. A view of the river at Greenriver is shown in Pl. XXX.

Estimated monthly discharge of Green River at Greenriver, Wyoming.

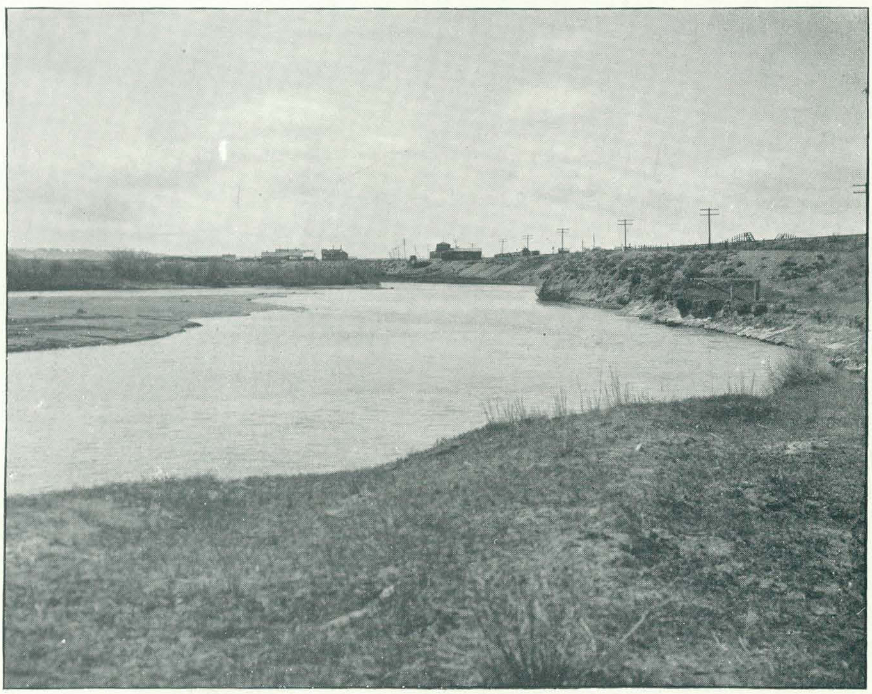
[Drainage area, 7,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,990	1,750	1,880	115,597	0.25	0.29
February	2,250	2,120	2,200	122,182	0.30	0.31
March	2,250	1,530	1,860	114,367	0.25	0.29
April	2,390	990	1,596	94,969	0.21	0.23
May	5,690	1,530	3,270	201,064	0.44	0.51
June	21,384	5,480	12,453	741,005	1.67	1.86
July	20,690	8,883	14,536	893,783	1.95	2.25
August	8,652	2,465	5,169	317,829	0.69	0.79
September	2,465	1,695	2,063	122,757	0.28	0.31
October	1,990	1,640	1,822	112,030	0.24	0.28
November	1,870	1,480	1,702	101,276	0.23	0.26
December	1,870	1,430	1,680	103,299	0.23	0.26
The year	21,384	990	4,186	3,040,158	0.56	7.64

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 287; rating table in Paper No. 39, page 451.



A. WATER WHEEL ON GREEN RIVER, WYOMING.



B. BLACK FORK OF GREEN RIVER BELOW GRANGER, WYOMING; LOW-WATER GAGE ON RIGHT.

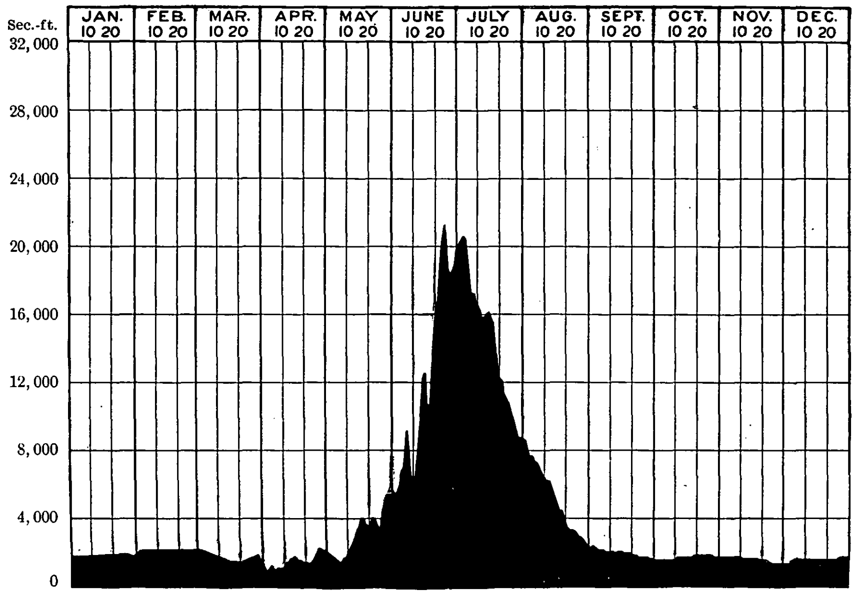


FIG. 192.—Discharge of Green River at Greenriver, Wyoming, 1899.

Estimated monthly discharge of Black Fork of Green River at Granger, Wyoming.

[Drainage area, 2,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	780	610	700	43,041	0.29	0.33
February	1,050	900	950	52,760	0.40	0.41
March	2,900	970	1,500	92,231	0.62	0.71
April	2,130	510	927	55,253	0.39	0.44
May	3,880	610	2,276	139,946	0.95	1.09
June	6,310	3,040	4,692	279,193	1.96	2.19
July	4,020	560	1,825	112,215	0.76	0.87
August	610	245	406	24,964	0.17	0.20
September	280	120	186	11,068	0.08	0.09
October	280	120	218	13,404	0.09	0.10
November	315	280	300	17,851	0.12	0.13
December	560	350	440	27,054	0.18	0.21
The year	6,310	120	1,202	868,980	0.50	6.77

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 288; rating table in Paper No. 39, page 451.

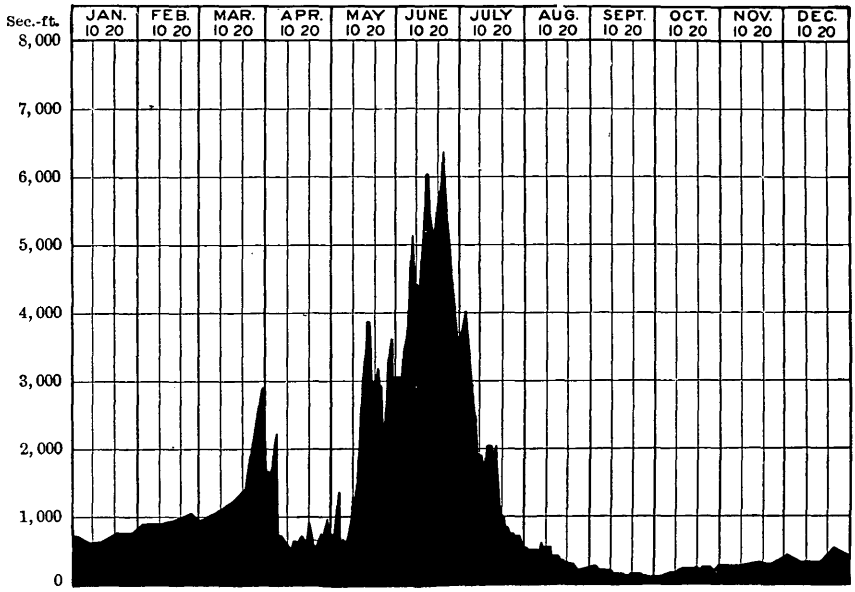


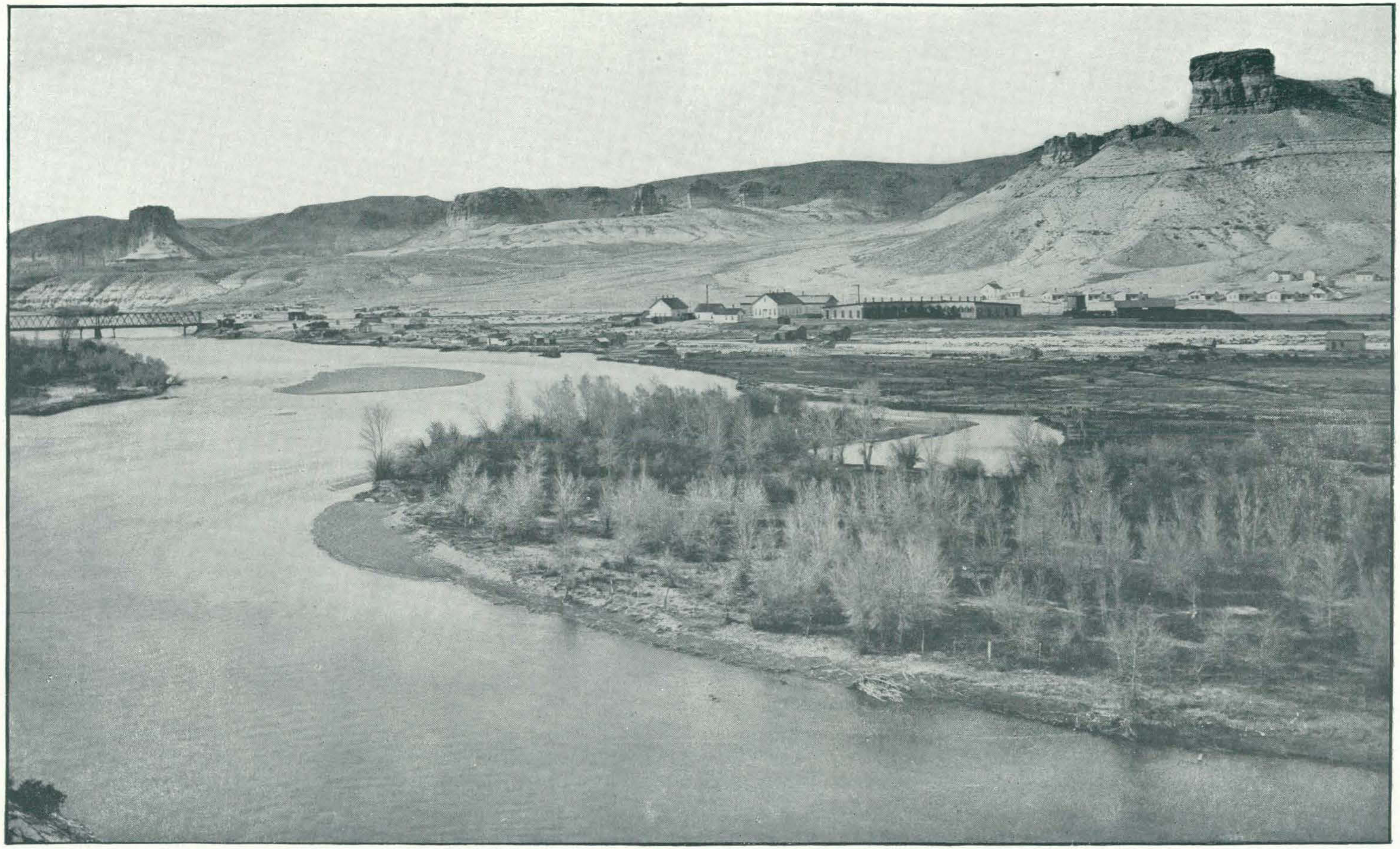
FIG. 193.—Discharge of Black Fork of Green River at Granger, Wyoming, 1899.

Estimated monthly discharge of Green River at Blake, Utah.

[Drainage area, 28,200 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,020	1,400	1,585	97,458	0.06	0.07
February	2,020	1,600	1,735	96,357	0.06	0.06
March	6,325	1,600	3,111	191,288	0.11	0.13
April	17,500	4,120	6,808	405,104	0.24	0.27
May	34,125	8,300	23,237	1,428,787	0.82	0.94
June	58,350	28,475	44,086	2,623,299	1.56	1.74
July	51,225	12,275	30,555	1,878,754	1.08	1.25
August	23,200	4,330	10,654	655,089	0.38	0.44
September	4,225	2,650	3,343	198,922	0.12	0.13
October 1 to 14	2,650	2,440	2,455	150,952	0.09	0.10

NOTE.—Gage heights and discharge measurement for 1899 are given in Water-Supply and Irrigation Paper No. 37, page 293; rating table in Paper No. 39, page 451.



GREEN RIVER AT GREENRIVER, WYOMING.

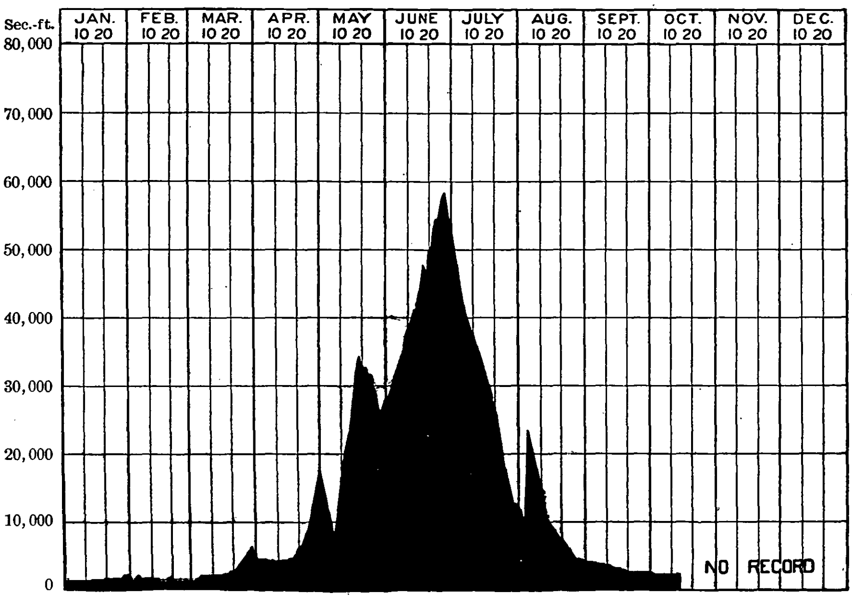


FIG. 194.—Discharge of Green River at Blake, Utah, 1899.

DUCHESNE RIVER.

This stream has its source in the high peaks of the Uinta and Wasatch mountains, and flows in a general easterly direction, emptying into Green River 3 miles above the mouth of White River. Practically the entire drainage basin is included within the Uinta Indian Reservation. Strawberry Creek is an important tributary of the Duchesne, and includes within its basin a tract of very fine grazing land, known as Strawberry Valley, of a rolling character, in contrast to the basin of the upper Duchesne, which is distinctly mountainous. In Strawberry Valley a number of small tributaries, averaging about 1 second-foot each, contribute to the supply of the river. The principal tributaries are Currant Creek, Red Creek, and Lake Creek. The gaging station, which was established October 26, 1899, is at Price road bridge. Measurements are made by C. C. Babb and C. T. Prall.

INVESTIGATION OF THE WATER SUPPLY OF THE UINTA INDIAN RESERVATION, UTAH.

The water resources of the Uinta Indian Reservation in northeastern Utah are known to be large, and efforts have been made by various persons and corporations to secure permission to divert water from the reservation to adjacent arid lands. In the act approved March 11, 1899, making appropriations for the current and contingent expenses of the Indian department, etc., is the following paragraph:

That the Secretary of the Interior be, and he is hereby, authorized in his discretion to grant rights of way for the construction and maintenance of dams, ditches, and canals on or through the Uinta Reservation in Utah, for the purposes of diverting and appropriating the waters of the streams in said reservation for useful purposes: *Provided*, That all such grants shall be subject at all times to the paramount rights of the Indians on said reservation to so much of said waters as may have been appropriated or may hereafter be appropriated or needed by them for agricultural and domestic purposes; and it shall be the duty of the Secretary of the Interior to prescribe such rules and regulations as he may deem necessary to secure to the Indians the quantity of water needed for their present and prospective wants, and to otherwise protect the rights and interests of the Indians and the Indian service.

On June 14, 1899, the Director of the Geological Survey was instructed to detail competent topographers and engineers to make an investigation and to ascertain the amount of available water upon the reservation for the permanent supply, also the number of acres of irrigable land. It was desired that the quantity of water flowing in the several streams should be ascertained, also the number of acres of contiguous land that could be irrigated, also what surplus of water, if any, there would be from each stream. This investigation was for the purpose of placing before the Department such information as would enable it to intelligently carry out the intent of the act above cited with respect to the rights of the Indians and also those of others concerned. In order to carry on the investigation, the sum of $2,000 was made available for field expenditures. To Mr. Cyrus C. Babb was intrusted the details of the work, and he outfitted from Provo, Utah, on September 7, 1899. A general reconnaissance was made from the western end of the reservation through the valleys of Strawberry Creek and Duchesne River, and river stations were established, as described on pages 291 and 292 of Water-Supply Paper No. 37.

In addition to systematic measurements of the streams, a survey of agricultural lands on the eastern edge of the reservation was begun, the topography being shown on maps prepared by use of the plane table. There was found to be a large body of irrigable land adjacent to Uinta River, especially to the westward, but it was soon found that, owing to the shortness of the season, the complete area could not be covered. The work was therefore planned so as to completely map the area east of Uinta River and a portion lying west of Fort Duchesne; in all, 176 square miles were surveyed, on a scale of 2 inches to the mile and with a contour interval of 20 feet. The area mapped is shown by fig. 195. The horizontal control was obtained by triangulation and the vertical by means of level lines, the latter work being intrusted to Mr. C. T. Prall. Mapping was brought to a close on November 30, and the parties disbanded, Mr. Prall being left to continue the stream gagings. The following facts concerning the reservation have been taken from the preliminary report submitted by Mr. Babb:

LOCATION AND PHYSICAL FEATURES OF THE RESERVATION.

The Uinta Indian Reservation is located in the northeastern corner of Utah. It was set aside by executive order of President Lincoln

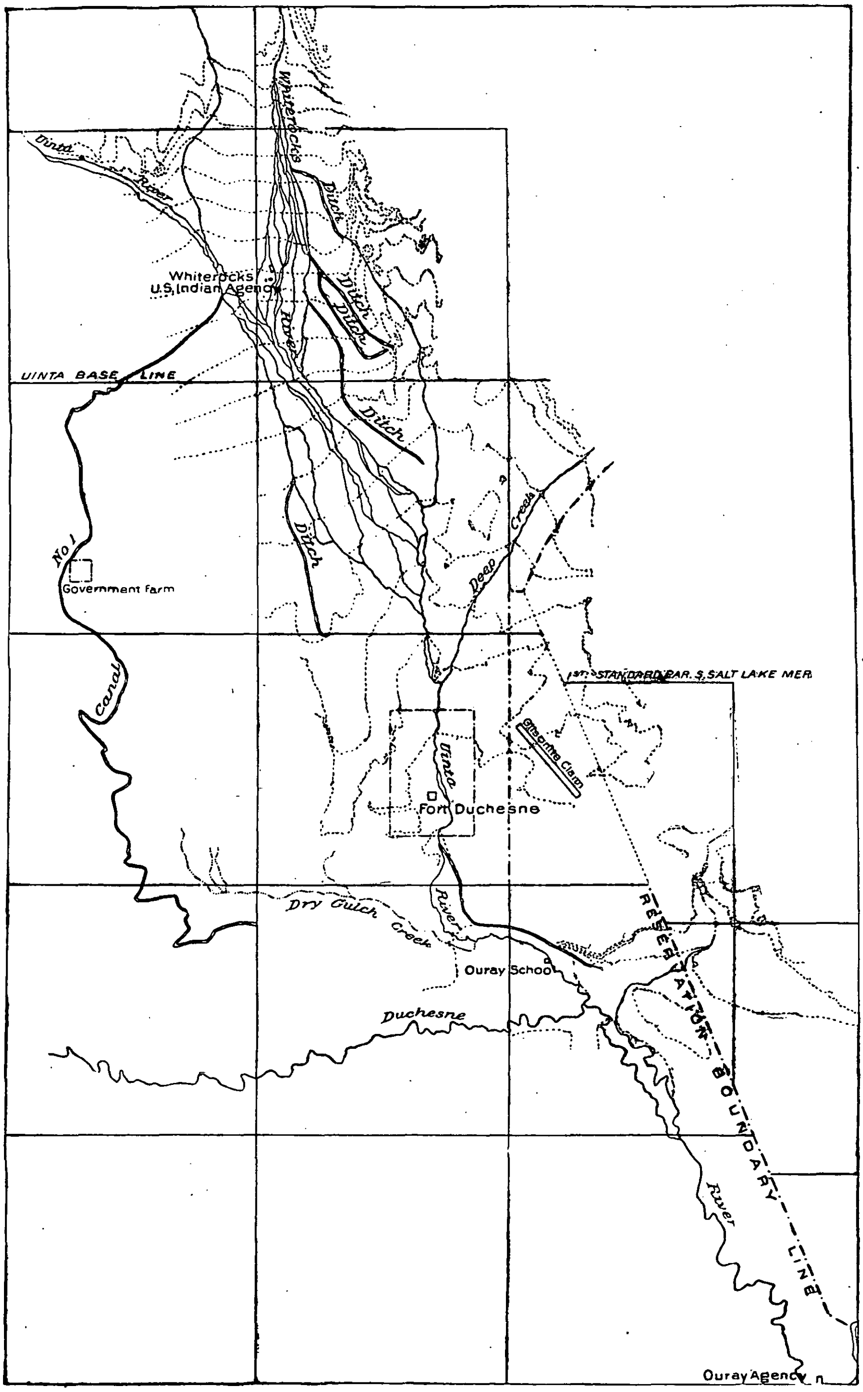


FIG. 195.—Map of a portion of the Uinta Indian Reservation, Utah, showing agricultural lands surveyed in October, 1899.

on October 3, 1861, which was subsequently approved by four acts of Congress, the latest bearing date May 24, 1868. The reservation was supposed to include the drainage basin of Duchesne River, with its main tributary, Uinta River. The surveys that were made of the boundary have excluded some portions of the drainage basin, and hence the area of the reservation does not wholly correspond with the area drained. The reservation covers an area of 2,039,040 acres, or 3,186 square miles. Its northern boundary is along the divide of the Uinta Mountains, whose peaks attain elevations of over 13,000 feet. Its western boundary is a portion of the Wasatch Range, while its southern boundary is an irregular line over the rolling country between the basin of Minniemaud Creek and small tributaries of the Duchesne. Immediately south of the southern boundary line is Tavaputs Plateau and Roan Cliffs, which overlook the valley of Price River. Green River forms the boundary line a short distance at the southeastern extremity. The eastern boundary line, as originally surveyed, was afterwards modified by act of Congress in order to exclude the so-called "Strip," a triangular area east of Fort Duchesne, which contains valuable uintaite, or gilsonite, deposits. Farther to the north a certain portion of Deep Creek drainage which enters the Uinta 2 miles above the military post is not included in the Indian reservation. This latter excluded area contains some fine agricultural land.

The greatest due east-west length of the reservation is about 75 miles, with a north-south width of approximately 60 miles. The main stream is Duchesne River, which flows in an easterly direction through a fine agricultural valley nearly 2 miles in width. Its main upper tributary is Strawberry Creek, which drains an area of 1,166 square miles. This creek passes through what is known as Strawberry Valley, a fine tract of level land with an average elevation of 7,500 feet. The altitude is rather high for general agricultural purposes, but is splendidly adapted to grazing. It is well grassed and will support numerous herds of cattle. The water supply for this valley is excellent, the streams having their source in the Wasatch Mountains, whose canyons sometimes contain snow the year round. For a number of years this area, to the extent of 675,000 acres, has been leased to certain cattle companies for grazing purposes.

A good idea of the country can be obtained from a description of the road between Heber Valley and Fort Duchesne: The divide at the head of Daniels Creek, overlooking Strawberry Valley, and on the reservation boundary line, is 8,100 feet in elevation. Strawberry Valley is about 10 miles long, with an average width of three-fourths of a mile. In passing down the valley in September, 1899, several small tributaries were crossed, the discharge of each of which averaged about 1 second-foot. The road to the east out of the valley makes a sudden ascent of 600 feet on entering the foothills about 4 miles north of the outlet canyon of Strawberry Creek, and then turns southward and descends to a small creek which flows into the Strawberry. The discharge of the small creek referred to did not exceed 2 second-feet on September 7, 1899. The road thence leads up a grade and down to a fork of Currant Creek, which was carrying 1 second-foot of water on that day. The grazing here in the bottom lands was good. For a mile the road followed the fork of the creek, then led over a divide and down to the main Currant Creek, which was discharging 20 second-feet of water. The hills for some distance east and west of this stream are of red sandstone. The country to the east is generally undulating, sloping eastward to Red Creek. Blacktail Mountain, with an elevation of 10,000 feet, is 10 miles to the north, the canyon of Strawberry Creek being 7 miles in the opposite direction. At the time of our visit Red Creek was discharging 8 second-feet. Three miles from the latter stream and on the mesa the roads fork, the left-hand road leading to Duchesne River. For 10 miles the general course of the right-hand road is to the east, over a rolling country sparsely covered with cedar. The next 5 miles it is through a rough country thickly timbered with cedar and piñon pine. The rock formations are massive sandstone ledges interstratified with purple and yellow shales, the strata having a general northeasterly dip. The distance from Red Creek to Strawberry Creek is 20 miles, with no water intervening.

On September 10 the discharge of Strawberry Creek about 4 miles above its mouth was 134 second-feet. The area drained at the same point is 1,166 square miles. Duchesne River above Strawberry Creek was carrying on the same day 302 second-feet, draining an area of 703 square miles. The drainage basin of the latter stream is much more mountainous than the drainage basin of the former stream, having a heavier precipitation and contributing a greater run-off to the square mile. A large portion of the drainage area of the lower part of Strawberry Creek, especially that to the south, contributes practically no water, except during the spring. Indian Creek enters Strawberry Creek within 1 mile of its mouth, and on the date stated was carrying 1 second-foot. The valley of Duchesne River down to Lake Creek averages 2 miles in width and is bordered on either side with sandstone cliffs approximately 200 feet in height. The cliffs on the northern side are capped with a heavy deposit of coarse river gravel and cobblestones. The measurement of Lake Creek 100 feet below the wagon bridge showed a discharge on September 11 of 128 second-feet. The area drained at this point is 475 square miles.

Duchesne River is very crooked, swinging backward and forward across its valley, with its course marked by a thick line of cottonwoods. The land on the north side is generally poor, judging from the dense growth of greasewood which covers it, and which usually denotes an alkaline soil.

The main water supply of the eastern portion of the reservation is from Uinta River, the main tributary of which is Whiterocks River. These streams rise in the extreme northern end of the reservation; in fact their source is in the Uinta Mountains, which form the northern boundary of the reservation. They flow in a general southeasterly direction and unite, through various channels, between the Indian agency and the military post. Six miles southeast of the latter place the streams, flowing through this distance in one channel, unite with Duchesne River.

Whiterocks and Uinta rivers emerge from their canyons about 10 miles above the agency. North of this point the country is distinctly mountainous and difficult of access. South of the canyons it is flat for some distance west of the river, and has a distinct southerly slope of about 40 feet to the mile. The Uinta and various washes cut this country with a still greater slope, and in the course of 5 to 7 miles below the mountainous area they have dissected the plateau into a number of mesas of varying width. While the slope of these mesas, as stated above, is about 40 feet, the slope of the washes is about 70 feet to the mile. As a result of this difference, cliffs from 150 to 200 feet in height are formed, bordering Duchesne River. Immediately south of the latter river the bottom land is bounded by a cliff about 200 feet high, with a series of mesas extending southward for a number of miles.

The following table shows the areas drained by Duchesne River and a number of its tributaries:

Drainage areas.

River.	Locality.	Area.
		Square miles.
Strawberry Creek	At mouth	1,166
Duchesne River	Above Strawberry Creek	703
Do	Above Lake Creek	2,247
Lake Creek	At mouth	475
Duchesne River	At Price road bridge	2,746
Whiterocks River	In canyon	114
Farm Creek	do	47
Uinta River	do	218
Do	At Fort Duchesne	672
Do	At Ouray School	967
Dry Gulch Creek	At mouth	260
Duchesne River	do	3,985
Ashley Creek	In canyon	250

VERNAL VALLEY.

The country east of Fort Duchesne is greatly dissected, forming a very rough and practically worthless area of a type similar to the well-known "bad lands" of various sections of the West. This type of topography continues until the divide overlooking Vernal Valley is reached, when the panorama suddenly changes and there is presented a large area of irrigated and cultivated land. The valley proper is approximately 20 miles long and 3 miles wide, with Vernal, the principal settlement, situated in the center. To the north is seen the

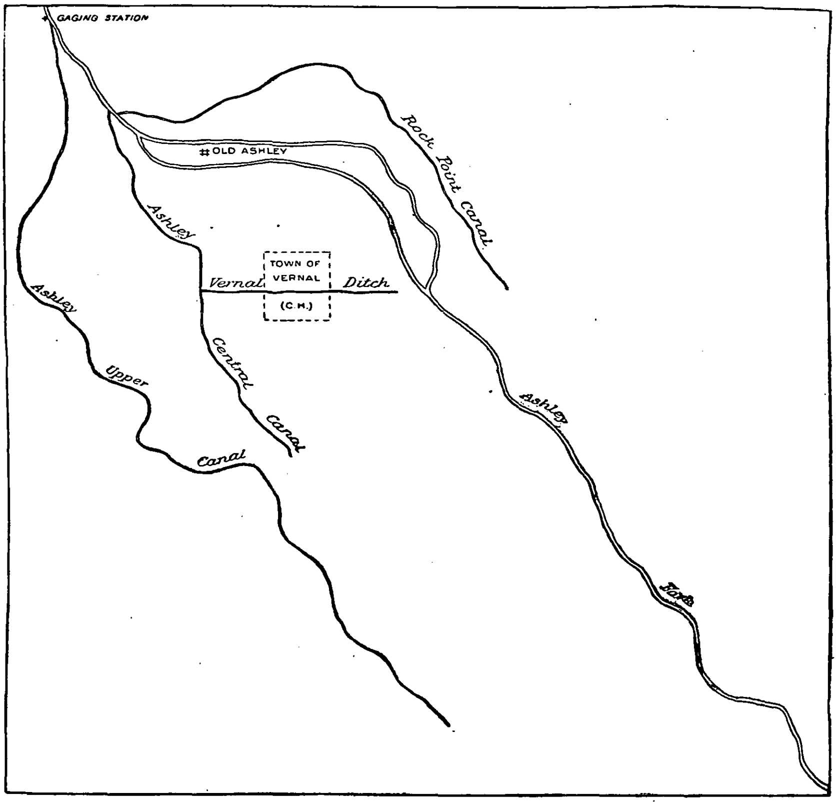


FIG. 196.—Map showing location of canals in Vernal Valley, Utah.

entering canyon of Ashley Creek. The boundaries of the valley are sharply defined by the foothills. The area cultivated by white settlers occupying the valley is approximately 30,000 acres, which is served entirely from Ashley Creek.

The principal canal on the east side is the Rock Point, which covers about 10,000 acres. On the west side are upper Ashley canal, built in 1880 and covering about 20,000 acres, and the central Ashley canal, built in 1878 and covering approximately 10,000 acres. The waters of Ashley Creek, by a court decision, are to be equally divided between these three canals, each receiving one-third. There are three or four smaller ditches lower down, the principal one being known as Island ditch. Ashley Creek is similar to Uinta River in that as soon as it leaves its canyon it divides into a number of branches. Island ditch irrigates land between the two main forks. All of these canals are cooperative affairs, the stockholders being the farmers whose lands are irrigated by them. A man's right and title to a certain quantity of water is dependent upon his use of it. If he owns shares covering 80 acres and is cultivating only 40 acres, he will use the entire amount of water, irrespective of his needs, in order to maintain his rights. As a consequence the crops of Ashley Valley more often suffer from too much water than from too little, and there is a large wastage.

The following estimate of the water supply was made during a visit to the head of the valley on September 13, 1899:

	Second-feet.
Rock Point canal	4
The two Ashley canals	16
Miscellaneous ditches	10
Total for valley	30

The autumn is the season of low-water stages for the streams in this vicinity, but it was reported that in the year 1899 the water supply was exceptionally deficient. The principal crops of the valley are alfalfa and oats. The few orchards seen were not thrifty. This was accounted for by the considerable elevation of the country, which is approximately 5,000 feet. The population of Vernal Valley is 6,000. There are 38,000 acres of land on the valley tax rolls, about 80 per cent of which is under cultivation. In the lower portion of the valley seepage water is now appearing in the river channels and is being used for irrigation purposes, thus increasing the duty of water in that section.

There is a voluntary observer of the Weather Bureau at Vernal who has kept a continuous record for five years, the mean annual precipitation for that period being 9.38 inches. The precipitation in 1899 was 8.41 inches, and the mean temperature 46°. There is no well-defined rainy season, but the principal rainfalls occur in June or July. The snowfall is generally light, the air usually dry, and strong winds are infrequent. The soil is a sandy loam. The mineral resources are said to be excellent in the surrounding mountains, deposits of gold, silver, and copper being worked to some extent. Coal also is found near by, and some deposits of uintaite of the asphaltum series. Transportation facilities are poor; the railroad is reached at Price, 140 miles away, by way of Fort Duchesne.

East of Ashley Creek are two peculiar streams, of the "disappearing" type, known as Little Brush Creek and Big Brush Creek. The main Brush Creek enters Green River 3 miles above the mouth of Ashley

Creek. The peculiarity of these two forks is that their waters disappear and then reappear at various points along their course. At one place Big Brush Creek enters a long, precipitous tunnel, which has been only partly explored and in which icicles and banks of ice are said to exist the year round.

FORT DUCHESNE MILITARY RESERVATION.

The following—General Orders No. 59, issued from the Adjutant-General's Office, United Sates Army, and dated Washington, September 3, 1887—is relative to the establishment of the military post at Fort Duchesne:

By authority of the President of the United States, dated September 1, 1887, the following-described tract of land in the Territory of Utah, embraced within the limits of the Uintah Indian Reservation, created by Executive Order dated October 3, 1861, and act of Congress approved May 5, 1864 (13 Stats., 63), is proclaimed a military reservation for the post of Fort Duchesne, viz:

Beginning at a point two (2) miles due north of the flagstaff of Fort Duchesne, Utah Territory, and running thence due west one (1) mile to the northwest corner; thence due south three (3) miles to the southwest corner; thence due east two (2) miles to the southeast corner; thence due north three (3) miles to the northeast corner; thence due west one (1) mile to the point of beginning. Area six (6) square miles, 2 by 3.

This with the proviso that "the use and occupancy of the land in question be subject to such right, title, and interest as the Indians have in and to the same, and that it be vacated whenever the interest of the Indians shall require it, upon notice to that effect to the Secretary of War."

The corners of the boundaries are marked with sticks 3 feet long, the northwest and southeast corners having bottles buried under the sticks, with a slip of paper in each bearing the words "Northwest corner of Fort Duchesne Military Reservation" and "Southeast corner of Fort Duchesne Military Reservation," respectively. The military post is designed to afford accommodations for six companies of infantry, although it is now occupied by two troops of cavalry. It is furnished with pump works for the water supply of the post, although at present it has no distributing system. A small ditch from the river furnishes water for irrigating purposes. An estimate of the needs for the water supply of this reservation will be given later.

UINTAITE OR GILSONITE DEPOSITS.

By act of Congress approved May 24, 1888, about 7,000 acres of the Uinta Indian Reservation, or what is known as The Strip, was purchased by treaty from the Indians, and thrown open to settlers. The western boundary of this area is only 2 miles from the military post. Several years previous to the opening of this section valuable deposits of asphaltum were discovered within it, which was the reason for the purchase. These deposits are known as uintaite or gilsonite, the latter name being derived from that of the earliest prospector, Mr. S. H.

Gilson, of Salt Lake. A number of other deposits of this character are found southeast of Fort Duchesne, on what was formerly the Uncompahgre Indian Reservation, which was the chief reason for the opening up of the latter reserve. The Fort Duchesne vein is about 2½ miles long and averages 2 feet in width. Its depth is unknown, but it may extend to several hundred feet. This deposit is the one which has received the greatest development, the openings having reached a depth of 175 feet. The quality of the material increases with the depth to a certain limit, the better quality being found at the bottom. This is due to the weathering of the upper layers. Near the point where the Colorado line crosses White River the gilsonite strips are of larger size, being from 12 to 18 feet in width, but they have not been as extensively worked as the one just described, owing largely to lack of railroad facilities. The three largest claims are known as East and West Bonanza and Cow Boy. Black Dragon is the other principal claim. It is located in the region of upper Evacuation Creek, about 15 miles south of the Bonanza and Cow Boy group. Uintaite is employed chiefly in the manufacture of low-grade black varnishes, such as are used on various kinds of iron work and japans. For high-grade varnishes, i. e., for those used on coaches, etc., it is said to be not adapted. It is also used to a certain extent in paving cements. A report on these deposits, by George H. Eldridge, was published in the Seventeenth Annual Report of the United States Geological Survey, Part I, pages 909 to 949.

ALLOTMENTS OF UNCOMPAHGRE INDIANS.

By act of Congress approved June 9, 1897, the President was authorized to appoint a commission to allot lands to the Uncompahgre Indians and to treat with them for the opening up of the remainder of their reservation. These Indians were originally settled upon a reservation in Colorado, but were moved to Utah in 1881. As a compensation for their removal they were to receive the proceeds of the sale of all the lands of their original reservation. For this reason the act above referred to required the Uncompahgres to pay for their allotments at the rate of $1.25 per acre from the proceeds of sales of their reservation in Colorado.

The greater proportion of the old Uncompahgre Indian Reservation is a desert not susceptible of irrigation, the only land adapted to this purpose lying along the bottom of Green and White rivers, and the area is not sufficient for the needs of the Indians. For this reason a second commission was appointed to treat with the Uinta Indians for the sale of certain of their lands along Duchesne River for the purpose of placing the Uncompahgres on them. This latter commission came to an agreement with the Indians, but its recommendations have not yet been ratified by Congress. The allotting commission was to locate the Indians according to the following: Each head of family, 160 acres of irrigable land, with 160 additional acres for grazing purposes; each single person over 18 years of age, 80 acres of irrigable land, with 80 acres for grazing purposes; each orphan under 18 years of age, 80 acres of irrigable land, with 80 acres for grazing purposes; each other person under 18 years of age born prior to the allotment was to receive 80 acres of irrigable land, with the same amount for grazing purposes.

In this way 550 Uncompahgres were given land on the Uinta Indian Reservation, principally along Duchesne River, in 284 allotments of 160 acres each, making a total of 45,440 acres. At $1.25 per acre this amounts to $56,800, which the Uncompahgre Indians will ultimately have to pay to the Uintas. One hundred allotments were made on the bottom lands on Green and White rivers.

The allotments were made subject to ratification by Congress. The commission did not have sufficient time to settle all of the Uncompahgres on lands, so that at the present time about 200 of these Indians are unprovided for. It is something of a problem where they shall be settled. The present allotments on the Duchesne extend to above Lake Creek, and the Uintas have objected to a further extension in that direction. There is no more land on Green and White rivers. These 200 Indians can be settled on the bench lands immediately south of Duchesne River if it can be shown that water can be carried there for the irrigation of the tracts allotted. This can be determined only after a survey of the country, and until this is made it would be impossible for the Indians to be placed there, for the law requires that they shall be given agricultural lands. If surveys show that the country can be irrigated, it would come within that purview.

The following table shows the Uncompahgre allotments on the Uinta Indian Reservation:

	Acres.
Township 3 S., range 1 W	3,360
Township 2 S., range 1 E	640
Township 3 S., range 1 E	8,480
Township 3 S., range 2 E	4,960
Township 3 S., range 1 W	4,480
Township 3 S., range 2 W	9,120
Township 3 S., range 3 W	8,000
Township 4 S., range 3 W	2,240
Township 4 S., ranges 2 and 3 E	3,200
Township 2 S., range 2 E	960
Total	45,440

PRESENT CONDITION OF INDIANS ON THE RESERVATION.

The Indian tribes originally settled on the Uinta Reservation were the following: Gosiute, Pavant, Uinta, Yampa, Grand River, and White River Utes. They all are now known as either the Uinta or White River Utes. On the Uncompahgre Reservation the Indians were the Tabeguache or Uncompahgre Utes. The census for 1899 showed the following number of the latter Indians:

Uncompahgres:	
Males over 18 years of age	294
Females over 14 years of age	298
Boys	128
Girls	118
	838
Southern Utes	13
Total	851

The greater proportion of the White River Utes were first settled on a reservation in Colorado, but after the massacre of their agent, Mr. Meeker, in 1878, they all were moved, two years later, to the Uinta Indian Reservation. The census of June 30, 1899, gave the following figures:

Uintas:	
Males over 18 years of age	144
Females over 14 years of age	135
Children	192
Total	471
White Rivers:	
Males over 18 years of age	111
Females over 14 years of age	92
Children	156
Total	359
Summary:	
Uintas	471
White Rivers	359
Shoshones	3
Delaware woman	1
Uncompahgres, by allotment	550
Total	1,384

The Utes are below the average Indian in intelligence and industry. To within the last few years they have been known as "blanket Indians." They are rather indolent, but, on the other hand, they have not given so much trouble as some of the tribes in other sections of the country. They are taking slowly but surely to civilization, and at the present time a certain portion of their subsistence is the result of their own industry. In the report of the Indian agent for 1898 the following percentages of subsistence are given: Indian labor, 20 per cent; hunting and fishing, 10 per cent; Government rations, 65 per cent; cash annuity, 5 per cent.

The Uinta Indians are the most industrious, cultivating areas of considerable extent. In fact they constitute by far the largest proportion of the farming population. Except for a band located on the upper Duchesne, about 60 miles from the agency, under the leadership of Tabby, who is also the general chief of the Uintas, the greater proportion are located on the west side of Uinta River, between Fort Duchesne and the agency at Whiterocks.

The White River Indians are the so-called bad Indians of the reservation, being located on the east side of Uinta River, in the vicinity of Whiterocks, the Indian agency. They have a few small ditches leading from the Uinta, and cultivate a limited area. The following will show the difference between the Unitas and the White Rivers: The former are requesting that they be permanently located on certain agricultural lands, and that water be furnished them; the latter, in a recent petition to the Government, in which they set forth certain grievances, stated that one of the conditions for a peaceful settlement was that all ditches and wire fences should be destroyed—they wanted nothing to do with such things.

The Uncompahgre Indians who have been located on this reservation within the last two years, are principally on the lower Duchesne River, their allotments covering nearly all of the agricultural lands from the mouth of the river to Lake Creek. The remainder of these Indians, about 200, are now scattered along bottom lands of White and Green rivers.

PRESENT CANAL SYSTEMS WITHIN THE RESERVATION.

The Government has constructed a number of canals on this reservation for the use of the Indians. Canal No. 1, as it is known, heads 1½ miles southwest of the Indian agency, and takes water from Uinta River to the west. This ditch was given a considerable fall throughout its entire length—the fall for the first mile being about 18 feet. The first 5 miles of the canal are along the mesa, which has a very stony soil, in certain sections partially cemented. On account of this characteristic this portion of the canal will permit a high velocity of the water without erosion. Unfortunately, however, while practically the same grade was given to the lower part of the canal, owing to the different quality of soil the erosion has been very great, and in places the canal is severely cut.

At the 5-mile post the water of the canal tumbles over a cliff into a natural channel. From that point to the 8-mile post the fall is 480 feet. At the 9-mile post are diversion works, which again take the water into an artificial channel. Owing to the great descent just mentioned the erosion has been extensive, and a large amount of sediment has been deposited in the stretches of the canal immediately below. On account of these difficulties—deposition in some places and erosion in others—this canal is now practically worthless, and the $20,000 which were used in its construction are practically wasted. At the present time only about 100 acres are irrigated from this canal. The capacity of the canal at its head is about 30 second-feet.

Bench ditch takes water from Uinta River about 5 miles south of Whiterocks, and irrigates the mesa between the military post and the agency. On October 14, when this canal was first measured, it was carrying 49 second-feet. Its maximum capacity is about 75 second-feet. The ranches which it serves form the most attractive feature of the reservation; the different fields are wire-fenced, and one imagines when passing through it that he is in a country cultivated by white men. Prosperous-looking fields of alfalfa and oats are seen on either side of the road, also a number of well-built log houses which have been erected by the Government. A number of these ranches are run by white men who do not own the land but rent it from the Indians. The houses are not all occupied, as one from a distance would suppose, the Indians in a number of cases living in their wickiups erected close by.

The main ditch extends in a southerly direction down the center of the mesa, the last 3 miles being directly along a section line. At the southern extremity of Bench ditch the water tumbles over a cliff a couple of hundred feet in height, and thence finds its way into Dry Gulch Creek, which empties into Uinta River a short distance above the Ouray School. The erosion from this falling water is extensive. and an immense amount of sediment is being transported to Dry Gulch Creek and gradually filling it. In fact, this channel has so filled within the last few years that at the bridge crossing it at the Price road the water is up to the stringers, and a heavy flood in Dry Gulch Creek would certainly carry off the structure.

The third ditch, 100 feet below the bridge and extending toward the Ouray School, 4 miles distant, was designed to divert this heavily surcharged water from Dry Gulch Creek, but it is now so filled with sediment that it is simply a line of sand, on a level with the surrounding banks, extending across the country.

There is a fine tract of agricultural land in the vicinity of the Ouray School, comprising the country between Uinta and Duchesne rivers. Its eastern and western length is about 5 miles. The ditch which irrigates it diverts water from Duchesne River about 8 miles above the school, and owing to the clearness of the water the ditch has not been filled with sediment. Its capacity is hardly sufficient for the entire area, but it could easily be enlarged.

A fifth canal heads on the upper Duchesne immediately above Antelope Creek and about 11 miles above the Price road bridge over the main river. It is 15 feet wide, and will furnish a good supply of water for the bottom lands of the Duchesne.

Two or three small canals divert water from Duchesne River below the Ouray School, and serve land between that point and the lower agency at Ouray. The water is used by the Uncompahgre Indians. The White River Indians on Uinta River, as before mentioned, have a few small canals.

Tabby's band of Uintas, on the upper Duchesne above Strawberry Creek, also cultivates small areas by means of a few ditches. The area cultivated during the last season was approximately as follows:

	Acres.
White Rivers	200
Uintas in the vicinity of Whiterocks	500
Under Bench ditch	1,000
Under Canal No. 1	100
Ouray School country	800
Upper Duchesne	400
Total	3,000

The following statistics are given by the Indian agent in his annual report for 1898:

The Indians had under fence 12,640 acres. The principal crops raised were hay, oats, wheat, and barley. The product of the first mentioned was 2,500 tons. The total for the cereals was 10,600 bushels. At the last round-up of horses and cattle it was estimated that the Indians own 6,020 horses and 2,000 head of cattle. The Uncompahgres have quite a bunch of sheep, approximating 3,500 in number.

PRESENT DIVERSIONS OF WATER FROM THE RESERVATION.

For a number of years water has been diverted from certain tributaries on upper Strawberry Creek within the Indian reservation, carried across the divide, and turned into Daniels Creek, whence it finds its way downward, and is again diverted and used on land in the vicinity of Heber. These diversions were made by white settlers in the latter valley without the consent or authorization of the Indian agent or of the Department of the Interior. The following information relative to these ditches was furnished by Mr. Wayman, overseer of irrigation:

There are three ditches diverting water—Strawberry ditch, Willow Creek ditch, and Hobble Creek ditch.

Strawberry ditch is 3 miles long, with an estimated capacity of 200 miners' inches. Its probable cost was $12,000. It is in fairly good condition.

Willow Creek ditch will carry about 60 miners' inches. It is 7 miles long and cost not less than $15,000. It has a tunnel 1,000 feet long. It is considerably out of repair at the present time, and it will cost about $3,000 to put it in good condition.

The Hobble Creek is a good cheap ditch and is in repair. It is about 2 miles in length, with an estimated capacity of 50 miners' inches.

PRECIPITATION.

Records of the amount of rainfall in this locality have been kept at Fort Duchesne, at Vernal, and at Heber. The latter station is in upper Provo River Valley. It is thought that the record there would better show the precipitation in the mountainous area than would the records at the other stations. The average annual precipitation at Fort Duchesne from 1891 to 1898, inclusive, was 6.79 inches. At Vernal, from 1895 to 1898, inclusive, it was 9.62 inches. Owing to an occasional month when observations were not kept, it is impossible to give an accurate average for the Heber station, but it is somewhere near 17 inches.

These records do not show the amount available for the river supply, as none of them are located in the mountains, which are the source of the main supply. For instance, the Fort Duchesne record would simply show the rainfall on the ranches on agricultural land. The elevation there is 4,941 feet. Without doubt the mountain peaks, which attain elevations of 13,000 feet, receive a greater rainfall and snowfall.

Precipitation at Fort Duchesne, Utah.

[Elevation, 4,941 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889.......	0.35	0.18	0.32	0.68	0.73	0.15	0.49	0.56	0.34	0.66	0.05	1.77	5.28
1890.......	1.01	0.27	0.02	0.21	0.00	0.00	1.35	0.85	0.32	1.17	0.03	0.27	5.50
1891.......	0.22	0.28	0.57	0.99	0.96	0.34	0.24	1.42	1.46	0.00	0.00	1.06	7.54
1892.......	0.40	0.30	0.78	1.24	1.35	0.03	0.16	0.08	T.	0.46	0.14	0.46	5.46
1893.......	0.42	0.44	3.10	2.01	0.92	0.00	0.47	0.57	0.36	0.16	0.24	0.49	9.18
1894.......	0.08	0.19	0.56	T.	0.20	0.34	0.26	0.30	1.88	0.34	0.00	0.69	4.84
1895.......	0.09	0.03	0.09	0.00	1.53	1.02	0.17	0.20	0.03	0.13	0.90	0.31	4.50
1896.......	0.60	0.09	0.14	0.21	1.40	0.03	1.45	0.64	2.23	0.54	0.20	0.00	6.99
1897.......	0.87	0.90	0.28	0.01	0.16	0.02	0.17	0.21	4.61	3.00	0.00	1.20	11.43
1898.......	0.60	0.10	0.75	0.17	0.61	0.45	0.66	0.66	0.08	0.05	0.13	0.10	4.36
1899.......	0.20	0.40	2.10	0.60	0.00	0.05	0.71	0.90	0.00	0.83	0.00	1.20	6.59

Precipitation at Vernal, Utah.

[Elevation, 5,050 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1895.......	1.00	0.54	1.30	0.08	1.51	0.53	0.76	0.40	0.38	1.03	1.33	0.27	9.13
1896.......	0.48	0.29	0.38	0.89	0.94	0.04	1.86	0.58	2.48	0.69	0.42	0.04	9.09
1897.......	0.96	1.11	0.86	0.58	0.62	0.23	1.08	0.26	2.83	2.34	0.42	1.20	12.69
1898.......	0.63	0.47	0.60	0.50	2.03	*a*0.45	0.34	*a*0.66	1.04	0.30	0.39	0.17	7.50
1899.......	0.40	0.55	1.93	0.39	......	0.78	......	1.63	T.	......	......	......	8.41

a Fort Duchesne record.

Precipitation at Heber, Utah.

[Elevation, 5,440 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1893	1.00	2.95	3.35	2.15	0.76	0.02	0.27	0.68	0.28	0.73	1.60	3.95	17.84
1894	3.65	1.60	1.65	0.41	0.54	0.79	0.62	1.16	2.47	1.70	0.00	2.60	17.19
1895	3.22	1.93	1.45	0.48	1.54	0.25	1.37	T.	0.50	0.40	0.60	......	....
1896	2.10	0.95	2.46	2.40	1.85	0.09	3.35	0.55	1.44	......	......	0.75	....
1897	1.30	4.10	2.90	0.90	0.70	0.38	0.56	0.49	3.14	1.50	1.00	......	....
1898	1.40	0.50	3.30	1.25	......	0.83	0.25	0.64	......	1.44	1.60	1.10	....
1899	2.45	5.85	3.00	0.89	......	0.97	......	2.10	0.15	......	......	......	....

WATER SUPPLY OF UINTA INDIAN RESERVATION.

Systematic measurements of the principal sources of the water supply for the Uinta Indian Reservation were begun in 1899, as described in Water-Supply and Irrigation Paper No. 37, pages 288 to 291. The stations were not established until the fall, the season of the lowest flow and also the season when practically no water is used for irrigation purposes. During the last year the low-water flow was much below the average, as stated by residents of the vicinity and by irrigators of Vernal Valley. The measurements will not show, therefore, the amounts available for irrigation purposes. This can be shown only after measurements have been taken for a year, or at least through the irrigating season. At the present time, reports from the observer on the reservation, who is continuing the gagings on the rivers, tend to show that this (1899-1900) is an open winter, with a light snowfall, and that measurements later, or in the spring and summer, when the water is most used, will be of value, because made during a low-water year. This is especially fortunate if it is the policy of the Government to allow water to be taken from the reservation to irrigate lands outside of it. The Indians should be fully protected, and it is desirable to know the minimum flow of the rivers.

Whiterocks and Uinta rivers above their canyon stations drain mountainous areas almost entirely, and hence the run-off per square mile of these basins is greater than for the other stations. In fact, this mountainous area is the efficient collecting area for the remainder of the basin. The increase in drainage area for the Fort Duchesne and Ouray School stations contributes little to the flow of the river except during the flood periods.

Farm Creek is a drainage entering the Uinta between that stream and Whiterocks River. Its collecting area is only 47 square miles at its canyon, and the water is all used on the lands in its basin cultivated by the Indians. The average summer flow probably does not exceed 20 second-feet. During the fall it was 2 second-feet.

The first of the following tables gives the measurements of discharge that have been made on the reservation since the commencement of the investigation in September last. It is followed by tables of the estimated mean monthly discharges.

Discharge measurements of streams in Uinta Indian Reservation.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1899.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-ft.*
Sept. 10	Strawberry Creek	At ford	63	......	84	1.60	134
Sept. 10	Duchesne River	.....do	63	......	81	3.73	302
Sept. 11	Lake Creek	At bridge	63	......	105	1.22	128
Sept. 14	Uinta River	Fort Duchesne	63	......	49	1.76	86
Sept. 15	Whiterocks River	In canyon	63	......	42	2.22	93
Sept. 16	Uinta River	.....do	63	1.15	62	3.08	191
Sept. 26	.....do	Fort Duchesne	63	2.30	45	1.58	71
Sept. 28	.....do	In canyon	63	1.00	46	3.09	142
Sept. 29	Whiterocks River	In canyon, foot incline	63	1.00	34	1.73	58
Oct. 6	Uinta River	In canyon	63	1.00	56	2.84	159
Oct. 7	Whiterocks River	.....do	63	1.00	45	1.67	75
Oct. 14	Canal No. 1	Near head	......	......	75	2.17	16
Oct. 14	Bench ditch	.....do	......	......	12	4.10	49
Oct. 17	Whiterocks River	In canyon	......	1.10	45	1.89	85
Oct. 18	Uinta River	.....do	......	1.10	59	2.79	165
Oct 26	Duchesne River	Price bridge	......	5.48	427	0.94	403
Oct. 27	Uinta River	Fort Duchesne	......	2.40	50	1.67	83
Nov. 1	Whiterocks River	In canyon	......	1.00	41	1.56	65
Nov. 2	Uinta River	.....do	......	1.00	56	2.50	141
Nov. 3	.....do	Fort Duchesne	......	2.50	53	1.93	102
Nov. 15	.....do	Ouray School	63	0.53	76	1.63	124
Nov. 16	Duchesne River	Price bridge	63	5.50	435	1.00	436
Nov. 18	Uinta River	Fort Duchesne	63	2.57	60	2.00	120
Nov. 20	.....do	Ouray School	63	0.56	73	1.72	124
Nov. 24	Bench ditch	At head	63	0.50	8	3.15	26
Nov. 24	Canal No. 1	.....do	63	0.60	3	0.59	2
Nov. 25	Uinta River	In canyon	63	1.00	48	2.48	119
Nov. 27	Whiterocks River	.....do	63	1.05	41	1.60	66
Nov. 29	Duchesne River	Price bridge	63	5.38	418	0.83	360
Dec. 1	Uinta River	Fort Duchesne	63	2.55	61	1.95	120
Dec. 2	.....do	Ouray School	63	0.49	72	1.66	120
Dec. 4	.....do	In canyon	63	1.00	52	2.59	136
Dec. 5	Whiterocks River	.....do	63	1.10	42	1.68	71
Dec. 7	Duchesne River	Price bridge	63	5.50	428	0.90	386
Dec. 8	Uinta River	Fort Duchesne	63	2.43	65	1.72	112
Dec. 9	.....do	Ouray School	63	0.50	74	1.56	115
Dec. 11	.....do	In canyon	......	0.97	60	2.40	136
Dec. 12	Whiterocks River	.....do	......	0.95	45	1.31	59
Dec. 13	Uinta River	Fort Duchesne	......	2.40	69	1.53	107
Dec. 14	Duchesne River	Price bridge	63	5.10	379	0.81	309
Dec. 16	Uinta River	Ouray School	63	0.45	70	1.48	103
Dec. 18	.....do	In canyon	63	1.00	62	2.00	*a*124
Dec. 19	Whiterocks River	.....do	63	0.95	45	1.24	56
Dec. 21	Uinta River	Fort Duchesne	63	2.35	69	1.47	102
Dec. 23	.....do	Ouray School	63	(*b*)	......	......	......

a Ice. *b* Frozen over.

Discharge measurements of streams in Uinta Indian Reservation—Continued.

Date.	Stream.	Locality.	Meter number.	Gage height.	Area of section.	Mean velocity.	Discharge.
1899.				*Feet.*	*Sq. feet.*	*Feet per second.*	*Sec.-ft.*
Dec. 26	Duchesne River	Price bridge	63	(*a*)			
Dec. 27	Uinta River	Fort Duchesne	63	2.59	79	1.67	131
Dec. 28	.....do	In canyon	63	(*b*)	78	1.14	86
Dec. 29	Whiterocks River	.....do	63	(*b*)	59	1.12	66
1900.							
Jan. 3	Uinta River	In canyon	63	1.05	51	2.24	114
Jan. 4	Whiterocks River	.....do	63	0.95	44	1.12	50
Jan. 5	Uinta River	Fort Duchesne	63	2.56	81	1.59	129
Jan. 6	Bench ditch	Near head	63	(*b*)	10	0.80	8
Jan. 8	Uinta River	In canyon	63	0.90	49	2.16	105
Jan. 9	Whiterocks River	.....do	63	0.95	42	1.09	46
Jan. 11	Uinta River	Fort Duchesne	63	2.50	71	1.65	118
Jan. 12	Bench ditch	At head	63	(*b*)	10	0.67	7
Jan. 16	Uinta River	In canyon	63	0.92	49	2.30	113
Jan. 17	Whiterocks River	.....do	63	0.93	40	1.16	46
Jan. 19	Uinta River	Fort Duchesne	63	2.60	49	2.67	132
Jan. 20	Bench ditch	Near head	63	*b*0.40	8	0.82	6
Jan. 22	Uinta River	In canyon	63	1.00	52	2.24	116
Jan. 23	Whiterocks River	.....do	63	0.90	49	1.00	49
Jan. 25	Uinta River	Fort Duchesne	63	2.55	49	2.53	123
Jan. 26	Bench ditch	At head	63	*b*0.95	10	0.73	8
Jan. 30	Uinta River	In canyon	63	1.05	54	2.11	114
Jan. 31	Whiterocks River	.....do	63	0.90	56	0.80	44
Feb. 2	Uinta River	Fort Duchesne	63	2.55	50	2.35	119
Feb. 5	.....do	In canyon		0.90	51	2.19	112

a Frozen over. *b* Doubtful; ice.

Estimated monthly discharge of Uinta River in canyon.

[Drainage area, 218 square miles.]

Date.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1899.				
September	165	9,818	0.73	0.81
October	162	9,961	0.72	0.83
November	130	7,736	0.58	0.64
December	120	7,379	0.53	0.61
1900.				
January	112	6,887	0.50	0.58

Estimated monthly discharge of Whiterocks River in canyon.

[Drainage area, 114 square miles.]

Date.	Mean discharge in second-feet	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1899.				
September	86	5,117	0.76	0.84
October	80	4,919	0.70	0.81
November	66	3,927	0.58	0.64
December	63	3,874	0.55	0.63
1900.				
January	47	2,890	0.41	0.47

Estimated monthly discharge of Uinta River at Fort Duchesne.

[Drainage area, 672 square miles.]

Date.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1899.				
September	78	4,641	0.11	0.12
October	83	5,013	0.12	0.14
November	111	6,605	0.16	0.18
December	114	7,010	0.17	0.20
1900.				
January	126	7,748	0.19	0.22

Estimated monthly discharge of Uinta River at Ouray School.

[Drainage area, 967 square miles.]

Date.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1899.				
November	124	7,378	0.13	0.14
December	113	6,948	0.12	0.14

Estimated monthly discharge of Duchesne River at Price road bridge.

[Drainage area, 2,746 square miles.]

Date.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1899.				
October	403	24,779	0.15	0.17
November	398	23,683	0.14	0.16
December	347	21,336	0.13	0.15

WATER SUPPLY OF FORT DUCHESNE MILITARY RESERVATION.

At present there are stationed at Fort Duchesne two troops of cavalry, numbering 250 people, with 350 animals. Placing the civilian population at 50 would make a total of 300. The Government estimate for water supply for military posts is 2 gallons per person per day and 5 gallons per animal per day. There would, therefore, be required 600 gallons for the inhabitants and 1,750 gallons for the stock, making a total of 2,350 gallons per day. The fort was originally established as a six-company post, which would represent a population of 800 people, with 500 animals, requiring a water supply of 4,100 gallons daily, or less than 0.1 second-foot. Trautwine estimates 60 gallons per day per inhabitant for the water supply for a town. On that basis, for a population of 800 people, 48,000 gallons, or 0.7 second-foot, would be necessary. These figures are very small compared with the amount required for irrigation.

A small acreage, including a garden and lawn, is now irrigated by a ditch from the river heading a short distance above the fort. A liberal estimate of the amount required for this purpose is 2 second-feet, which should, and could very easily, be provided. At present water is pumped direct from the river into a tank, whence it is distributed at the post. During the fall the quality of the supply is excellent, but in the spring Deep Creek, which enters the Uinta about 2 miles above the post, brings down an immense amount of sediment, which makes the supply objectionable. The commander of the post has already requested authority to put in a pipe line, taking the water of the Uinta immediately above the mouth of Deep Creek. If carried out this would insure a good supply of potable water throughout the year.

FUTURE NEEDS OF THE INDIANS AND WATER AVAILABLE.

In planning an irrigation system for any section of the country the first point to be considered is the amount of water that will be required to irrigate a certain area.

The unit of land division in the reservation is 160 acres. It is considered that 1 second-foot for 160 acres is a conservative estimate and sufficient for all needs of the Indians.

On the bench between the military post and the agency, as elsewhere stated, the land has been fenced according to section lines, and certain Indians have been settled there, each receiving 160 acres. Twenty allotments have been made, covering an area of 3,200 acres. It is not possible to give the total number of people living there, as these twenty allotments are to heads of families; but considered on the basis of the Uncompahgre allotment, these twenty allotments would represent a population of 40, with 80 acres to the individual. It was estimated elsewhere in this report that 1,000 acres were under cultivation on this bench land, or about one-third of the available acreage; this is about what the number of Indians at present located there can control. On the basis of 1,000 acres irrigated the area cultivated would be 25 acres to the individual.

Some time in the future all of the Uintas will undoubtedly be allotted lands. This is even now being brought about unofficially, as the Indians request it, by the employees of the agency.

The statistics for the Uncompahgre allotments were based on heads of families, on other males over 18 years of age, and on females over 14. The census simply gives the number of males, females, and children, and not the number of families, so that it is difficult to determine the actual number of acres which the Uintas will require. Estimates can be made, however, based on the Uncompahgre allotments, of which there are 284 of 160 acres each, with 550 people settled upon them. This is about two people to an allotment, or one person to every 80 acres. The total number of Uintas and White Rivers, as elsewhere stated, is 830. On the above basis they would require 80 times that number, or 66,400 acres. Separating these two tribes, we find that the Uintas, numbering 471, will require 37,680 acres, and that the White Rivers, numbering 359, will require 28,720 acres. On the basis of 1 second-foot of water to 160 acres of land, the Uintas will require 235 second-feet and the White Rivers 180 second-feet, or a total of 415 second-feet.

There are on the reservation two distinct tracts of fine agricultural land which are not at present cultivated, and on these Indians can ultimately be settled. East of Whiterocks River is an area of 11,200 acres, most of it in what is known as the Deep Creek country, which is susceptible of irrigation. West of Uinta River and under Canal No. 1 are 40,000 acres, which can also be easily irrigated.

The bottom land of Uinta River is covered with a dense growth of cottonwoods and alders, and a number of Indians are settled along it in the vicinity of Whiterocks. It is very poor land, however, for general agricultural purposes, on account of its rocky nature.

In fact it is simply one mass of river gravel and bowlders, which have been brought down by the streams from the mountainous area. The transporting power of the Uinta is enormous, on account of the grade of the country, which is about 75 feet to the mile, increasing rapidly in the canyons. This bottom land is crossed by a network of river channels of all sizes, very noticeable on the map, and in the spring of the year they are running banks full.

The Indians, especially the White Rivers, will dislike to move away from this bottom land, but their removal should be arranged and they should be given allotments on the fine agricultural bench lands. A compromise might, however, be made by giving them some land along the stream and some land on the benches. The White Rivers are few in number, are unprogressive, and do not take kindly to civilization. They are at present located on the bottom land along the east side of Uinta River. They will, however, undoubtedly desire, from time to time, that land be allotted to them. This can be done by giving them lands from the 11,200 acres of Deep Creek country within the reservation. On the basis of 80 acres to the individual, 140 Indians could be settled there, and on the basis of 1 second-foot of water to 160 acres 70 second-feet will be required to irrigate the same.

A large number of the Uinta Indians are located on Uinta River above Whiterocks. They should gradually be settled on the 40,000 acres of bench land under Canal No. 1, where they can do well. Small patches of agricultural land occur along the river plain, where some of the Indians can be settled. In this way the required acreage (66,400) can be allotted, including portions of this bottom land, the Deep Creek country, and the mesas under Canal No. 1.

It was found that 415 second-feet was the amount necessary to serve the agricultural lands upon which the Uinta and White River Indians would ultimately be settled. From the records of gagings since the commencement of the investigations, the maximum monthly flow of Uinta and Whiterocks rivers in their canyons was in September, 1899, when the total discharge was 251 second-feet. The flow of these streams gradually decreased after that date. According to this there was not sufficient water in the two streams to supply the ultimate needs of the Indians.

As has been stated elsewhere, the last fall has been one of exceedingly low water. The records for the coming spring and summer may show a surplus over 415 second-feet, and if they do, this surplus might be diverted from the reservation. It has been suggested that the surplus of Whiterocks River be thus diverted. It was found that 70 second-feet would be required to irrigate the lands of the Indians in the Deep Creek country east of Whiterocks River. The maximum discharge of this river to date is 86 second-feet. According to this figure, the amount of water was about sufficient for the Deep Creek country.

Undoubtedly there will be a larger supply in the spring. If there should be a surplus in Whiterocks River above the needs of the land adjacent thereto, the same could be diverted into the Uinta at small expense, and used to the west.

The conclusion at present is that there is not a surplus of water in Whiterocks and Uinta rivers beyond the amount that can be used by the Indians in the future.

Another consideration in regard to the taking of water off the reservation is the point of diversion. The Indians undoubtedly have a prior right to the water, and if a canal should be built by outside parties heading above the ditches of the Indians, the latter should, in times of shortage, receive their supply first; but it is too often the case all over the West that a canal company heading higher upstream, though with a later appropriation, receives its quota before those who have prior rights. This might be the case on the Uinta Reservation. It is therefore recommended, if later records show that there is a surplus of water above the needs of the Indians, and if the Department decides to allow this water to be diverted, that the point at which the canal be allowed to take water be located lower down on the stream than the heads of any of the ditches of the Indians. This would more likely insure to the Indians their water rights.

The topographic map shows that the contour of 5,200 feet covers practically all of the agricultural land on The Strip, which, it is understood, is one of the areas desired to be irrigated by water from the reservation. Its contour crosses Uinta River at various points in section 27, township 1 S., range 1 E. It is therefore recommended that no diversions by outside parties, for the purpose of taking water off the reservation, be allowed north of sections 26 and 27, township 1 S., range 1 E., of the Uinta Special meridian.

Lake Creek is an important stream entering Duchesne River from the north, about 15 miles west of Fort Duchesne. It drains an area of 475 square miles, and on September 11, 1899, when it was measured at the bridge a short distance above its mouth, it was carrying 128 second-feet. It may be possible to divert this water to irrigate a portion of the Dry Gulch Creek area, or some of the land that is now controlled by Canal No. 1. From a casual inspection of the ground this would seem feasible, but a survey will be necessary to determine it. If found practicable, some of the Uinta River water could be released and used on the land east of the river and perhaps off the reservation. In other words, we have found, from the records, that the combined water supply of Uinta and Whiterocks rivers is not sufficient to serve the land that will ultimately be needed by the Indians. If it is found that the waters of Lake Creek can be diverted to supply a portion of this country, the Uinta River water might be used elsewhere. As previously stated in this report, there is a large tract of bench land south of Duchesne River which it may be possible to irrigate from Strawberry Creek.

IRRIGABLE LANDS OUTSIDE OF THE RESERVATION.

As already stated, there is an area just east of the reservation, in The Strip, which it is possible to irrigate. The area of agricultural land under the 5,200-foot contour is, approximately, 5,000 acres. East of Ouray School is a large tract of agricultural land, bounded on the west by the reservation boundary line and on the east by Green River. It is in the form of a rude triangle, and comprises, approximately, 17,000 acres. It would seem from a casual inspection of the ground that this tract of land might be irrigated by a canal diverting water from Uinta River below Fort Duchesne and bringing it around to the south of the bluffs overlooking Ouray School. This would be impracticable, however, as shown by the little ditch of the Indians, which skirts the foot of this cliff but can not attain the divide and reach Green River. This tract of land could be irrigated, though, by diverting water above the mouth of Deep Creek, bringing it across The Strip and over the divide immediately south of the Vernal road. As soon as this divide is reached the country slopes rapidly southward and drains into a wash. The 5,100-foot contour crosses the Vernal road divide a short distance east of the gilsonite claim. A canal at that grade and point could easily be continued and turned into the wash, the water being again diverted a short distance below. The 4,900-foot contour controls all of the agricultural land east of the Ouray School.

The main features for a canal to irrigate this land would be as follows: It should head on Uinta River at such an elevation as to cross the little divide in section 35, township 1 S., range 1 E. It will therefore be considered as heading at the 5,180-foot contour. Within a mile and a half it would cross Deep Creek, continue eastward for a short distance, and then southward. It would control most of The Strip country, and could be brought across the Vernal divide at the 5,100-foot contour, at a distance 11 miles from its head. The fall would be greater in its 3-mile course down the dry wash. The water could be diverted again at about the 4,900-foot contour. The general direction of the main canal would thence be southeasterly for 8 miles, then practically due south, in which direction it would continue until Green River and the lower end of the triangular tract of land are reached.

The following are the approximate distances along this canal from the head:

	Miles.
Deep Creek	1.5
Reservation line	4.0
Vernal road divide	11.0
4,900-foot contour, in wash	14.5
At bend to the south	22.0
End of canal	29.0

It will thus be seen that a canal heading at about the 5,180-foot contour could furnish water for most of the agricultural land of The Strip, cross the divide near the lower extremity of the gilsonite claim, and irrigate lands to the south. The amount of irrigable land off the reservation is approximately as follows:

	Acres.
In The Strip	5,000
In the Green River triangle	17,000
Total	22,000

On the basis of 1 second-foot of water to 160 acres, 138 second-feet would be required.

SUMMARY.

The following table shows the amount of irrigable land on and off the reservation:

Table of irrigable lands.

	Acres.
On the reservation:	
West of Uinta River	40,000
East of Whiterocks River	11,200
Uinta River bottom	15,200
Total needed for Indians	66,400
Off the reservation:	
The Strip (so called)	5,000
Green River triangle	17,000
Total	22,000

The total water supply necessary for the Indians, on the basis of 1 second-foot to 160 acres, is 415 second-feet. The maximum supply of Uinta and Whiterocks rivers combined was found in September, 1899, to amount to 251 second-feet, which is not sufficient for the future needs of the Indians.

The amount of irrigable land off the reservation is 22,000 acres. On the same basis as above, this area will require 138 second-feet.

GILA RIVER.

This river rises in southwestern New Mexico, and flows in a general southwesterly direction until it crosses the Territorial line into Arizona at about 32° 40′ north latitude. Its principal sources of supply are from the Black Range on the east and from a number of ranges on the west, including Little Range, Mogollon Range, and Diablo Range. The average elevation of these mountain peaks is from 9,000 to 10,000 feet. The general character of the country is a high and rolling plateau, the river flowing through it in a deep canyon, and with practically no agricultural lands within its area. The river emerges from its upper canyon about 10 miles before it reaches the Arizona line, and then flows through a valley of considerable width known as Duncan Valley, until just before it receives the waters of San Francisco River.

Estimated monthly discharge of Gila River at Buttes, Arizona.

[Drainage area, 17,834 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	800	170	318	19, 552	0. 0178	0. 0209
February	550	125	239	13, 273	0. 0130	0. 0135
March	155	100	131	7, 993	0. 0070	0. 0080
April	100	20	62	3, 689	0. 0036	0. 0040
May	38	4	18	1, 107	0. 0010	0. 0010
June	30	1	5. 4	307	0. 0003	0. 0003
July	8, 700	0. 2	1, 188	73, 060	0. 0666	0. 0767
August	4, 100	60	672	41, 307	0. 0376	0. 0437
September	10, 187	24	733	43, 622	0. 0411	0. 0460

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 319; discharge measurements, pages 317-318.

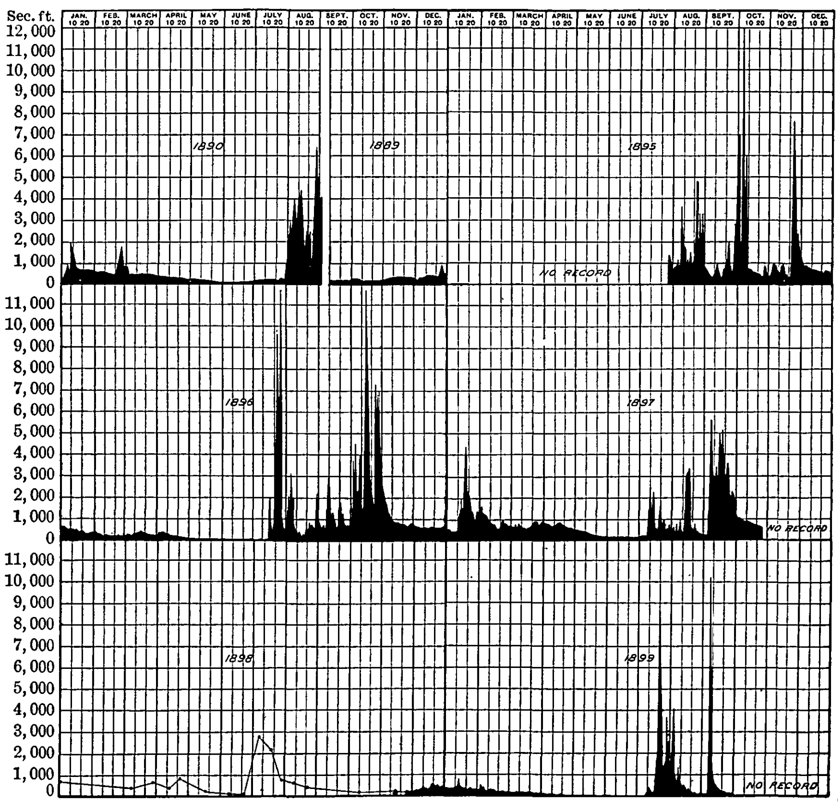


FIG. 197.—Discharge of Gila River at Buttes, Arizona, 1889-1899.

Estimated monthly discharge of Gila River at San Carlos, Arizona.

[Drainage area, 13,455 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
July 11 to 31			1,785	109,755	0.13	0.15
August	3,188	80	405	24,902	0.03	0.03
September	7,920	60	453	26,955	0.03	0.03
October 1 to 14			161	9,900	0.01	0.01

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 314.

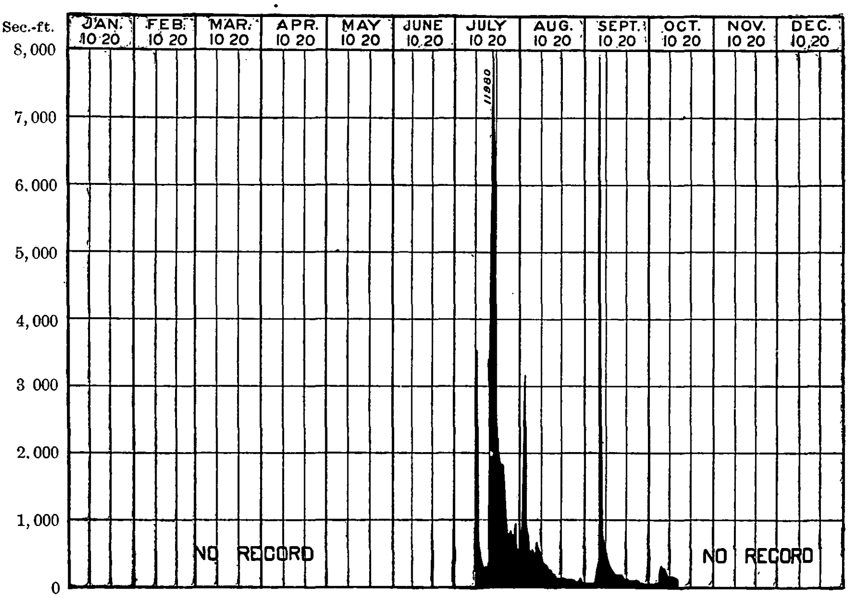


FIG. 198.—Discharge of Gila River at San Carlos, Arizona, 1899.

Year after year the Indian agents and others interested in the welfare of the Pima and Maricopa Indians on the reservations along Gila River, Arizona, have appealed to the Government to take some steps toward securing a supply of water for the cultivation of their lands. The earliest (1535) accounts we have of these tribes mentions their cultivation of the soil by means of irrigation, the water being derived from Gila River. With the settlement of the country by the whites and the development of agriculture more and more water has been diverted from the river above the reservation, and the Indians, although possessing priority of rights, have gradually been deprived of their needed supply. As a consequence of continued agitation, in the fall of 1895 a preliminary examination was ordered. This was prosecuted during the following winter by Mr. Arthur P. Davis, hydrographer of the United States Geological Survey. The results of his investigation are given in Senate Document No. 27, Fifty-fourth Congress, second session. Mr. Davis's report demonstrated the difficulty of securing an ample supply of water without the construction of large storage works, the feasibility of which could be ascertained only through careful engineering examinations. The matter was brought to the attention of Congress, and an investigation was authorized by act approved July 1, 1898 (Stat. L., vol. 30, p. 594).

A brief description of Gila River was published in the Twentieth Annual Report, Part IV, page 405, also in previous annual reports. A general reconnaissance of the river has been made by Mr. Cyrus C. Babb, whose report follows, pages 334 to 356. Detailed surveys of reservoir sites have also been made, under act approved July 1, 1898 (Stat. L., vol. 30, p. 594), reading as follows:

For ascertaining the depth of the bed rock at a place on the Gila River in Gila County, Arizona, known as The Buttes, and particularly described in Senate Document No. 27, Fifty-fourth Congress, second session, and for ascertaining the feasibility and estimating in detail the cost of the construction of a dam across the river at that point for purpose of irrigating the Sacaton Reservation, and for ascertaining the average daily flow of water in the river at that point, twenty thousand dollars, or so much thereof as may be necessary, the same to be expended by the Director of the United States Geological Survey, under the direction of the Secretary of the Interior: *Provided*, That nothing herein shall be construed as in any way committing the United States to the construction of said dam. And said Director shall also ascertain and report the feasibility and cost of the Queen Creek project mentioned in said Senate Document.

In accordance with this law, measurements of the daily flow of water in Gila River at Buttes, also in Queen Creek, were begun; machinery was obtained for ascertaining the depth of bed rock, and field work entered upon for ascertaining the feasibility of water storage and estimating the cost of construction of a dam. The work was at first under the immediate direction of Mr. Arthur P. Davis, but as his services were required by the Isthmian Canal Commission the supervision was placed in charge of Mr. J. B. Lippincott, who had previously assisted Mr. Davis. The results of the investigation have been printed in Water-Supply and Irrigation Paper No. 33, entitled Storage of Water on Gila River, Arizona. The report of the reconnaissance made by Mr. Babb was not, however, published in full in that paper, and it is therefore given herewith.

The location of the river, the Indian reservation, and the principal points mentioned in the report are shown in fig. 199. The Buttes reservoir site is at the point marked "20," and the San Carlos site at the point marked "10."

The reconnaissance of Gila River by Mr. Babb was part of the general system of examination of the feasibility of water storage on this river above the Sacaton Indian Reservation. Detailed surveys were made of the reservoir sites which were found to exist, and estimates of cost prepared. As the conclusions drawn from these investigations are of importance, it was considered desirable to secure the services of a consulting engineer to pass upon the details, as is customary in such cases. Accordingly, arrangements were made with Mr. James D. Schuyler, of Los Angeles, California, who prepared a review of the whole matter, which is also published herein — pages 358 to 379.

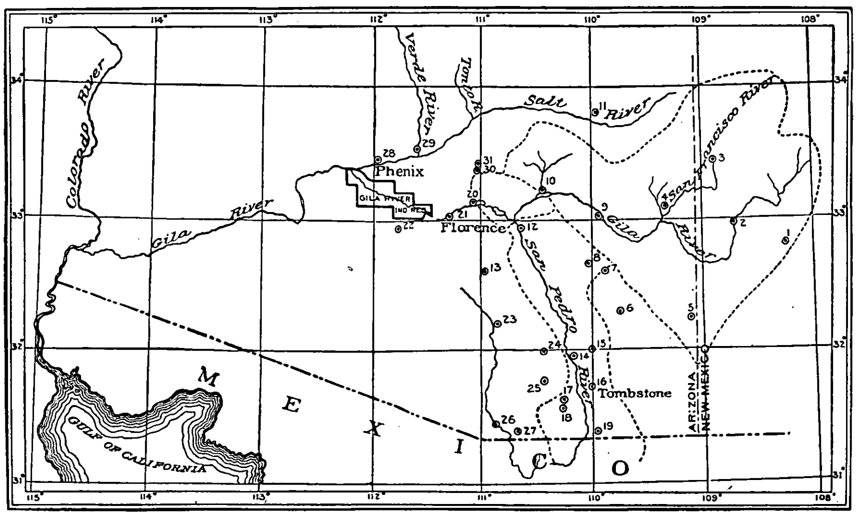


FIG. 199.—Map of portion of southern Arizona.

Rainfall stations:

1. Fort Bayard.
2. Gila.
3. Alma.
4. Oro (Clifton).
5. San Simon.
6. Willcox.
7. Fort Grant.
8. Cedar Springs.
9. Fort Thomas.
10. San Carlos.
11. Fort Apache.
12. Dudleyville.
13. Oracle.
14. Benson.
15. Dragoon.
16. Tombstone.
17. Fort Huachuca.
18. Huachuca Mountains.
19. Bisbee.
20. Buttes.
21. Florence.
22. Casa Grande.
23. Tucson.
24. Pantano.
25. St. Helena Ranch.
26. Calabasas.
27. Lochiel.
28. Phœnix.
29. Fort McDowell.
30. Pinal Ranch.
31. Silver King.

RECONNAISSANCE OF GILA RIVER BASIN, BY CYRUS C. BABB.

Gila River is the most southerly of the large tributaries of Colorado River. It rises in New Mexico and flows westerly across Arizona. It passes alternately through narrow canyons and out upon valleys, where its waters are diverted for irrigation. The development of agriculture by this means has been so extensive that all of the available summer flow is used, and there is need of additional water to bring extensive tracts of fertile land under cultivation.

There are only two stations within this section at which rainfall records have been kept, viz, at Fort Bayard, New Mexico, and at Gila, Arizona. The record at Fort Bayard dates from 1867. Unfortunately, the annual records from 1878 to 1886, inclusive, are missing; since that time they are continuous. The elevation of the station is

6,022 feet. Fort Bayard is located about 8 miles northeast of Silver City, and is really not within the Gila River drainage area; but as it is only a few miles outside of it, the precipitation at the station may be assumed as the average for that country, including the adjoining region of the Gila Basin. The record at Gila, farther down the stream and at an elevation of about 5,000 feet, is continuous from 1895 to 1898, inclusive. The average annual precipitation for that period is 14.98 inches. For the Fort Bayard station the average is 14.06 inches.

DUNCAN VALLEY.

About 10 miles before Gila River reaches the Arizona line the canyon broadens into a valley of considerable width, known as Duncan Valley, named from the town of Duncan, Arizona, located about 5 miles from the Arizona–New Mexico line. A number of ditches divert water from Gila River for the irrigation of this country, numbering in all 17. Their location is shown in fig. 200. A series of measurements of the flow of water in these diversion channels, also of the flow of the main river in the canyon above, was made March 22, 1899. At that time the main river above the head of the Telles, or uppermost, ditch was carrying 160 second-feet. The ditches, beginning at the head of the stream and following down, with their discharges in second-feet, are as follows:

Measurements of discharge of ditches above Duncan, Arizona, March 22, 1899.

No. on map.	Ditch.	Discharge.
		Second-feet.
16	Telles	4.0
15	Rucker	1.6
17	Hughes	2.8
12	Martin	3.0
13	Wilson	4.7
14	Hill	0.0
5	Casper & Windham	6.8
9	Model	0.0
11	Johnson	0.7
10	Schriver	6.2
8	Franklin	13.9
7	Valley	22.9
18	Owen	1.8
6	Day	6.0
4	Ward & Courtney	7.8
3	Duncan	0.0
2	Black & McCloskey	3.8
	Total	86.0

On the same day, March 22, 1899, Gila River was carrying in the canyon above the head of all ditches 160 second-feet. The total amount diverted by the canals was 86 second-feet. At Duncan, below all diversions, the discharge was 104 second-feet, showing a gain of 30 second-feet in a distance of about 15 miles.

Fig. 200 shows the location of the ditches diverting water from Gila River in the vicinity of the Arizona–New Mexico line.

Gila River at Duncan has been dry on two occasions within the last twenty-five years. These droughts occurred, one in June, 1896, and

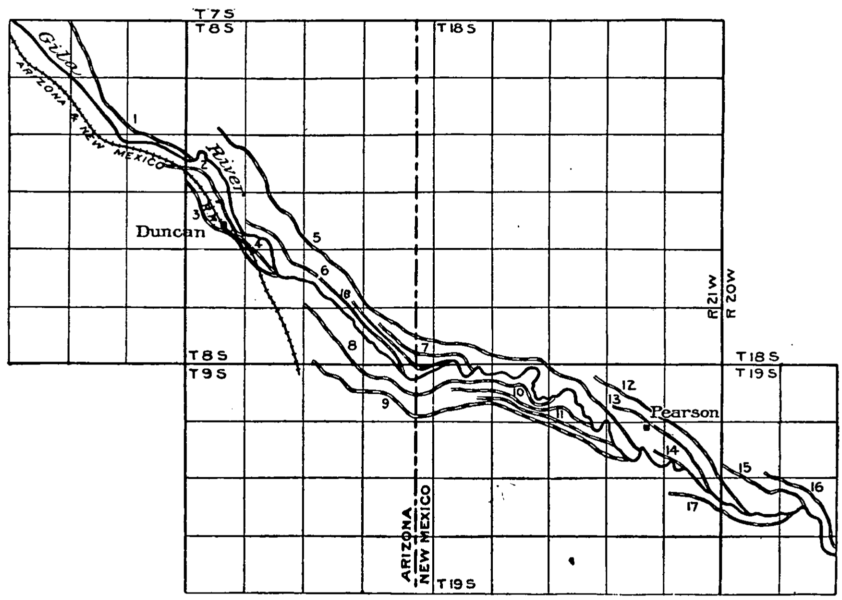


FIG. 200.—Map showing location of canals taking water from Gila River in the vicinity of Duncan, Arizona.

Ditches diverting water from Gila River:

1. Waters.
2. Black & McCloskey.
3. Duncan.
4. Ward & Courtney.
5. Casper & Windham.
6. Day.
7. Valley.
8. Franklin.
9. Model.
10. Schriver.
11. Johnson.
12. Martin.
13. Wilson.
14. Hill.
15. Rucker.
16. Telles.
17. Hughes.
18. Owen.

the other in June, 1897. During August, 1897, occurred the greatest flood within the same period. The water flooded the town of Duncan, rising 8 feet above the river bed.

About 13 miles below Duncan the Gila River is crossed by a lava ridge, through which the river channel has cut a gorge. It is locally known as York Canyon. The gorge is about 200 feet wide at the bottom and about 2,000 feet long, opening above and below into broad valleys. At first sight it would appear that here is an excellent reservoir site. There is one fact, however, which is sufficient to disqualify it from serious consideration. The rock at the dam site is exceedingly poor. It has been greatly contorted and crushed, and at an elevation of about 40 feet above the bed of the river occurs a seam, from 15 to 20 feet in width, of what might be called an unconsolidated clay. Large pieces of this material can easily be broken off by hand. It was considered desirable, however, to make a reconnaissance of the site. The survey was made for a 140-foot dam, as a natural spillway, the lowest elevation of which is 131 feet, occurs a half mile east of the dam site. The main wagon road across the valley passes directly through the spillway. The length of the dam at the bed of the river would be 200 feet and at the top 800 feet. A map of the reservoir site was published as Pl. XXIX of Water-Supply Paper No. 33. The reservoir areas and capacities for each 10 feet in height are given in the following table:

Storage capacity of Duncan reservoir site.

Contour.	Area.	Capacity.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
10	14	70	70
20	45	295	365
30	154	995	1,360
40	390	2,720	4,080
50	699	5,445	9,525
60	1,000	8,495	18,020
70	1,431	12,155	30,175
80	1,875	16,530	46,705
90	2,383	21,290	67,995
100	2,844	26,135	94,130
110	3,311	30,775	124,905
120	3,692	36,365	161,270
130	4,696	43,290	204,560
140	5,552	51,240	255,800

On May 15, 1899, at the time of a second visit to Duncan, the river was discharging only 10 second-feet, having dropped from 104 second-feet since April 30.

Gila River Valley below York Canyon broadens again and then gradually narrows by the closing in of the long stony ridges which extend from the higher mesas above. At Guthrie, at the crossing of the road from Solomonsville to Clifton, the valley is perhaps 300 or 400 yards wide. The canyon proper of this section commences about 2 miles below Guthrie and is about 20 miles long, extending to within 10 miles of Solomonsville. Five miles below Guthrie, Gila River receives its largest tributary—the San Francisco.

Looking westward from the mouth of the canyon above Duncan there appears to be a low divide through which it has been thought water diverted from Gila River at about the canyon could be carried to irrigate lands in San Simon Valley. In order to determine the feasibility of this scheme an elevation line was run from Duncan toward this divide. The summit was not quite reached, an elevation of only about 700 feet above Duncan being obtained. The top of the divide is about 100 feet higher, or at an elevation of 800 feet above Duncan. As the average fall of Gila River above Duncan is about 12 feet to the mile, a level line from the top of the divide would intercept the river about 67 miles above here, passing through a very rough country. These facts show the impracticability of the San Simon project.

SAN FRANCISCO RIVER.

This river, the principal tributary of the Gila, rises at the eastern edge of Arizona, at about latitude 33° 55′ north. Within a distance of 15 miles it passes into New Mexico. This portion of the stream drains about 75 square miles in Arizona. The general course of the river in New Mexico is southerly. It again passes into Arizona at about latitude 33° 10′ north. The area drained in New Mexico is high and mountainous, the principal ranges being the San Francisco, the Tularosa, and the western slope of the Mogollon, with peaks ranging from 8,000 to 10,000 feet. The course of the river through this portion is characterized by a succession of canyons, alternating with valley-like openings which have been more or less settled. At Luna, New Mexico, the valley is about 5 miles long, and has been occupied within the last few years by a Mormon colony, which diverts water by means of a canal heading in Arizona, 12 miles above the town. In April, 1899, this canal was carrying 8 second-feet, which was all the water in the river at the point of diversion.

The average fall of the stream is from 35 to 40 feet to the mile. The side slopes of the valley are even greater than this, and in fact the valleys below, which range from 2 to 3 miles in length and about a quarter of a mile in width, are in the nature of mesa land, the leveler portions being from 30 to 100 feet above the bed of the river. In Luna Valley there are about 1,000 acres under cultivation. Four miles below the town of Luna the river enters a canyon in which it continues for about 15 miles. It is impassable to teams. A few miles above Frisco the canyon again opens into a narrow valley which is somewhat settled. A certain amount of water is collected in the canyon, but is diverted again, by means of two canals, for the irrigation of this section. Three miles below Frisco is a Mexican settlement called Lower Plaza.

Tularosa River, the second largest tributary of the San Francisco, enters that stream about 6 miles below Frisco. On April 10, 1899, it was carrying 15 second-feet, with no water in the main stream immediately above. The Tularosa is in canyon nearly its entire length, except in its upper portion, where irrigation is practiced on a small scale. The principal crops of this section are hay and grain, the altitude being too great for fruits. The elevation at Luna is about 6,700 feet. Toward the mouth of the Tularosa the country gradually closes into a canyon which extends down almost to Alma, a distance of 30 miles. At that point is another narrow valley largely occupied as a cattle ranch. Williams Valley is next below, and is the last opening on San Francisco River before it enters its canyon in Arizona.

Blue River is the largest tributary of the San Francisco. It has its source in Arizona, near the headwaters of the parent stream, and flows almost due south, entering the main stream about 7 miles west of the New Mexico line. Its drainage area is wholly in Arizona, although the stream is within 7 to 10 miles of the Territorial line. On April 5, 1899, this river was carrying 43 second-feet at its mouth, and the main stream, immediately above, 54 second-feet. At Alma the discharge was about 13 second-feet. The gain of 30 second-feet was made in a distance of 30 miles. On April 5, 1899, the measurement of San Francisco River, 13 miles below the mouth of the Blue and about 7 miles above Clifton, gave a discharge of 94 second-feet. Later in the month, or on the 13th, San Francisco River was carrying 92 second-feet 4 miles below Clifton and about 6 miles above its mouth. The next day, at Guthrie, 5 miles above the mouth of San Francisco River, Gila River was carrying 95 second-feet. The two streams, therefore, were discharging about the same amount of water; but later there was more water in San Francisco River than in Gila River. In fact it is probable that the former stream carries more water than the latter during the entire season.

Rainfall records have been kept at Alma, New Mexico, since 1895, and at Oro, Arizona, for the years 1890 and 1891, and from 1896 to the present time. The elevation of the former station is 5,500 feet, and of the latter station about 4,000 feet. These records will be found in the reports of the Weather Bureau.

SOLOMONSVILLE AND SAN SIMON VALLEYS.

Gila River is in canyon for about 20 miles below the mouth of the San Francisco, or to within 10 miles of Solomonsville. At that point it broadens into a large valley, which has been extensively settled and is now one of the finest irrigated portions of Arizona.

The largest body of irrigated land is in the Pueblo Viejo Valley, extending westward from the canyons above Solomonsville. In this valley, besides the land under crop, there are large tracts to which water can be brought by the ditches at present in operation, the names of which, as reported to the Survey by Mr. T. E. Farish in 1889, are given on the next page.

Ditches and irrigable lands of Solomonsville Valley, Arizona.

Ditch.	Length.	Area covered.	Ditch.	Length.	Area covered.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Montezuma	9	6,000	Mejia	5	2,000
San Jose	7	3,000	Maxey	8	4,500
Union	8	6,000	Oregon	5	2,500
Central	12	6,000	Nevada	6	3,000
Sunflower	3	1,500	Darby	4	1,000
Smithville	5	2,000	Michelena	4	1,500
Gonzales	5	2,000			

Besides the foregoing, there are two or three small private ditches, covering, in the aggregate, about 4,000 acres. In Pinal County there are three private canals between the mouth of the San Pedro and the town of Riverside, as follows:

Small canals between mouth of San Pedro River and town of Riverside.

Ditch.	Length.	Area covered.
	Miles.	*Acres.*
Shields	2½	480
Winkleman	1½	480
Brannaman	1¼	320

Many of the ditches mentioned have sufficient water at all times for the area under crop, while others are reported to be dry for a few weeks in June and July. The question of water storage, however, has not yet attained great prominence, for the greater portion of the tilled lands in this basin along the river have ample water, and there are still tracts in various localities which may, with proper care and economy of water, be brought under irrigation.

The location of the canals and ditches in Solomonsville Valley is shown in fig. 201.

From April 14 to 18, inclusive, a series of measurements of the ditches of this valley, also of the main river at various places, was made, in order to determine the amount of seepage waters returning to the river. In all forty-three discharge measurements were made. The results are considered excellent, as all the conditions were favorable, the river not varying during the time stated. In the table on the next page the results of these measurements are given.

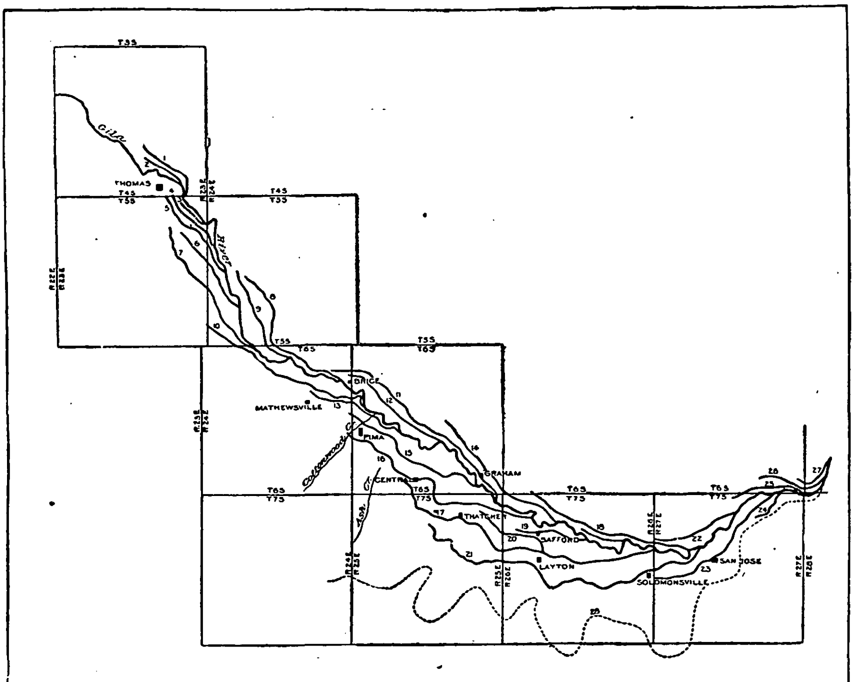


FIG. 201.—Map showing location of canals taking water from Gila River in the vicinity of Solomonsville, Arizona.

1. Saline.
2. Mexican.
3. Lower Thompson.
4. Upper Thompson.
5. Fort Thomas.
6. Reid.
7. Vogel.
8. Curtis.
9. Kempton.
10. Mathewsville.
11. Oregon.
12. Brice.
13. Dodge.
14. Graham.
15. Smithville.
16. Central.
17. Union.
18. Gonzales.
19. Sunflower.
20. Union Branch.
20a. Lee.
21. Montezuma.
22. Michelena.
23. San Jose.
24. Old San Jose.
25. Mejia.
26. Sanchez.
27. Brown.
28. Enterprise (under construction).

Discharge measurements in Solomonsville Valley, Arizona.

Date.	Stream.	Point of measurement.	Year constructed.a	Area of section.	Mean velocity.	Discharge.
1899.				*Sq. feet.*	*Feet per second.*	*Sec.-ft.*
Apr. 15.	Brown ditch	Near head	1883	0.6	1.0	0.6
Do	Sanchez ditch	do	1893	6.1	1.24	7.6
Do	Gila River	Narrows below Sanchez ditch.		141.0	1.68	237.0
Do	Mejia ditch	Below waste	1885	2.1	2.04	4.3
Do	Old San Jose ditch		1881	6.0	1.94	11.6
Do	San Jose ditch		1874	16.0	2.81	45.0
Do	Gila River	Below San Jose ditch		85.0	2.23	189.0
Do	Waste	North side				2.0
Do	Michelena ditch	Below waste gate	1874	5.4	1.73	9.4
Do	Montezuma ditch	do	1873	27.0	3.75	101.0
Do	Gonzales ditch		1884	3.2	1.24	4.0
Do	Gila River	Below Gonzales ditch		43.0	1.47	63.0

a The dates given are on the authority of Mr. Frank Dysart, County Clerk, Solomonsville, Arizona.

Discharge measurements in Solomonsville Valley, Arizona—Continued.

Date.	Stream.	Point of measurement.	Year constructed.	Area of section.	Mean velocity.	Discharge.
1899.				*Sq. feet.*	*Feet per second.*	*Sec.-ft.*
Apr. 15.	Waste	Montezuma ditch		10.3	2.65	27.0
Do	.....do	Above Union ditch		3.5	2.82	10.0
Do	Union ditch	At head	1878	42.0	2.22	93.0
Do	Gila River	Below Union ditch		19.4	0.54	10.4
Apr. 16.	Lee ditch	At head	1892	3.4	1.00	3.3
Do	Sunflower ditch	.....do	1875	2.8	1.76	4.9
Do	Graham ditch	.....do	1882	11.7	1.58	18.6
Do	Central ditch	.....do	1874	11.7	1.66	19.5
Do	Gila River	Below Central ditch		9.5	0.72	6.8
Do	Oregon ditch		1877	28.5	0.39	11.1
Do	Smithville ditch		1880	18.4	0.71	13.2
Do	Gila River	Below Smithville ditch				1.5
Do	Brice ditch		1881	5.7	1.30	7.4
Do	Dodge ditch		1892	10.0	0.67	6.7
Apr. 17.	Mathewsville ditch		1879	13.2	2.50	33.0
Do	Gila River	Below Mathewsville ditch.		3.8	0.74	2.8
Do	Curtis ditch		1881	11.0	1.30	14.3
Do	Gila River	Below Curtis ditch				0.0
Do	Kempton ditch		1882	3.9	2.39	9.3
Do	Vogel ditch		1895			0.0
Do	Gila River	Below Vogel ditch		6.0	1.17	7.0
Do	Reid ditch		1895	2.6	1.47	3.8
Do	Gila River	Below Reid ditch		6.2	1.74	10.8
Do	Fort Thomas ditch		1898	5.6	0.66	3.7
Do	Upper Thompson ditch		1878			0.0
Do	Lower Thompson ditch		1882	4.4	1.20	5.3
Do	Military Ditch Company's ditch.	Flume Fort Thomas	1898	5.5	1.07	5.9
Do	Saline ditch		1898	1.5	0.5	0.7
Do	Mexican ditch			0.8	1.0	0.8
Do	Gila River	Opposite Fort Thomas		8.6	2.33	20.0
Do	.....do	3 miles below Fort Thomas.		33.7	0.97	32.8

Computations of seepage on Gila River in Solomonsville Valley, Arizona.

Stream.	Water in river.	Discharge of ditches.	Waste returning to river.
	Second-feet.	*Second-feet.*	*Second-feet.*
Brown ditch		0.6	
Sanchez ditch		7.6	
Gila River near Narrows below Sanchez ditch	237		
Mejia ditch		4.3	
Old San Jose ditch		11.6	
San Jose ditch		45.0	
Gila River below San Jose ditch	189		
		60.9	
	237—61=176; 189—176=13 second-feet=gain in 2.2 miles=gain of 5.9 second-feet per mile.		
Gila River below San Jose ditch	189		
Waste, north side			2
Michelena ditch		9.4	
Montezuma ditch		101.0	
Gonzales ditch		4.0	
Gila River below Gonzales ditch	63		
		114.4	
	189+2—114=77; 77—63=14 second-feet, loss in 4.5 miles, or a loss of 3.1 second-feet per mile.		
Gila River below Gonzales ditch	63.0		
Waste from Montezuma ditch			27
Waste above Union ditch			10
Union ditch		93	
Gila River below Union ditch	10.4		
		93	37
	63+37=100; 100—93=7; 10.4—7=3.4 second-feet gain in 1.5 miles, or a gain of 2.3 second-feet per mile.		

Computations of seepage on Gila River in Solomonsville Valley, Arizona—Continued.

Stream.	Water in river.	Discharge of ditches.	Waste returning to river.
	Second-feet.	*Second-feet.*	*Second-feet.*
Gila River below Union ditch	10.4		
Lee ditch		3.3	
Sunflower ditch		4.9	
Graham ditch		18.6	
Central ditch		19.5	
Gila River below Central ditch	6.8		
		46.3	
	46.3—10.4=35.9+6.8=42.7 second-feet gain in 5.5 miles, or a gain of 7.8 second-feet per mile.		
Gila River below Central ditch	6.8		
Oregon ditch		11.1	
Smithville ditch		13.2	
Gila River below Smithville ditch	1.5		
		24.3	
	24.3—6.8=17.5+1.5=19.0 second-feet gain in 3 miles, or a gain of 6.3 second-feet per mile.		
Gila River below Smithville ditch	1.5		
Brice ditch		7.4	
Dodge ditch		6.7	
Mathewsville ditch		33.0	
Gila River below Mathewsville ditch	2.8		
		47.1	
	47.1—1.5=45.6+2.8=48.4 second-feet gain in 7 miles, or a gain of 6.9 second-feet per mile.		

Computations of seepage on Gila River in Solomonsville Valley, Arizona—Continued.

Stream.	Water in river.	Discharge of ditches.	Waste returning to river.
	Second-feet.	*Second-feet.*	*Second-feet.*
Gila River below Mathewsville ditch	2.8	....	....
Curtis ditch	....	14.3	....
Gila River below Curtis ditch	0.0	....	....
	....	14.3	....
	14.3—2.8=11.5 second-feet gain in 1.5 miles, or a gain of 7.7 second-feet per mile.		
Gila River below Curtis ditch	0.0	....	....
Kempton ditch	....	9.3	....
Vogel ditch	....	0.0	....
Gila River below Vogel ditch	7.0	....	....
	....	9.3	....
	7.0 + 9.3=16.3 second-feet gain in 4.3 miles, or 3.8 second-feet gain per mile.		
Gila River below Vogel ditch	7.0	....	....
Reid ditch	....	3.8	....
Gila River below Reid ditch	10.8	....	....
	....	3.8	....
	7.0 — 3.8 = 3.2 + 10.8 = 14.0 second-feet gain in 2.2 miles, or 6.4 second-feet gain per mile.		

Computations of seepage on Gila River in Solomonsville Valley, Arizona—Continued.

Stream.	Water in river.	Discharge of ditches.	Water returning to river.
	Second-feet.	*Second-feet.*	*Second-feet.*
Gila River below Reid ditch	10.8		
Fort Thomas ditch		3.7	
Lower Thompson ditch		5.3	
Military Ditch Co.'s ditch		5.9	
Saline ditch		0.7	
Mexican ditch		0.8	
Gila River opposite Fort Thomas	20.0		
		16.4	
	16.4 — 10.8 = 5.6 + 20 = 25.6 second-feet gain in 6 miles, or 4.4 second-feet gain per mile.		
Gila River opposite Fort Thomas	20.0		
Gila River 3 miles below Fort Thomas	32.8		
	12.8 second-feet gain in 3 miles, or 4.3 second-feet gain per mile.		

SUMMARY.

		Second-feet.
Total discharge of ditches		429.8
Gila River near Narrows below Sanchez ditch	237	
Total waste	39	
		276.0
Gain by seepage in 40.7 miles		153.8
Gain by seepage per mile		3.8

The amount of water in the canyon above Solomonsville is 237 second-feet. To this should be added 39 second-feet wasting into the river, making a total of 276 second-feet. In the twenty-four ditches measured, 429.8 second-feet was found to be running. This shows a total gain of 153.8 second-feet in a distance of 40.7 miles, or a gain of 3.8 second-feet per mile. A loss was found between the head of the San Jose and the Gonzales ditches, amounting to 14 second-feet, or 3.1 second-feet per mile. The greatest gain per mile was between the heads of the Union and Central ditches, amounting to 7.8 second-feet per mile. In the valley, about opposite Thatcher and Pima, a number of large washes come in from the south, draining the northern slope of Mount Graham. A portion of the underground seepage may come from the coarse gravel of these washes and not altogether from the return water by irrigation.

The San Simon Valley, which heads some distance south of the Southern Pacific Railway tracks, drains northward and into Gila River. It carries water, however, during the rainy season only, and even then intermittently. In other words, San Simon Creek is a running stream only after a heavy and constant rain. At certain seasons of the year considerable water comes down it, however, as in July, 1899, when the Bowie and Globe Railroad tracks were washed out a number of times near Safford and Solomonsville.

Within recent years, in Solomonsville Valley the low-water flow of the river has been increasing, by reason of the increase in the number of canals and the return of the seepage water from the larger extent of irrigated land; and, as one rancher in the lower portion of the valley has said, they now have less discussion and litigation over the water than they did several years ago, when there were fewer canals.

All of the larger ditches are owned by companies. Each share of stock entitles its holder to a certain amount of water. The Montezuma is the largest canal in the valley, and is a representative example of the method of distributing the water. The stock of the company is divided into 400 shares, and each share entitles its owner to sufficient water to irrigate 10 acres. The discharge of this canal on April 15, 1899, was 101 second-feet, or 0.25 second-foot to the share. One second-foot would, then, irrigate 40 acres. It was found that 429 second-feet was the total amount diverted by all the ditches. With this duty of water the total area irrigated would be 17,080 acres. It has been estimated from tax receipts that 22,000 acres are irrigated. A conservative estimate would probably be 20,000 acres. With 429 second-feet as the total amount of water used, this would give a duty of 1 second-foot to each 47 acres.

A custom which prevails in this section is the renting of shares or portions of shares, and transferring them to different pieces of land. In the decision of Judge Sloan, in the Phœnix district court, February, 1899, this matter was discussed; his decision was adverse to the practice. Another custom, however, which prevails in this section is excellent. In times of scarcity of water, instead of prorating, and thus reducing the quantity of water delivered to each consumer, the water is rotated; that is, an irrigating stream, as it is called, is delivered to a consumer and he is allowed the use of it for a certain number of hours. As the water in the canal lowers, the consumer receives the same amount, but his use of it is limited to a shorter period. In the winter the water is free, or, rather, it can be used at any time. In the spring it is placed "on turn," as it is called, and then the "water boss" divides the water. Ten hours per share is the maximum rate. If a man has a half share, he can use an irrigating stream five hours. The minimum known in the valley is one hour per share. "Irrigating stream" is an expression used in this locality. It evidently means the amount of water that one man can conveniently handle while irrigating. It was difficult to determine the amount of water covered by the term, but it was finally decided to be in the neighborhood of 3 second-feet.

During the spring of 1899 work was being prosecuted on what is known as Enterprise canal. It heads above Mejia ditch and is to be about 36 miles long, 25 feet wide on the bottom, 4 feet deep, and to have a grade of 1.5 feet to the mile. The estimated discharge is 300 second-feet. It will cover about 50,000 acres of land, 25,000 acres of which are now watered by the other canals of the valley. This canal is controlled by the Mormon Church. Work on it has been intermittent during the last three years, and is now proceeding slowly. Very little money is used in the construction. The settlers work out shares in the canal, which are valued at $25 each and cover sufficient water to irrigate 10 acres.

The principal crops of Solomonsville Valley are alfalfa and the cereals, chiefly wheat. The soil is exceptionally fertile, as evidenced by the excellent crops produced, and with its abundant water supply this section of Arizona is very productive. The soil in certain places in the upper part of the valley is of an adobe nature, but a little farther down it is more sandy and gravelly. This characteristic is well shown in exposures along the upper road of the valley leading from Safford to Thomas. In places streaks of very coarse gravel are encountered, and low cliffs of almost unconsolidated conglomerate are passed. The valley proper, on both sides of the river, is level and easily irrigated, but its boundaries are distinctly marked by low foothills rising gradually to the mountains above. It is thus seen that the soil is well adapted to the rapid percolation of water through it, which tends to explain the large increase in seepage, as shown in the tables.

The valley under discussion extends from 10 miles above Solomonsville to the canyon 6 miles below San Carlos, and is about 70 miles long. The portion below Geronimo is within the Apache Indian Reservation. The Indians have a few canals leading from the river, but they do not divert a large quantity of water.

San Carlos Creek is an important tributary, coming in from the north and draining a mountainous section of country in the central portion of the White Mountain Indian Reservation. The valley of the lower 10 miles of its course is rather extensively irrigated by the Indians, who have a number of small canals for that purpose.

Several rainfall stations have been maintained for a number of years in the section under discussion.

San Simon, at an elevation of 3,611 feet, is located on the Southern Pacific Railroad, and the records show the amount of precipitation in the San Simon Valley. The average rainfall from 1882 to 1896, inclusive, was 4.65 inches.

The record at Willcox, at an elevation of 4,164 feet, is continuous from 1881 to 1899. The average annual precipitation for that period is 9.42 inches.

Fort Grant is located on the southwest slope of Mount Graham, at an elevation of 4,860 feet. The rainfall record there dates back to 1873. The average annual precipitation from that date to the present is 15.22 inches. The maximum precipitation—25.67 inches—occurred in 1884, and the minimum—7.90 inches—in 1892.

The record at Fort Thomas, at an elevation of 2,700 feet, is from 1881 to 1890, inclusive. The average for that period is 12.32 inches.

At the military post at San Carlos, at an elevation of 2,450 feet, the record is from 1882 to the present time, the average being 12.31 inches.

Details in regard to the rainfall in Gila River Basin have been published in Water-Supply Paper No. 33, pages 18 to 21.

The record at Fort Apache, with an elevation of 5,050 feet, is mentioned here, although the station is not located within the upper Gila Basin, being within the drainage area of Salt River. The record, however, is probably typical of the section of White Mountain Indian Reservation which drains southward into Gila River through Gila Bonito and San Carlos creeks. These streams head in a mountainous region similar to the Fort Apache country. The rainfall record at this station is from 1876 to 1898, inclusive, and shows an average annual precipitation for that period of 19.54 inches.

GILA RIVER FROM SAN CARLOS TO MOUTH OF SAN PEDRO RIVER.

A reconnaissance traverse of the canyon of Gila River from the San Carlos dam site to the mouth of the San Pedro was made in July, 1899. The river was at an extremely low stage, and in fact it is only under these conditions that a trip through the entire canyon can be made. The distance as found by this survey was 31.5 miles. Results of the map work are shown in fig. 202. At a number of points below the San Carlos dam site the canyon boxes to widths of from 100 to 150 feet. Eight miles below the San Carlos site occurs a box which is almost filled with bowlders of various sizes, ranging from 20 feet in diameter down, which have fallen from the high cliffs above. El Capitano Canyon is the largest drainage coming in from the north. After it has been passed, going downstream, the canyon of the main river widens, averaging from 500 to 700 feet in width, and no further boxes are encountered. At many places through here, should a person be caught by a flood he would find great difficulty in making his way out, owing to the high and precipitous slopes, unless fortunate enough to work his way up some of the small side canyons. The country through this stretch, both north and south of the river, is rough and mountainous, with elevations varying from 3,000 to 5,000 feet. Pinal Mountain, the highest peak on the north, attains an elevation of 8,000 feet. At high altitudes in this mountain range water can be found in the small canyons throughout the greater portion of the year. It disappears, however, through evaporation and percolation, farther downstream. As the survey of the canyon was made in midsummer, when the evaporation was excessive and the river exceedingly low, one would expect to find the discharge diminishing the farther downstream the measurements were made. The flow was practically constant, however, showing that the invisible percolation from the areas of high elevation about offset the evaporation. The entire flow of the river did not vary from 2.5 to 4.0 second-feet, except at one point, 14.6 miles below the San Carlos site, where the water disappeared. It appeared again, however, 4,000 feet below. At that point the river makes a sharp bend, and the distance, in a straight line, between where the water disappears and reappears is only 2,000 feet. This neck of land is about 100 feet above the bed of the river,

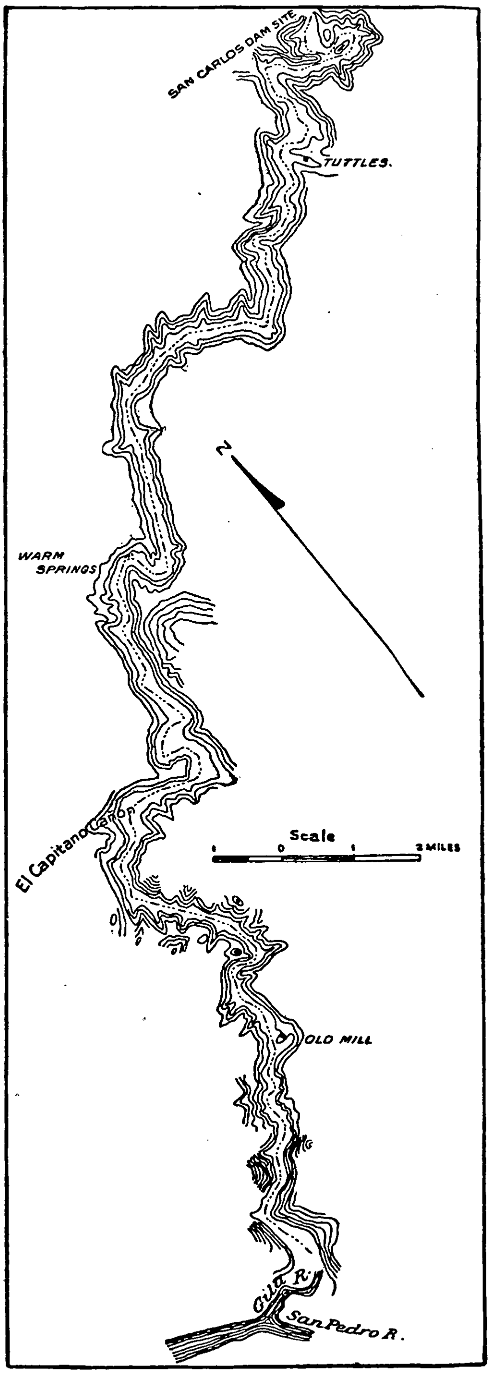


FIG. 202.—Map of Gila River canyon from San Carlos dam site to mouth of San Pedro River.

and it is bordered by a steep cliff of that height. The water comes to the surface in a series of springs at the foot of this cliff on the side next to the place where the water disappears. From there down to within a mile of the mouth of the San Pedro the flow at the time of our visit averaged 3 second-feet. At that point the water disappears and the river is dry until the canyon below Riverside is reached, a distance of 20 miles. This fact tends to prove that there is seepage into the river through the canyon section, as the Riverside Valley is comparatively wide and not bordered by high mountains, especially on the south side. Naturally this lower drainage country would not receive the amount of precipitation that the higher elevations receive, and hence there would not be as much water stored in the ground and slowly percolating to lower elevations.

Again, from the Riverside dam site to the Buttes the river is practically in canyon, with high elevations on either side; the flow of the river is continuous, although slight. Through this section the percolation evidently about offsets the evaporation. To obtain some idea of the amount of water that is evaporated in the Apache Indian Reservation Canyon, which name is applied to the portion of the river under discussion—i. e., to the part which extends from San Carlos to the mouth of the San Pedro—let us draw some deductions from observations taken at the Buttes gaging station. The length of this canyon is 166,100 feet, and at the season of the year when it was visited the river bed, or the wetted portion of it, which is subject to the same evaporation as the water surface itself, averages perhaps 200 feet in length. This would give, through the entire length of the canyon, a surface exposed to evaporation of 33,220,000 square feet, or 762.6 acres. The record at the Buttes shows that the average daily evaporation in July was 0.390 inch. This would give a total daily evaporation of 24.8 acre-feet, or 0.79 acre-foot per mile per day. The distance from the San Carlos to the Buttes dam site is 66 miles, divided as follows: Thirty-one miles from San Carlos site to mouth of San Pedro River; 20 miles from the latter point to the Riverside dam site; 15 miles from the Riverside dam site to the Buttes dam site. Assuming that the river surface, or that portion of it subject to direct evaporation, is 200 feet wide, and that the daily evaporation, as above, is 0.390 inch, the total amount evaporated would be 52 acre-feet per day.

SAN PEDRO RIVER.

This stream rises in Sonora, Mexico, crossing the national boundary into Cochise County, Arizona. Thence it flows in a northerly direction, entering Gila River at Dudleyville, 50 miles above Florence, Arizona. The drainage area in Mexico, as determined from existing maps, is 120 square miles. The total area drained at its mouth is 3,456 square miles. The basin is a long and narrow one, bordered by mountains with an elevation of from 5,000 to 6,000 feet. The river receives its principal supply from the rainfall in the headwater canyons. The period of greatest precipitation is in the months of July and August, when floods of considerable size come down San Pedro River. During the rest of the year the stream is small, winding back and forth in its sandy bed.

The valley of this river is comparatively wide and is occupied by ranches. In its upper half the chief industry is stock raising and the principal crop raised is alfalfa. Lower down, however, more diversified farming is practiced. Beginning about 12 miles south of the railroad and going upstream, most of the valley lands are included in two Spanish claims. The title to the lower claim has been in litigation for a long period, and the land has been taken up by a number of settlers. A very recent decision, however, confirms the original land grant, and, as a consequence, it is the property of a few individuals. It is reported that the small ranchers who were so unfortunate as to locate within its boundaries are now abandoning their homes and moving elsewhere.

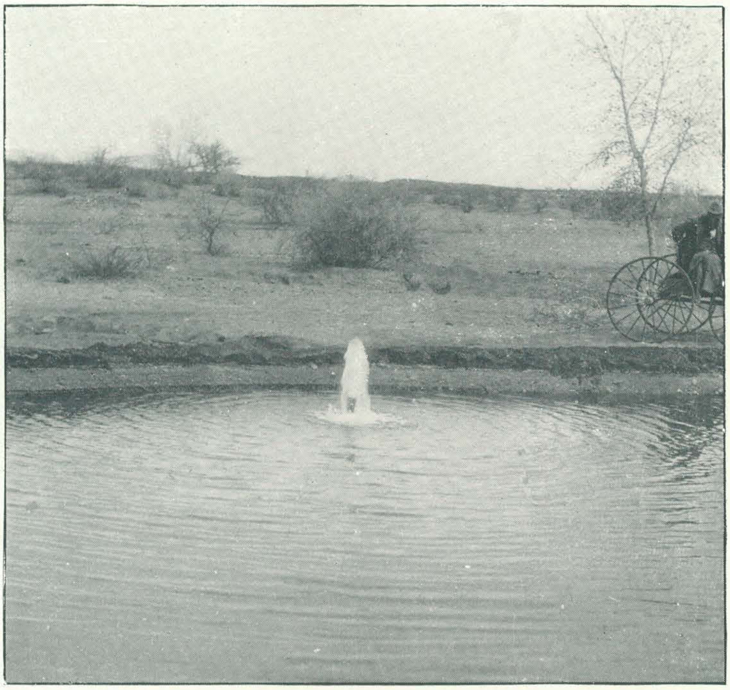
The following is a list of the canals in San Pedro Valley, furnished by Mr. T. E. Farish in 1889:

Canals in San Pedro Valley, Arizona.

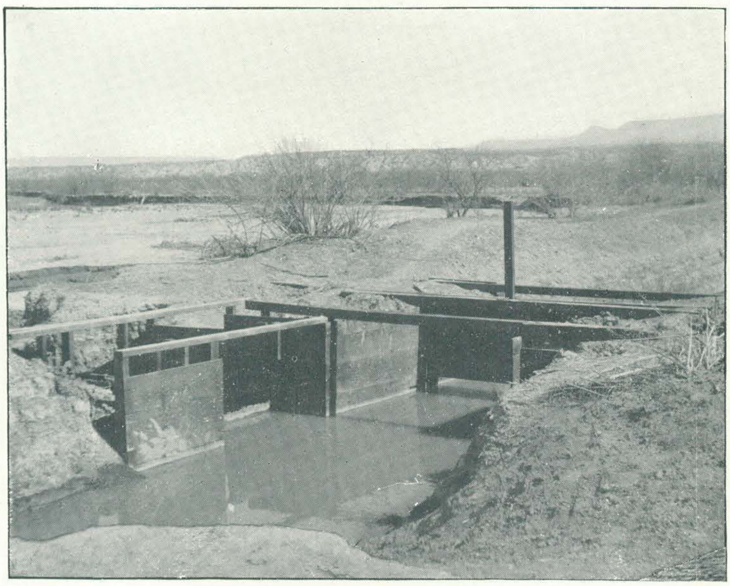
Canal.	Length.	Area covered.	Canal.	Length.	Area covered.
	Miles.	*Acres.*		*Miles.*	*Acres.*
Brown	1¼	160	Watterman No. 2	1½	320
Cook	1½	200	Watterman No. 1	1½	320
Dodson	2	320	Swingle	2	480
Push	2	640	Harrington	1¾	480
Bates	1½	160	Lattin	1	80

In the lower portion of its course the river is in places dry, owing to the diversions made by a large number of small canals. In addition to the main stream there are in the mountains, at the outlets of various canyons, a number of small springs whose waters have been used for agricultural purposes and which are of considerable value to the owners; but these do not form a notable feature in the water supply of the district. The total area upon which crops were raised in this district during the census year 1890, was 2,672 acres, or nearly 4.2 square miles, being 0.15 per cent of the area of the entire basin.

The Mormon settlement of St. David, from 4 to 8 miles above Benson, Arizona, is interesting on account of the artesian wells that have been sunk there. The total number of wells is 55. Of these, 9 occur in sections 33, 34, and 35, township 17 S., range 21 E. The remainder occur in townships immediately south, in sections 3, 4, 5, 8, 9, 10,



A. ARTESIAN WELL NEAR ST. DAVID, ARIZONA.



B. HEAD GATE OF SAN PEDRO DITCH, ARIZONA.

15, and 16. They vary in depth from 150 to 450 feet, the average being 350 feet. The two largest wells are located in township 18 S., range 21 E., and have a depth of 275 feet and 450 feet, respectively. The former is located in the northeast quarter of section 5 and the latter in the northwest quarter of the northeast quarter of section 16 and within a half mile of Old St. David. They each discharge 85 gallons per minute from a 2-inch pipe. The average flow of the other wells is 40 gallons per minute. The formations passed through are, first, soil and gravel to a depth of from 50 to 150 feet, and then a very impervious red clay, with a thickness of 75 to 150 feet, which evidently forms the impervious strata over the water-bearing gravel immediately beneath. This red clay does not have to be cased. The water obtained is excellent for domestic purposes.

Pl. XXXI, *A*, is a view of the flowing well of Peter Gould, near St. David, Arizona. It is 500 feet deep, has a 2-inch pipe, and flows 50 gallons per minute. John S. Merrill also has a flowing well near St. David 295 feet deep, with a pipe 1½ inches in diameter, which flows 45 gallons a minute. It was put down in three days, at a cost of $3.50 per day. The pipe cost 16 cents per foot, making a total of less than $55. It is claimed that this well has sufficient water to irrigate 20 acres of land.

This Mormon settlement also irrigates a maximum of 300 acres from the St. David canal, which was built in 1881. The only canal above St. David is the one irrigating the Spanish claims mentioned.

In T. 12 S., R. 19 E., San Pedro River passes through what is known as The Narrows. At this point are cliffs 25 feet high, the width of the river being 225 feet. Above the perpendicular height of 25 feet the slope on either side is very gradual. The width at the 50-foot elevation is about 800 feet. As the fall of the river is about 18 feet to the mile, the site would accommodate a reservoir of very small capacity. A number of small canals, aggregating 41, take water from the river. They all are individual concerns, serving one or two, and in a few cases three, ranches. There can not be more than 75 ranches served by them, and probably 3,500 acres would represent the amount that is actually irrigated in San Pedro Valley. Fig. 203 is a map of the San Pedro, showing the ditches diverting water from it. The table on the next page is an enumeration of these canals, with the amount of water carried in each, as measured in March, 1899, beginning at the head of the river and following downstream.

Canals diverting water from San Pedro River, Arizona.

Canal.	Location.	Discharge.
		Second-feet.
St. David Canal Co.'s	East side	7.3
Etts	do	1.2
Chisholm	West side	2
Gibson	do	2
Tres Alamosa	do	2
Dunbar	East side	1
Lopnaw	West side	1
Aperdiser	do	1
Bohn	East side	2
Blanchard	do	2
Mexican	do	2
Frenchman	do	2
Pantano	do	1
Mange	do	2
Soso	West side	2
Do	East side	2
Los Angeles	West side	4.2
Warner	East side	2
Patton	do	3
Bayless & Berkalow	West side (from a spring)	3
Do	do	3
Do	East side	3
Miley	do	2
Clark	do	2.3
Acton	do	2
Figueroa	West side	3
Brown	East side	9.1
Busand	do	3.4
Brown & Wills	do	5
Cook	do	6.4
Push	do	4
Dodson	West side	7.6
Indian	East side	1
Finch & Draper	West side	2.8
Swingle	do	3.7
Scott & Cunningham	East side	6.6
Young	do	2
Lattin	do	2
Bates	West side	2
Piercy	do	2
Total		117.6

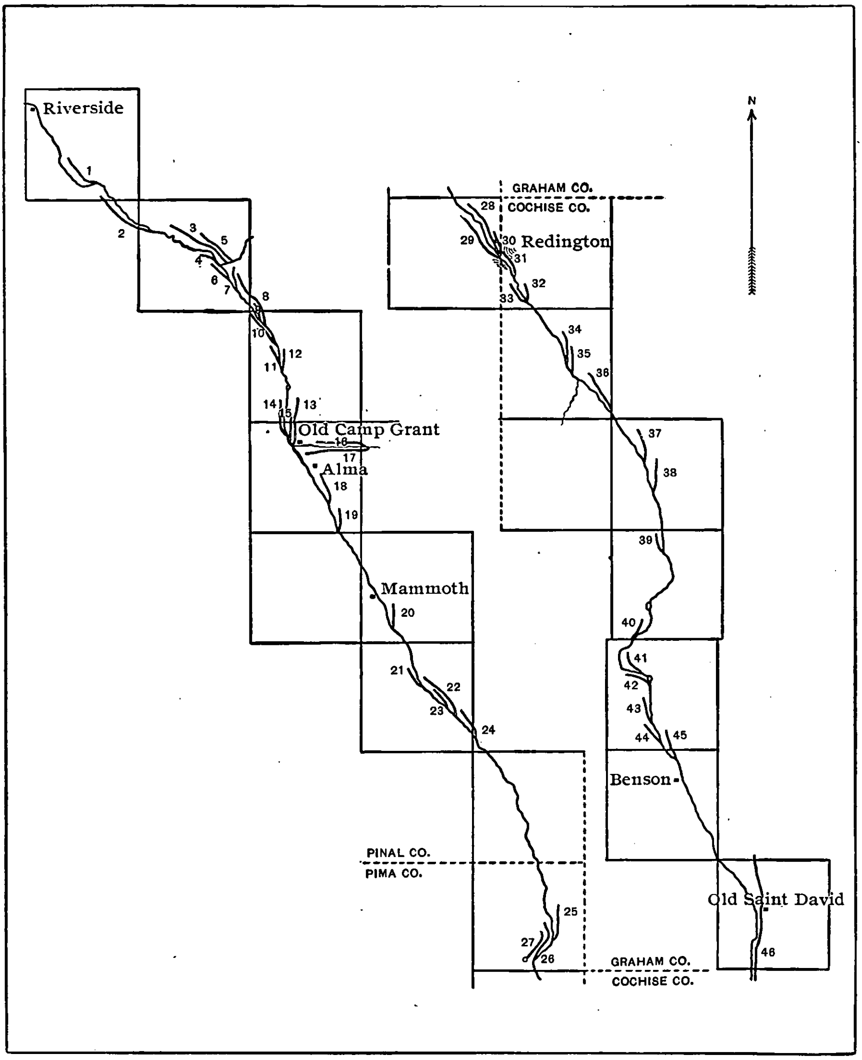


FIG. 203.—Map showing location of canals diverting water from San Pedro River.

Canals:
1. Mason.
2. Branneman.
3. Burns & Lopez.
4. Piercy.
5. Winkleman.
6. Bates.
7. Lattin.
8. Scott & Cunningham.
9. Young.
10. Swingle.
11. Finch & Draper.
12. Indian.
13. Cook.
14. Dodson.
15. Push.
16. Gibson.
17. Putnam & Land.
18. Brown & Wills.
19. Busand.
20. Brown.
21. Figueroa.
22. Clark.
23. Acton.
24. Miley.
25. Bayless & Berkalow.
26. Do.
27. Do
28. Patton.
29. Los Angeles.
30. Warner.
32. Soso, west side.
33. Soso, east side.
34. Pantano.
35. Frenchman.
36. Mexican.
37. Blanchard.
38. Bohn.
39. Aperdiser.
40. Lopnaw.
41. Dunbar.
42. Tres Alamosa.
43. Gibson.
44. Chisholm.
45. Etts.
46. St. David Canal Co.'s.

The San Pedro contributes a very large percentage of the sediment of lower Gila River. The basin of the former stream, as already stated, is largely occupied as cattle ranges, and for ten months of the year the cattle graze over the hills, cutting and loosening the soil, so that when the heavy rains of the summer season arrive the gulleys contain volumes of what may be called liquid mud, which finds its way to the main stream. Probably the percentage of sediment for the San Carlos reservoir site is not so great as for the Buttes. The elevation at the mouth of the river is approximately 1,900 feet, while at Benson, 90 miles upstream, it is 3,550 feet. The distance between the two points being 90 miles, the average slope of the river is 18 feet to the mile.

GILA RIVER INDIAN RESERVATION.[1]

A sketch map showing the location of the canals built by the Indians and supplying water to their lands has been drawn by Rev. Charles H.

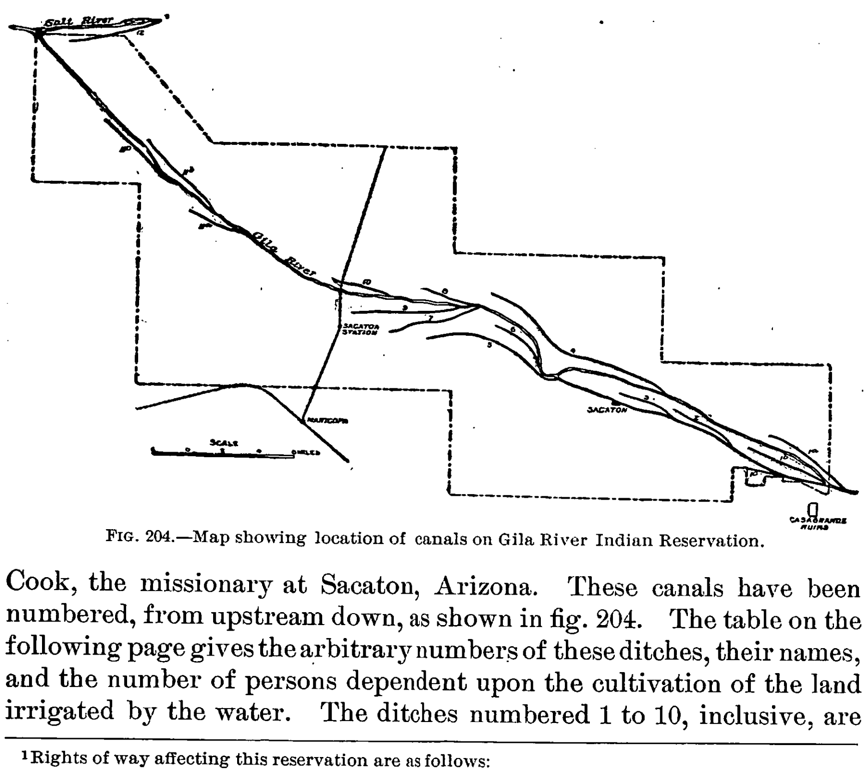


FIG. 204.—Map showing location of canals on Gila River Indian Reservation.

Cook, the missionary at Sacaton, Arizona. These canals have been numbered, from upstream down, as shown in fig. 204. The table on the following page gives the arbitrary numbers of these ditches, their names, and the number of persons dependent upon the cultivation of the land irrigated by the water. The ditches numbered 1 to 10, inclusive, are

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[1] Rights of way affecting this reservation are as follows:

An act to grant to the Hudson Reservoir and Canal Company right of way through the Gila River Indian Reservation. Fifty-fourth Congress, second session, volume 29, chapter 228, page 527, February 15, 1897.

An act granting to Citrous Water Company right of way across Papago Indian Reservation, in Maricopa County, Arizona. Fiftieth Congress, second session, volume 25, chapter 18, page 639, January 1, 1899.

An act granting right of way to the Pima Land and Water Companies across Fort Lowell Military Reservation, in Arizona, and for other purposes. Fiftieth Congress, second session, volume 29, chapter 237, page 693, February 25, 1889.

An act to restore to the public domain a portion of the White Mountain Apache Indian Reservation, in the Territory of Arizona, and for other purposes. Fifty-second Congress, second session, volume 27, chapter 147, page 469, February 20, 1893.

practically without water, while number 11, supplying three Gila Crossing villages, and number 12 (Salt River canal) receive a small amount from seepage.

We are also indebted to Mr. Cook for other interesting facts in regard to these Indians.

Canals on Gila River Indian Reservation diverting water from Gila River.

No.	Village supplied.	Families.	Males.	Females.	Total.
1	Blackwater *a*	91	251	260	511
2	Sacaton Flats, or Hassañkoek	70	183	183	366
3	Cottonwoods, or S'oufpack	47	135	131	266
4	Santan	98	222	221	443
4	Lower Santan, or Hirlchirlechirk	52	119	110	229
4	S'totonñick	39	114	96	210
5	Wakey	61	129	131	260
6	Babechirl	43	95	102	197
7	South Sho-otk	17	53	46	99
8	North Sho-otk	25	48	55	103
9	Railroad Crossing, or South Shonnick	20	38	44	82
10	Highland, or North Shonnick	23	41	46	87
	Total	586	1,427	1,425	2,853

a Three villages supplied by canals 1*a*, 1*b*, and 1*c*.

The following other canals are in use by the Pima and Maricopa Indians:

About 900 Pimas live at Gila Crossing, some 32 to 35 miles below the Sacaton Agency, or about 12 to 15 miles below the Maricopa and Phœnix Railroad crossing. The underground flow of the valley above comes to the surface here and supplies, or partially supplies, four small canals. About 900 Pimas, who formerly lived farther up, now have small farms here and manage to eke out a living.

About 200 Maricopas have a small canal leading from Salt River about 6 miles above its junction with the Gila (see fig. 204, canal No. 12). The land lies very low and much of it is not suited to farming.

The Pimas of the Salt River Reservation, some 12 to 15 miles above Phœnix, about 450 in all, receive water from the Arizona canal—not all that they could use, but enough to enable them to live.

About 90 Pimas and Maricopas live on the east side of Salt River near the Salt River Reservation. Some twenty-two years ago they helped the Mormons to build a canal. Of 220 Maricopas who formerly lived there, only about 9 families are left in the neighborhood;

they have nearly died out. The Mormons have tried at different times to drive them away, but unsuccessfully.

Of the 586 families residing in Gila Valley above the Maricopa and Phœnix Railroad crossing, 432 families have had no water for irrigation during this year (1900) and have raised no crops.

At the heads of the Sacaton Flats, Cottonwoods, and Santan canals (the last two surveyed by Rev. Charles H. Cook many years ago), a little water still comes to the surface during the spring. Out of 154 families, 7 families report an average wheat crop for this year, 17 familes report about three-fourths of the usual crop, 39 families report about half of the usual crop, and 91 families report from one-sixth to one-fourth of the usual crop. In this connection a letter from Mr. Cook, dated May 31, 1900, states that the Santan canal has been dry for several weeks, and that the other two will be dry soon unless they have rains in the near future. He also states that the cattle belonging to the Indians have greatly decreased in numbers during the last two years, and that there is much suffering caused by a lack of the necessaries of life.

The Papagoes, who formerly got nearly all of their bread supply during harvest time from the villages above the Phœnix and Maricopa Railroad, have scattered over Arizona and into Sonora, Mexico, in order to secure a supply of wheat for home use.

WATER STORAGE FOR IRRIGATION ON GILA RIVER, ARIZONA,[1] BY JAMES DIX SCHUYLER.

SCOPE OF INVESTIGATION.

The purpose of the engineering investigation authorized by act of Congress approved July 1, 1898, was to ascertain the feasibility and cost of impounding sufficient water to irrigate the lands of the Gila River Indians. Reservoir sites were known to exist, as shown by a report[2] of a previous investigation made by Arthur P. Davis, hydrographer of the United States Geological Survey. These are at the Buttes, on Gila River, and at Queen Creek, a small intermittent stream draining a limited territory lying between Gila and Salt rivers. The depth to bed rock at these sites had not been definitely ascertained in the original investigation of Mr. Davis, for lack of adequate facilities, and further examination and study of the entire subject had been recommended prior to a definite determination by Congress as to the steps necessary to be taken for the relief of the impoverished Indians, suffering from a lack of water previously enjoyed but appropriated in recent years by settlers higher up the river.

Mr. Davis, who had had valuable experience on similar work on the

[1] Printed as Senate Document No. 152, Fifty-sixth Congress, first session.

[2] Senate Document No. 27, Fifty-fourth Congress, second session

Nicaragua Canal route, was put in charge of the second investigation. He secured the machinery used with success on the Nicaragua work, and was able not only to reach bed rock through the overlying detritus and ascertain its depth below the surface, but to penetrate it and bring samples of it to the light for testing. The history of this work is recorded in detail in the report of Mr. J. B. Lippincott,[1] who was placed in active charge of field operations in May, 1899, on the return of Mr. Davis to his duties in connection with the Isthmian Canal Commission. The depth to bed rock at the Buttes having early been proved so great as to demonstrate that the dam would necessarily be a very costly one, if, indeed, feasible, trial borings were made at the Dikes, 4 miles above, at Riverside, 12 miles above, and at San Carlos, 60 miles above, while surveys were made of a site still farther up the river, at Duncan, near the line dividing Arizona and New Mexico.

The study of the water supply involved a comprehensive examination and measurement of Gila River and all of its main tributaries; an enumeration and measurement of the various canals and ditches diverting water from these streams above the Buttes, and an investigation of the areas of land thus irrigated; a study of the intricate and interesting phenomena attending the return of water to the river from the irrigated fields by seepage; an investigation into the loss of water by evaporation, and the compilation of rainfall statistics from all of the stations where precipitation has been observed and recorded on or near the watershed of the Gila.

In order to determine the feasibility of establishing reservoirs upon the stream, a detailed contour survey of all the projected dam and reservoir sites was necessary; and a computation of their area and capacity and of the area of the watershed tributary to them, a consideration and determination of the volume of silt carried by the river and a computation of its probable total volume per annum, together with a compilation of all the measurements of the flow of the river at all points and times of which there is record, were essential to an intelligent solution of the problems involved.

The study of the cost and feasibility of the erection of dams of the types considered has involved the examination and test of the various building materials available; analyses and tests of strength of the rocks, to determine their suitability for foundations; quarry tests of the neighboring cliffs, to ascertain the behavior of the rocks when thrown down in large masses and their quality beneath the surface exposure; and tests of limestones, clays, and fuels, to determine the feasibility of manufacturing hydraulic lime, natural cement, artificial cement, and sand cement from imported Portland cement, in the endeavor to overcome the disadvantages of the remoteness of the sites from the seaboard and reach the maximum economy of construction.

[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 33.

The successive steps taken in these various investigations are treated at length in Mr. Lippincott's report. It must be concluded, from this brief summary of the work accomplished, that the entire investigation has been upon broad lines, that it has been thorough, and that its general scope, as determined by the engineers in charge, has been sufficiently comprehensive to secure all the data necessary to form the basis for intelligent action.

VOLUME OF WATER TO BE STORED.

One of the first matters to be considered is the volume of water which would be required to irrigate the lands to be tilled by the Indians residing on the Gila River Reservation. This reservation covers an area of 357,120 acres, most of which is arable and irrigable land if water could be had for it, but all of which is arid and unfit for habitation without irrigation. The area is larger than actually required for the sustenance of the Indians. Mr. Davis estimates their needs at about an acre and a half of ground per capita.

The number of Indians now living on the reservation is estimated by the agent to be 7,250, including the migratory Papagoes. In his opinion 2 acres per capita are needed for their sustenance. On this basis nearly 15,000 acres would be tilled if water were provided for irrigation. Assuming a rate of consumption of 2 acre-feet per acre, equivalent to 24 inches of rainfall, the volume of water needed would be 30,000 acre-feet. Possibly a less amount would suffice for immediate needs, but to provide for future increase in population and greater demand as they progress toward civilization a reasonable surplus should be available. It is believed that a storage capacity of 40,000 acre-feet would not be an excessive allowance. More than half of that quantity would probably be used at once if available. This volume of 40,000 acre-feet can be better appreciated perhaps by practical irrigators when it is understood that it would suffice to maintain a canal 10 feet wide at bottom, 17 feet wide at top, and 3 feet deep, flowing at a mean velocity of 2 feet per second for two hundred and fifty days of each year. In the Salt River Valley a canal of this size would be looked upon as an ordinary lateral of a main canal.

QUEEN CREEK PROJECT.

The assumed minimum storage provision required of 40,000 acre-feet is so much in excess of the mean annual run-off of Queen Creek, as determined by the measurements of the last four years, as to render it impracticable to obtain the needed supply from this source. The total run-off during a period of nearly four years, from January 1, 1896, to August 11, 1899, was but 42,500 acre-feet, while the minimum year gave only 6,000 acre-feet. This site being so inadequate for the purposes sought, further discussion of the construction of the dam is quite unnecessary. The sole resource for adequate water supply is therefore narrowed down to the main Gila River.

STORAGE UPON GILA RIVER.

From all previous measurements and available data for the years 1889, 1895, 1896, 1897, 1898, and 1899, Mr. Lippincott concludes that the minimum flow past the Buttes during that period was 353,639 acre-feet per annum, the maximum flow 616,206 acre-feet, and the mean flow 469,093 acre-feet per annum. Having to deal with a river of so large volume, the question at once arises whether it is feasible, desirable, or proper to construct a dam and reservoir in the immediate channel of the Gila of so small capacity as 40,000 acre-feet, through which all the water of the stream must necessarily pass, when the maximum flow of the river is more than fifteen times the suggested reservoir capacity. That the reply to this question should be negative admits of no doubt or discussion.

It may be accepted as an axiom applicable to almost every reservoir site that the nearer its capacity reaches the maximum annual run-off of the stream upon which it is located, unless it is in a basin at one side and fed by a conduit, the longer will be its period of usefulness. This is true because all streams carry more or less sediment in suspension, the total volume of which bears a certain relation to the total volume of flow. On some streams this proportion of silt is very large, and in others it is so small as to be negligible in reservoir calculations. When a sediment-bearing stream passes through a lake or quiet body of water, as a reservoir, its load of silt is mostly precipitated, and the basin in time becomes filled. If the reservoir receives barely sufficient water to fill it once a year, it will last very much longer as a useful storage than if it receives several times as much water as would be required to fill it, with its proportionate amount of sediment. The silt problem is one of prime importance in nearly all reservoirs, but it is particularly serious on streams so heavily laden as the Gila. It would be folly to construct a reservoir of but 40,000 acre-feet capacity across Gila River, unless provision were made to increase the height of the dam every two or three years. This would be injudicious and costly, and would be bad engineering.

For these considerations it has been deemed wise to estimate, in the case of each of the three reservoirs discussed in the following pages, the maximum height of dam which could be safely built or which would form a storage that could reasonably be expected to fill from the stream in driest years. The reason for this decision is manifest. The permanence of the work is a prime consideration, while at the same time the opportunity offers for reclaiming a very large section of the arid public domain with the water that may be stored in addition to the requirements of the Indians. From a financial point of view it is obviously proper to make this enterprise, which is necessitated by simple justice to the Indians, of such magnitude as to reimburse the cost and to be of general utility and advantage.

BUTTES DAM SITE.

The dam site at the Buttes, 14 miles above Florence and 25 miles above the Gila River Reservation, is the first point above the great valley of the Gila where a storage reservoir can be built. On casual inspection it appears to be an ideal dam site. The cliffs rise boldly to a height several hundred feet above the bed of the river, and a gap on one side, a considerable distance from the dam site, seems at just about the right elevation for a natural spillway. The unprofes-

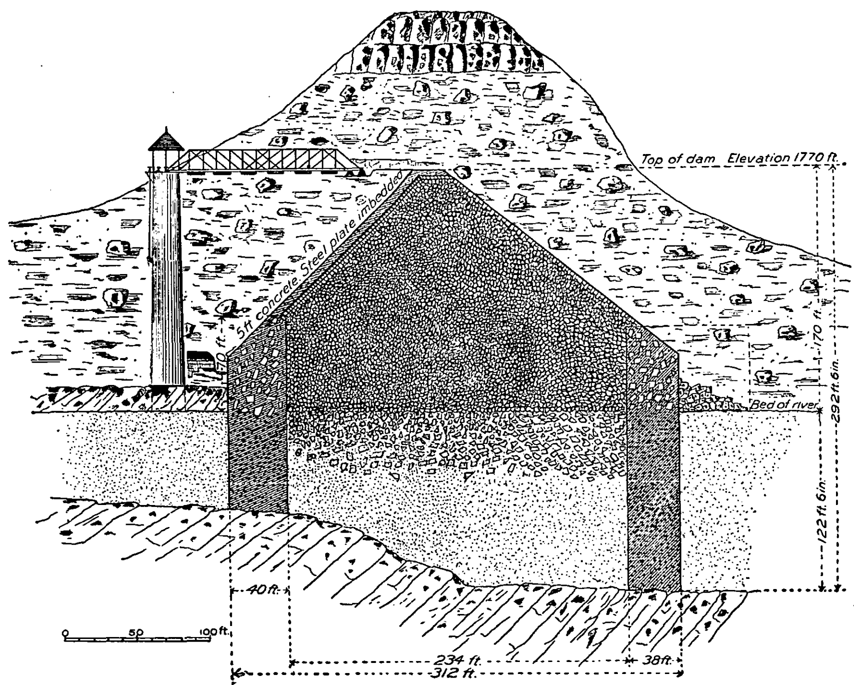


FIG. 205.—Maximum cross section of proposed dam at Buttes, Arizona.

sional man is invariably impressed with the location and is likely to pronounce it a perfect dam site. A careful inspection, however, of the character of the rock composing the abutments, the quality of the ledges available for quarries, the ability of the stone at the "natural spillway" to withstand the erosion of floods pouring over it, and the bearing power of the underlying bed rock to sustain the weight of heavy masonry, made additionally heavy by the great depth of the rock below the surface, is disappointing, and reveals the fact that the site is in reality very inferior.

The extreme height of dam required and the rotten nature of the bed rock determine the unsuitability of the site for a masonry structure which would have a maximum height from foundation to crest of nearly 300 feet in order to form a reservoir of 174,000 acre-feet capacity. This capacity is little more than half what it should be to properly utilize the mean flow of the stream, and no lower dam should be considered at this point. Nevertheless, a dam of the size required surpasses the safe limits of a masonry structure for that purpose and exceeds all known precedents in dam construction. These considerations have rendered it unnecessary to estimate the cost of a masonry dam. The only other type of dam possible to construct at this site, of the height required, is a loose rock embankment with concrete retaining wall at either toe, the water face being made water-tight by a covering of concrete above the toe wall, 5 feet in thickness, with a web plate of sheet steel embedded in the concrete entirely over the face. This kind of dam can be built successfully, although the difficulties to be overcome during construction are serious and numerous. Fully two and probably three years' time would be needed for its erection.

The plan agreed upon and the method of construction proposed are described with minuteness in Mr. Lippincott's report,[1] and need not be repeated here. The writer fully concurs in the general design and indorses the plans as in his opinion practicable, feasible, and operative. The estimates of cost have been prepared after careful study of the entire situation, and are believed to be conservative and safe, without being excessive. Improved methods and mechanical appliances for excavation to the great depths here required, where water is to be encountered, may serve to reduce the cost of foundations below the estimate, but there is always so large an element of uncertainty and so many unforeseen contingencies about all works to be built below the water level in the path of possible great floods that it has been thought best not to reduce the estimate below what is regarded as a safe figure by reason of such known possibilities. There are various alternative methods of performing the work of sinking the foundations for the toe walls other than that suggested in Mr. Lippincott's report. One of these is the Sooysmith freezing method, by which the quicksand on either side of the wall is kept frozen and stable while excavation and construction are in progress. It is perhaps questionable whether this method, which has been successfully employed in sinking shafts in quicksand, could be made equally successful on so large a scale as would be necessary at the Buttes dam, or whether the cost might not be prohibitive.

A second method is that of filling the quicksand on each side of the wall, from surface to bed rock, with Portland-cement grout, injected by pumping the liquid into it through small pipes driven at frequent intervals, the pipes being slowly raised as the cement fills the lower

[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 33.

voids. In this way a wall could be formed on each side of the required excavation which in a few weeks would have sufficient strength to act as a retaining wall or caisson, and be sufficiently impermeable to materially reduce the difficulties of pumping the water from the pit. This method has been described by Robert L. Harris, member of the American Society of Civil Engineers, in a paper read before that society in March, 1891, entitled "A cofferdam or caisson without timber or iron in its construction." Mr. Harris used a mixture of equal parts of cement and fine sand. He subsequently employed the method to solidify quicksands in sewer trenches in Providence, Rhode Island, and obtained a patent upon the application of the method.

Monolithic construction under water by cement grouting was employed by Mr. W. R. Kinipple, member of the Institution of Civil Engineers, in the construction cf breakwaters in England, and the process was described by him in a paper read before the International Maritime Congress held in London, England, in 1893. Mr. Kinipple placed his pipes at intervals of 8 or 10 feet and used pure cement

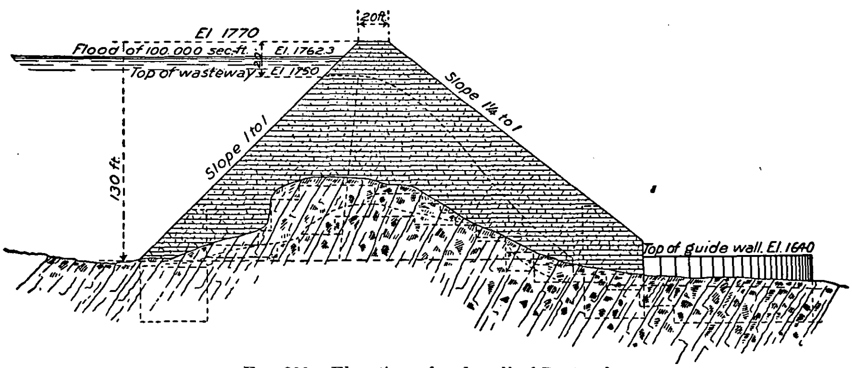


FIG. 206.—Elevation of end wall of Buttes dam.

grout. He found that the grout displaced the water in the voids, converting blocks of broken stone and concrete into a monolith. French engineers many years ago used the grouting method for foundations under water, and Mr. William Worthen, member of the American Society of Civil Engineers, as early as 1845 employed it successfully in repairing the foundations of a flume.

A modification of the grouting method was described by Mr. Fr. Neukirch, of Bremen, Germany, in a paper presented at the International Engineering Congress held in Chicago in 1893. By Mr. Neukirch's process dry cement is introduced into the sand by means of compressed air. The pipe used by him is 1½ inches in diameter, drawn to a point or nozzle at the lower end, in which there are three or more holes three-eighths inch in diameter. The air is reheated to keep moisture out of the pipe and to prevent the cement from clogging, and the pipes are driven by means of an air jet issuing from the point and keeping the sand and water in ebullition. The air was compressed to six atmospheres, and some 500 barrels of cement were thus injected in the works described in the paper.

These citations are made to show that the process of solidifying quicksand in place by injecting cement has been quite generally used on various classes of construction. The research made by the writer does not reveal an instance in which the application has been made to the foundations of a dam in a river bed filled with quicksand, or for the forming of a cofferdam so extensive as would be needed in the case under consideration; but there is no reason to question the feasibility of the methods for the cofferdams needed in the bed of the Gila in the construction of any of the several dams discussed in this report. It may even be possible to solidify in this manner the entire base of the Buttes dam to such a degree of perfection as to obviate the necessity for building the toe walls below the surface, or at least to reduce the construction below to a thin wall at the upper toe, forming the filling of a trench, 8 or 10 feet wide, cut down to bed rock through the solidified quicksand.

It is not suggested that this induration of the quicksand base of the dam site from bed rock up might render it advisable to reconsider the conclusion that a masonry dam is not practicable at this site, because the character of the bed rock is not deemed suitable for such a dam, however broad the artificial base thus formed might be made. An exhaustive series of tests of the density and strength of such solidified quicksand would need to be made before depending upon it as a foundation for masonry. The suggestion is made, however, to illustrate the possibility of improving the nature of the base of the rock fill, in case there were doubts of the stability of the untreated quicksand as a base for the rock embankment, though confined on all sides.

Rock-fill dams are of American origin and of purely western American conception. They were first built in the mining regions of California, for impounding water for hydraulic mining, in the earlier days of the American occupation, and originated from the lack of materials with which to build structures of masonry. At the beginning they were made as log cribs, filled with stone and faced with a skin of wooden planks in two or three layers.

The first improvement upon this crude form was the omission of the log cribs and the building of the embankments with faces of dry masonry of considerable thickness, varying with the height. Many variations of the original form have since been developed, chiefly in the character of materials used to secure water-tightness. Facings of concrete, of stone masonry, of asphalt concrete, of earth, and of steel, and inner cores of steel plates riveted together and smeared with asphalt, have been tried, and a dam is now under construction in Colorado which is to have a facing of steel plates bolted to the bed-rock walls on the sides and bottom and covering its entire inner slope, somewhat in the manner proposed for the Buttes dam, although only partially embedded in concrete. This Colorado dam, which is to store water to furnish the city of Denver with a domestic supply and power, is to have an extreme height of 210 feet from stream bed to crest. Its upper slope will be ½ to 1, and its lower slope 1 to 1. The section is therefore somewhat lighter for equal height than that proposed for the Buttes dam.

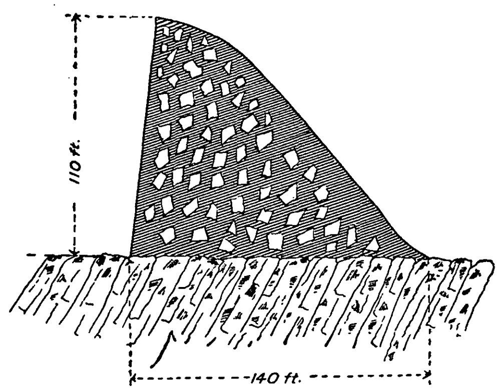


FIG. 207.—Maximum cross section of spillway of Buttes dam.

The spillway provision at the Buttes dam has been confined, in the plans, to the right bank, because of the unstable character of the indurated volcanic ash composing the bed rock at the natural spillway gap. It was decided, as the result of inspection and the quarry and laboratory tests, that this material would not withstand the erosion of a large volume of water pouring over it, in a cascade, at high velocity. To be used at all for that purpose, it would be necessary to cover the dam from its crest down to the river bed with a high class of concrete made of the best selected materials. This construction would be very elaborate and costly. The material forming the right-hand spur or buttress of the dam site is largely composed of glassy perlite, or obsidian, much more dense, of higher specific gravity, and superior in its power to resist erosive action. This was therefore chosen as the most suitable site for the spillway, which has been planned with a length of 650 feet, and will consist of a concrete dam of heavy gravity section, in rollerway form of crest. The greater portion of this dam will be less than 10 feet in height. The top of the spillway will be 20 feet lower than the crest of the rock-fill dam, and its capacity of discharge will be as follows:

Capacity of spillway.

Depth of overflow.	Second-feet.	Acre-feet in 24 hours.
10 feet	73,270	145,000
11 feet	84,400	167,000
12 feet	96,180	191,000
13 feet	108,400	215,000
14 feet	121,200	240,000
16 feet	148,000	294,000
20 feet	206,000	405,000

The capacity of the reservoir being 174,040 acre-feet to the spillway level, it will be seen from the foregoing table that with a depth of overflow of 12 feet the discharging capacity would be sufficient to fill the reservoir in twenty-three hours, and before the rock fill could be overtopped the flow must be double the estimated maximum discharge of the river, as computed by Mr. Davis from highest flood marks, a rate sufficient to discharge in one day almost as much as the mean annual flow of the river during the period of measurement, and sufficient to discharge in a day and a half the maximum total flow of an entire year since observations have begun. It may be safely concluded that the spillway provision, the lack of which has been so often fatal to the stability of dams, has been ample in these plans.

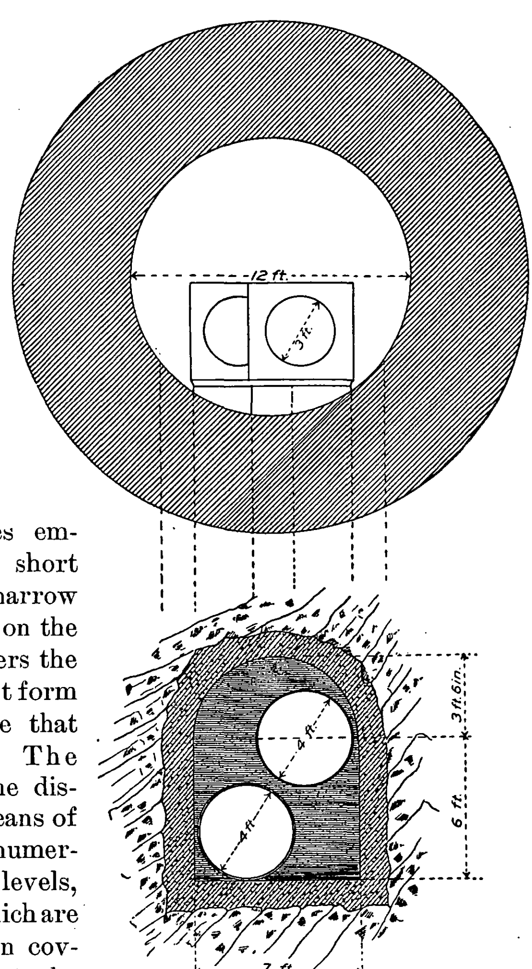


FIG. 208.—Cross sections of tower and outlet tunnel of Buttes dam.

RESERVOIR OUTLETS.

The service outlets of the reservoir have been provided for in the plans by large cast-iron pipes embedded in concrete in a short tunnel cut through the narrow spur of hard perlitic rock on the left bank. This plan offers the most stable and permanent form of construction, and one that is always satisfactory. The method of controlling the discharge of water is by means of a tower provided with numerous elbows, at varying levels, the upturned mouths of which are closed with plain cast-iron covers. Inside the tower, at the mouth of the tunnel, the outlet pipes are controlled by balanced valves, the operation of which is so simple and certain that one man can readily open and close them. At the outer side of the dam a third system of control can be applied by attaching gate valves to the outer ends of the pipes, if it were ever necessary or desirable.

DISTRIBUTION.

It is proposed to release the water into the channel of the river at the dam and pick it up again at the points of diversion below. For the supply of the Indian reservation this diversion can be made, as in the past, until such time as the demand for water will justify the construction of permanent headworks near the Buttes and a proper canal to carry the water away from those headworks. It would be wasteful and improvident to run the water of the reservoir in the broad sandy bed of the Gila for the 22 miles from the head of the Florence canal to the reservation, for it is in this stretch of the river that the loss by absorption is very great. Such a disposition of the stored supply could not be considered as a permissible permanent arrangement, although until the demand for water is great enough outside the reservation to justify the construction of permanent canals and headworks to avoid the waste, the river channel might be used and an abundance of water delivered from the reservoir to supply the Indians.

The Florence canal is located so as to take water from the river channel at a point where all water turned in from a reservoir above could be picked up and conveyed to the public lands that can be irrigated, as well as to the reservation. To serve this enlarged purpose new and permanent headworks should be built, the canal should be enlarged and extended, with large laterals reaching to the reservation as well as to the greater territory of fertile public lands that may be watered from the reservoir outside the Indian lands.

Summarizing the general results of the investigation of the Buttes dam site, it appears that a safe dam can be built at this point, in three years' time, at a cost of approximately $2,600,000, which would store water to a maximum depth of 150 feet, in a reservoir covering 3,149 acres of surface and impounding 174,040 acre-feet of water—36 per cent of the mean annual flow of the river at this point—the dam having a maximum height of 293 feet above lowest foundations. To construct a dam which would store the minimum yearly supply, or 353,000 acre-feet, would necessitate about 40 feet increase in height, which is not deemed feasible at this site.

RIVERSIDE DAM SITE.

The survey of the reservoir basin at the Riverside site developed the fact that its capacity is very great. At the height of 153 feet above low water in the stream it can be made to store double the quantity of water that can be impounded at the Buttes at the 150-foot contour. This height was the limit of the survey. The topography of the site will permit of indefinite extension of the height, limited only by practical bounds of safe construction. With 170 feet depth at the dam the capacity would probably exceed 500,000 acre-feet, and at a height of 200 feet the indications are that the capacity would be more than 650,000 acre-feet. These enormous figures are difficult to comprehend. Comparing them with the maximum yearly discharge that has been observed in the river since measurements began, the reservoir at the height of 200 feet would bottle up the entire river for one year.

A dam of this height would be entirely feasible, and its cost comparatively moderate for a work of that magnitude. The bed rock at the abutments and foundations, as revealed by the surface croppings and diamond-drill borings, is of hard granite weighing 157 pounds per cubic foot. No better foundation could be desired. The site is best adapted to a structure of masonry. The rock available for construction is eminently suitable for masonry or concrete of the class best adapted to dams. Eleven holes reached bed rock, and the maximum depth was found to be 75.5 feet, the minimum depth 6.1 feet, and the mean depth 44.3 feet. The materials composing the river bed are much coarser here than at the Buttes, and the underflow must be materially greater. This condition will augment the difficulties of excavation for foundations, as the percolation of water into a pit would be great in volume. It is believed, however, that the grouting process is applicable to this location, although the injection pipe could not be forced down to bed rock with equal facility. The coarser bowlders and gravel lie next to bed rock, but if the pit could be kept open by holding back the sand that would tend to slip into it, the chief source of annoyance and expense would be overcome. This much, at least, could be accomplished by grouting a zone of 30 or 40 feet thickness across the channel above and below the dam site as deep as the injection pipes could readily be inserted.

The height of dam on which the estimate was based was 133 feet above the stream bed, which gives a reservoir capacity of 221,134 acre-feet, or about 47,000 acre-feet more than the Buttes site at the 150-foot contour, and 20,000 acre-feet less than the San Carlos site at maximum height of 130 feet. The very considerable width of the canyon at this point, requiring a dam 350 feet long at bottom and 850 feet long at top, and the fact that an overflow weir dam seemed best adapted to the situation, account for the large amount of masonry in the 133-foot dam, viz, 186,147 cubic yards. In order to reduce the section and volume of the dam it would be necessary to excavate spillways at each end, in solid rock, where the slopes are so abrupt that a maximum depth of cutting of more than 100 feet would be required to secure the necessary width of spillway channel. Any advantage that might be gained in this way would be overcome by the cost of refilling the spillways with masonry when the dam was raised to its ultimate height.

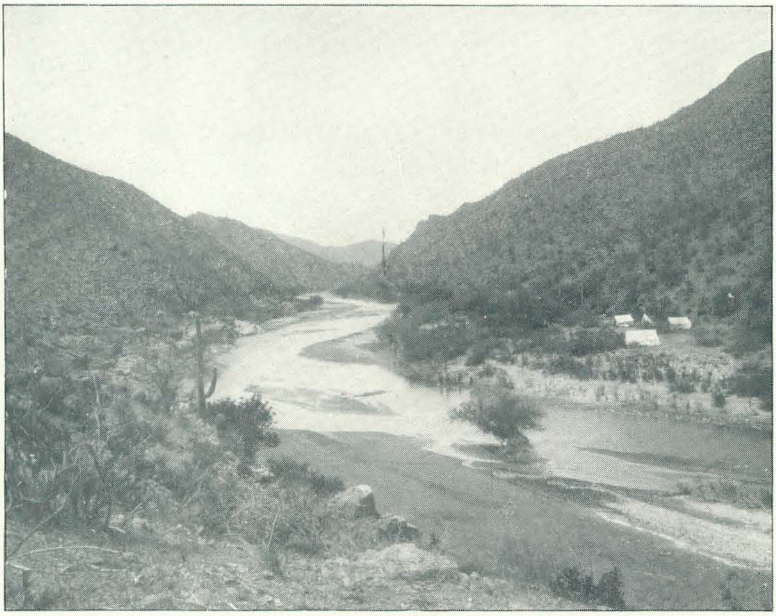
The existence of valuable copper-mining claims within the Riverside reservoir basin, and the recent addition of costly improvements, in the way of reduction works for the Ray copper mines on the river and a railway down Mineral Creek from the mines to the works, offer too many obstacles to consider the utilization of this reservoir site at the present time, and it can therefore only be regarded as available in the future, when it becomes desirable to provide further storage on the river, or when the mines have been exhausted. For present consideration, the cost of a dam at this site, while much less expensive than that at the Buttes, compares so unfavorably with the dam projected 40 miles higher up the river, at San Carlos Canyon, that even were the site free from right-of-way complications the upper location would be preferable. It is assumed that it is the desire and purpose of the Government to provide water storage for the Indians at this time in the cheapest and most effective manner possible.

Pl. XXXII, *A*, is a view of the Riverside dam site, looking downstream; Pl. XXXII, *B*, is a view of Riverside reservoir site.

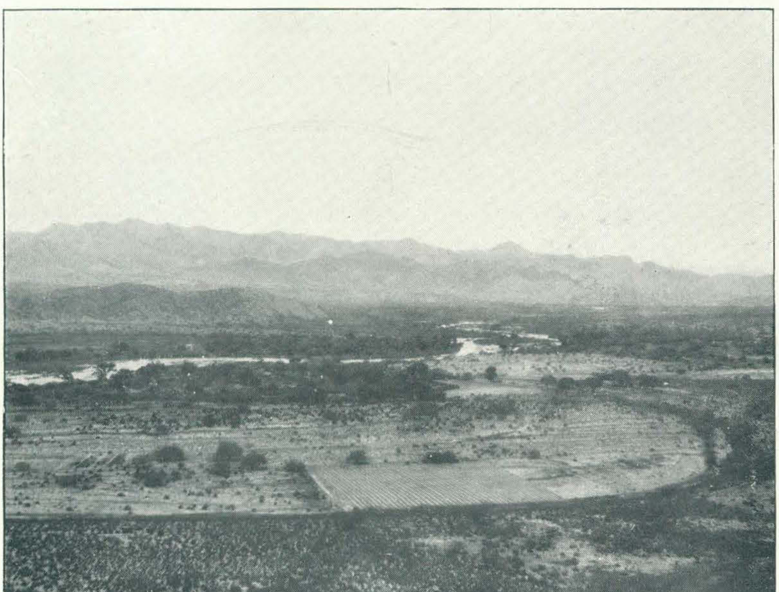
SAN CARLOS DAM SITE.

The exploration of Gila River above the Buttes, made by Mr. Cyrus C. Babb, hydrographer, in the spring of 1899, resulted in the discovery of a dam and reservoir site below the junction of San Carlos River with the Gila, which subsequent surveys have proved to surpass all other sites on the watershed of the river, not only for capacity of reservoir but for cheapness and feasibility of construction of the dam. The site had not before been known to exist, and its discovery is a notable achievement. It is in every way preferable to the Buttes—better in the matter of foundations, materials of construction, capacity of reservoir, and cost of construction. The San Carlos (Pls. XXXIII and XXXIV) is as superior to the Riverside site as the latter is superior to the Buttes site. Comparing the dam sites at Riverside and San Carlos, the latter is, in general terms, one-third to one-fourth the width of the former, requiring about half the amount of masonry, with about the same maximum depth to bed rock, so far as ascertained, and with a quality of rock for foundations, abutments, and construction purposes of higher specific gravity, greater density, and superior resistance to erosion.

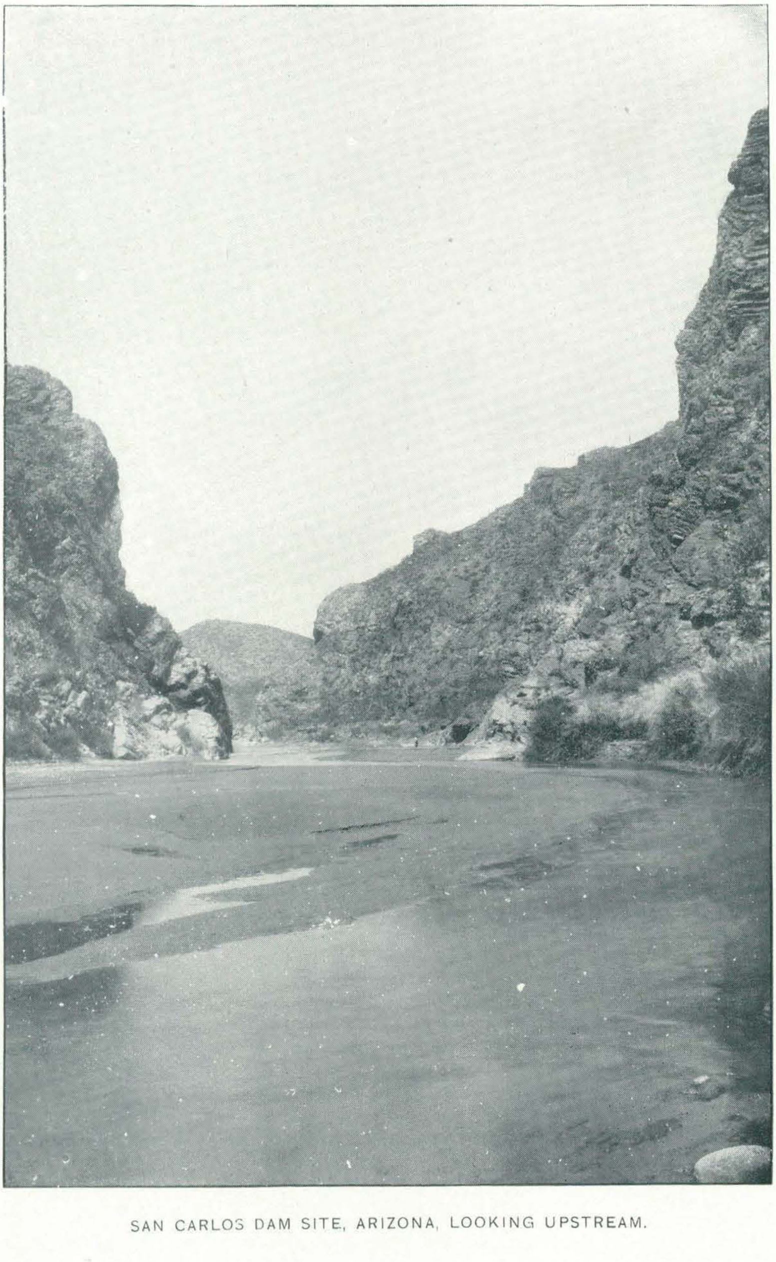
The reservoir basin also is of greater capacity, with a slightly lower dam. The site for the dam is one which is eminently suited to the erection of a masonry structure of the highest type. No other kind of dam has been considered for this site, as it fulfills all requisites of stability in a more satisfactory manner than any other type that could be built and can be made as enduring as time. The form and dimensions of dam best suited to the peculiar conditions there existing have been given careful study by all the engineers engaged upon the work, and as presented in the drawings accompanying Mr. Lippincott's



A. RIVERSIDE DAM SITE, ARIZONA, LOOKING DOWNSTREAM.



B. RIVERSIDE RESERVOIR SITE.



SAN CARLOS DAM SITE, ARIZONA, LOOKING UPSTREAM.

report, it is believed to be well designed and to be located in the most advantageous position available.

The situation permitted the extension of the abutment walls of the dam to such a length as to allow what is believed to be ample spillway capacity around the ends of the main dam, without overtopping

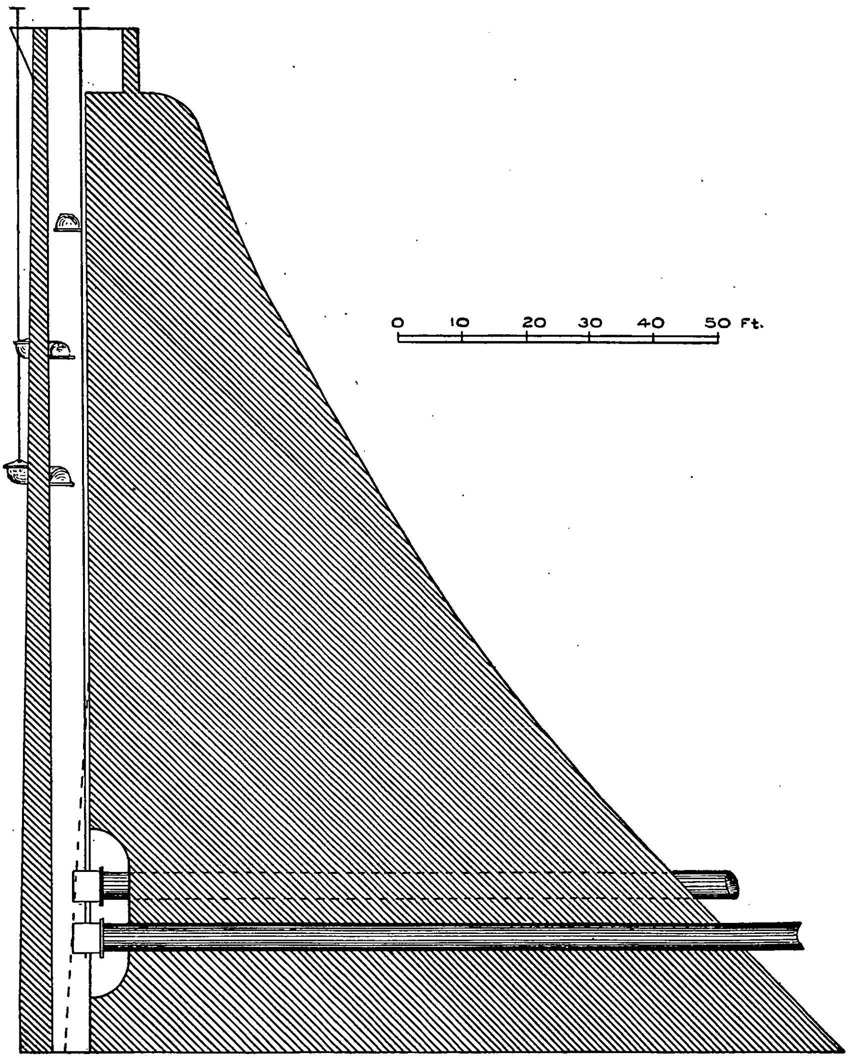


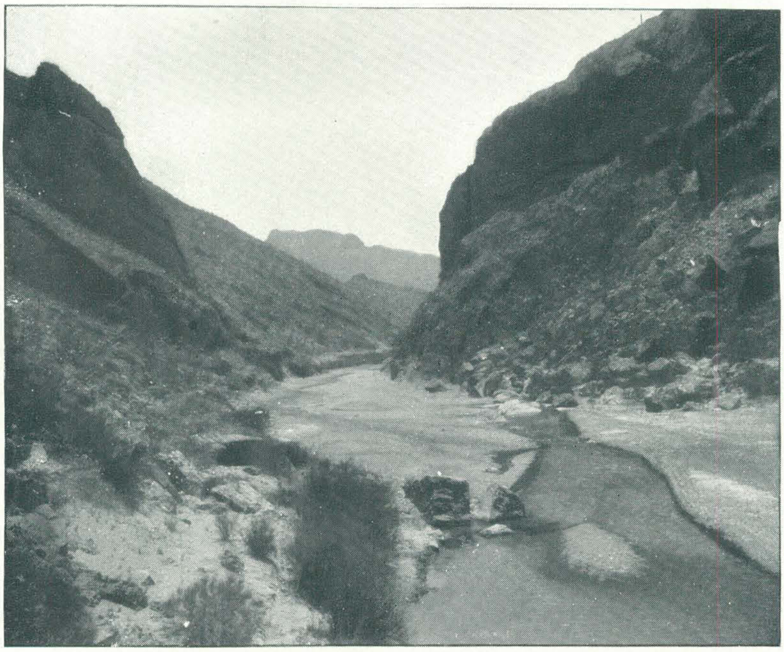
FIG. 209.—Cross section of San Carlos dam through tower.

its crest. The capacity thus provided exceeds 57,000 cubic feet per second, with a depth of 12.5 feet in the spillways. Three feet additional depth would give a capacity exceeding 79,000 second-feet in the spillways and 4,000 second-feet over the crest of the dam. There appears to be a doubt as to the volume of maximum floods in the Gila, and a lack of reliable data regarding it. In previous pages of this report attention is called to the disproportion between the assumed maximum flood discharge of 100,000 second-feet, as computed from measurements of flood marks by Mr. A. T. Colton, quoted in Mr. Davis's report of 1896, and the maximum annual discharge of the river, which would be made up in three days at the rate of 100,000 cubic feet per second. If the river ever reaches so high a rate of discharge it must be for but a few hours at a time, and possibly but a portion of an hour, while the crest of the flood wave is passing.

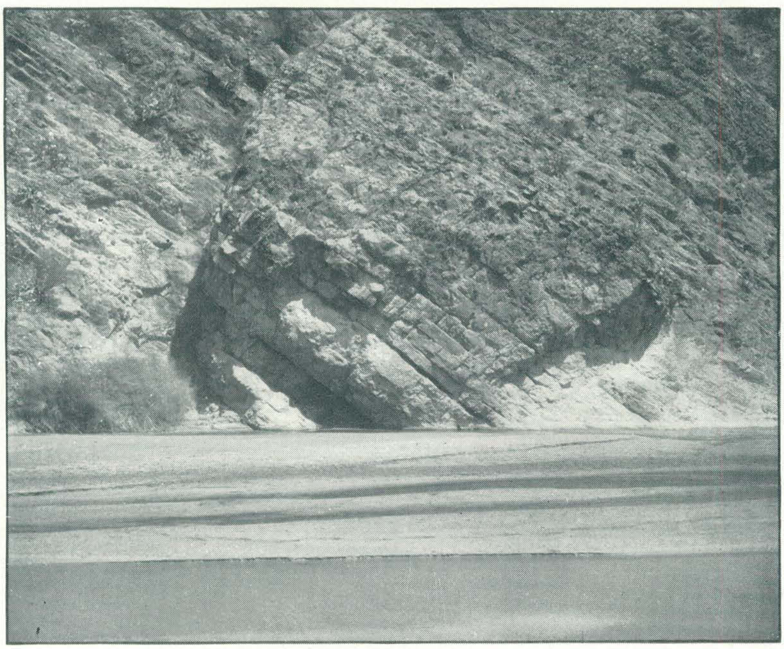
In a large reservoir the equalizing effect of the storage area above the crest of the spillway would tend to modify the overflow at the dam to discharge very much below the assumed maximum. For example, the San Carlos reservoir could receive a flood of 100,000 second-feet (assuming it to be full when the flood wave reached it), flowing for nearly two hours before the depth over the spillways would be more than 1 foot, and the maximum would have to be maintained for about twenty-four hours before the spillways would be filled to the level of the top of the dam, and in the twenty-four hours the amount of discharge would be equivalent to half the mean annual discharge of the river as determined by the gagings that have been made. This is so improbable that it is almost a demonstrable certainty that the dam proper would never be called upon to pass any water over its crest. The writer is of the opinion that not more than 25,000 second-feet will ever be wasting over the dam at one time. He believes, therefore, that the spillway provision is ample. Pls. XXXIII and XXXIV are views of the San Carlos dam site; Pl. XXXV is an elevation of the dam and wasteways.

The estimate of cost of the dam, including damage to the buildings of the Indian agency and military post, the construction of a new system of irrigation for the Apache Indians higher up the river, and the removal and reconstruction of the railroad that now passes through the basin, is $1,015,927. This figure is a very liberal one. It includes $150,000 for the excavation of foundations, which is at the rate of nearly $5 per cubic yard for the material that would have to be taken out if a tight cofferdam were sunk to bed rock at the upper and lower toe of the dam. The estimate of $6 per cubic yard for the concrete masonry may appear low for a locality so remote that railroad freights from the seaboard bring the cost of Portland cement to about $8 per barrel. (This latter figure is used for safety, on the basis of present quotations on freights, although when actual construction begins it is confidently believed that special rates may be made on large quantities that will be materially lower.) The method proposed of regrinding cement with silica sand in equal parts and producing a product commercially known as "sand cement," as recommended by Mr. E. Duryee, C. E., in his report,[1] offers the possibility of so material a reduction

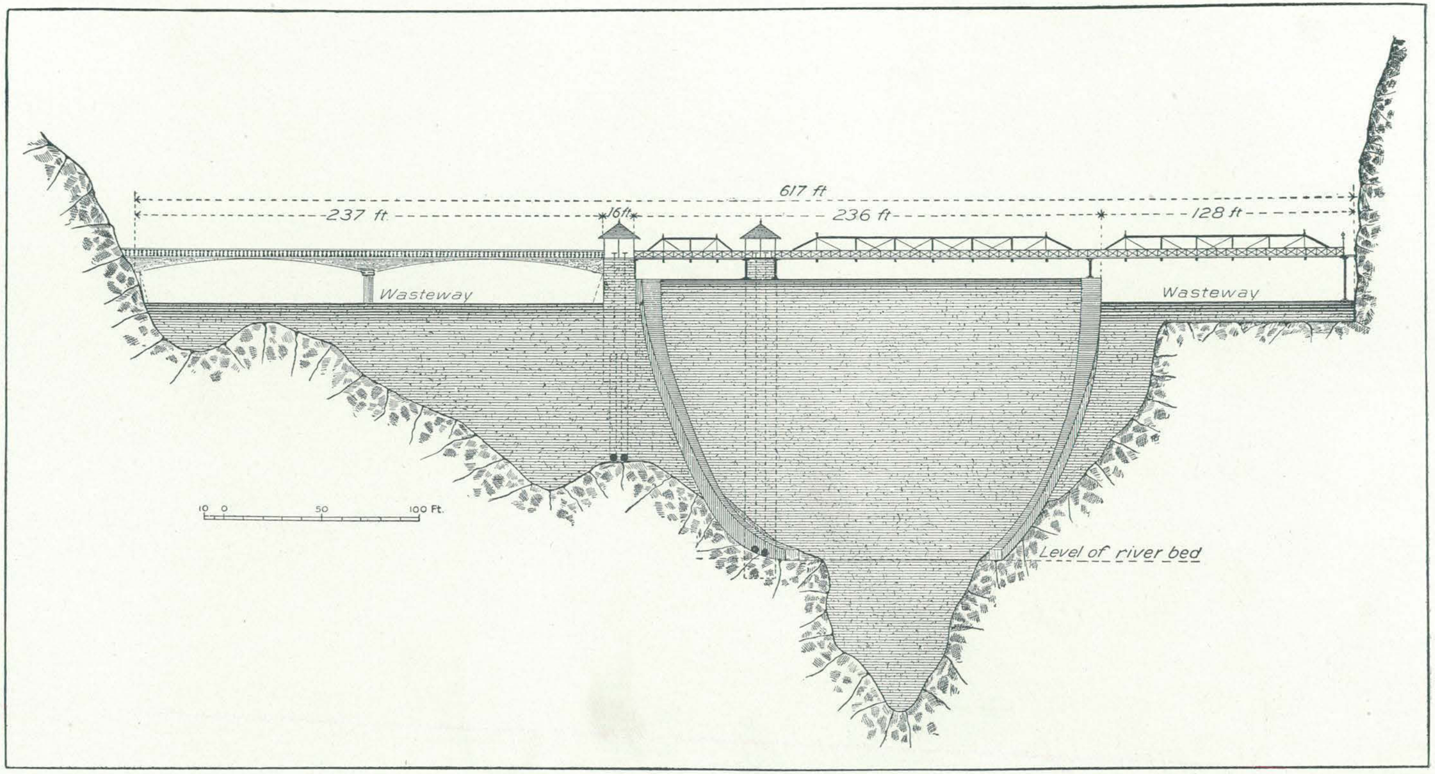
[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 33, pp. 82–90.



A. SAN CARLOS DAM SITE, ARIZONA, LOOKING DOWNSTREAM.



B. LEFT ABUTMENT OF SAN CARLOS DAM SITE.



ELEVATION OF SAN CARLOS DAM AND WASTEWAYS.

in the amount of cement necessary as to justify the figure used in the estimate—$6 per cubic yard for first-class concrete masonry. The writer is personally familiar with the product called "sand cement," has investigated its manufacture and tests, and fully indorses its use in the dam in the manner proposed. The material was first brought out in Copenhagen some years ago, by an engineer named F. L. Smidth, who obtained patents in Europe and this country on the tube mills used to grind it and on the general principle involved in its manufacture. The tube mill consists of a steel cylinder, usually some 4 feet in diameter and 16 feet long, lined with cast-iron plates and provided with longitudinal ribs a few inches in height. Several barrels of hard flint pebbles 2 to 3 inches in diameter, usually obtained from Iceland, are placed in the cylinder, which is slowly revolved. The dried sand and cement are then fed into one end of the cylinder, and in passing through are ground to exceeding fineness by the action of the pebbles, which, with the cement, are carried up the sides of the cylinder by the longitudinal ribs, and in falling pulverize the finer material between them.

The grinding is accomplished by passing the material once through the cylinder, and the finished product emerges in a constant stream at the end opposite from that at which the material is fed into it. Sand cement is coming into very general use in Russia, France, Australia, and South Africa, and in this country there are several plants in operation, one of which, located in Brooklyn, New York, manufactures 500 barrels a day. At the suggestion of the writer this cement was used in lining the canal of the new hydraulic laboratory at Cornell University, where it was particularly essential that there should be no leakage.

The tests of silica cement given in Mr. Duryee's report are confirmatory of the many published tests of the manufacturers of the article, and all prove that a superior quality of concrete can be made of it. The greater number of tests given by Mr. Duryee were made with cement manufactured at Colton, California, with a silica rock obtained near the Gila River dam sites. Compared with standard brands of cement imported from Europe, they make a creditable showing for the Colton cement. If the high standard shown can be maintained with absolute uniformity, the local product should be regarded as entitled to consideration in work of this character.

The plan of outlets for the San Carlos reservoir is the same as that described for the Buttes, except that the outlet pipes of the former reservoir pass through the masonry of the dam instead of through a tunnel cut in the solid rock. The arrangement for control of the water through a tower is the same, except that two towers are provided at the San Carlos and only one at the Buttes. When construction details are planned it may be considered desirable to modify the arrangement of outlets shown on the preliminary plans to provide for the utilization of the very considerable power which manifestly will be available and which should be made a source of revenue. Otherwise the plans are sufficiently complete for the purpose of providing the storage required and the means of releasing the water to the stream channel, by which it will be conveyed to the reservation. For the purpose of sluicing silt from the reservoir it will be desirable to utilize the working tunnel mentioned in the estimate, by which the low-water flow is to be

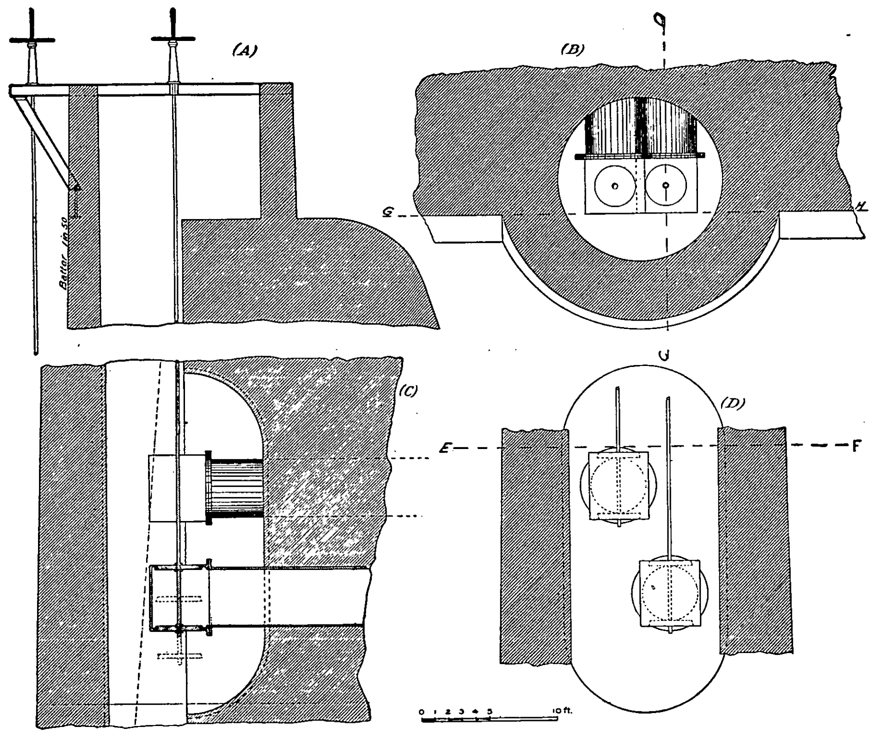


FIG. 210.—Details of towers for San Carlos dam. At B is a horizontal section on line EF of D; at C is a vertical section on line CD of B; and at D is a vertical section on line GH of B.

carried around the excavation during construction, making it large enough to serve as the sluicing channel and providing it with gates easily controlled.

SILT PROBLEM.

The determination of the probable volume of silt carried in suspension by the water of the Gila reveals the fact that the river carries on an average about 2 per cent of solid matter. This great load of sediment is exceeded by few rivers in the world. Determinations on Ganges River have shown that it carries at flood about 2.6 per cent, and several of the northern California rivers during the progress of hydraulic mining were found to carry 3.3 to 3.5 per cent, according to samples taken by the State engineering department of California in 1878. The Mississippi in flood carries 0.12 to 0.17 per cent, the average for twelve months being 0.05 to 0.08 per cent; the Rhone, 0.43 per cent; the Nile, 0.15 per cent; the Indus, 0.18 to 0.50 per cent.

Mr. Lippincott estimates[1] that the mean annual solids carried past San Carlos are equivalent to 8,443 acre-feet. This quantity expressed in more familiar terms is equal to 13,600,000 cubic yards, which gives a better idea of the magnitude of the problem of silt disposal in the construction of reservoirs wherein the greater portion of the load carried by the river will inevitably be deposited.

It would seem to be essential, in planning any reservoir on the Gila, to prepare for the ultimate construction of the highest dam which it is practicable to build at the site. This ultimate height appears to have been reached at the Buttes in the dam there projected, which would be filled in eighteen years. At Riverside the dam can safely be carried to a height of at least 200 feet above the stream bed, which would give a probable capacity of 650,000 acre-feet and require sixty-seven years to fill with sediment. At San Carlos a dam 200 feet above the stream bed is entirely practical and would furnish a storage capacity of approximately 550,000 acre-feet. At the estimated rate of deposit this dam would require sixty-three years to fill.

The raising of the dam to its ultimate height offers the cheapest practicable disposal of the silt during the period of its life of utility, and to this end all future plans should be made. The land should be segregated below the extreme elevation to which the water might require to be raised by increasing the dam to its ultimate height, and permanent improvements upon it should not be made. Finally, when in time this remedy becomes exhausted and the capacity of the reservoir area actually needed is being encroached upon, a by-pass channel could be constructed and the silt be sluiced out by that means and by hydraulic dredging. The latter could be done at a cost of 2 to 4 cents per cubic yard. This would put an annual tax of $2.50 to $5 per acre upon the land irrigated, which might by that time be borne with equanimity. The power available from the dam should have a commercial value sufficient to bear this burden. It is now salable at the rate of $100 per horsepower per annum. Five thousand horsepower net delivered electrically to the neighboring mining regions should command a price sufficient to pay for the dredging required annually. These suggestions are not of immediate value or application. The problem is one which future generations must meet and solve. The way is indicated for the solution of the problem when the time comes. The most urgent need for the present is to reserve all of the sites on the river for future utilization to the limit of their practical capacity.

One of the advantages possessed by the San Carlos site which has not been mentioned but which has been recognized throughout the investigation lies in the fact that it is above the mouth of San Pedro

[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 33, p. 40.

River, which is known to carry a much heavier percentage of silt than any other tributary of the Gila. The silt determinations on the Gila have been at the Buttes, below the San Pedro. Hence the percentage of sediment computed for the San Carlos site may be slightly in excess of the actual. The watershed above San Carlos is 75 per cent of the area tributary to the Buttes, but the run-off at San Carlos is estimated at 90 per cent. The remaining 10 per cent is contributed by the San Pedro, Mineral Creek, and other minor channels, but chiefly by the San Pedro. The comfort to be obtained from this source is therefore small, and whatever the San Pedro may bring down in the way of sediment, even were it several times the average of the main Gila, its relative discharge is so small that the estimate of the probable burden of the waters at San Carlos can not be greatly reduced. Direct determinations of the silt passing the San Carlos site are highly important, however, and should be systematically carried on.

GILA RIVER AS AN IRRIGATION CONDUIT.

The possible losses by evaporation and infiltration in the 60 miles of river channel below San Carlos have not been overlooked in this investigation, and the canyon between San Carlos and the Buttes was carefully examined at low water. It was found that the flow of the stream was practically undiminished all the way down, and that while the loss from evaporation was considerable it was about balanced by the underflow or seepage coming in from the tributary drainage area between these points. The subject is intelligently discussed in Mr. Lippincott's report, and the conclusion is reached that for all practical purposes there are no disadvantages in storing the water at San Carlos, 60 miles above the Buttes, and no greater loss of water to be expected than if the reservoir were located at the latter place. Also that the flood discharge of the stream below San Carlos will be available for diversion below the Buttes during a portion of the year, and when such diversion is made the storage at San Carlos need not be drawn upon, which will increase the duty of the San Carlos reservoir. These conclusions are fully concurred in by the writer as sound and well based.

SEEPAGE MEASUREMENTS.

The growth of the river through Solomonsville Valley above San Carlos, resulting largely from the return waters of irrigation percolating back to the streams through the soil, as determined by the measurements of Mr. Cyrus C. Babb and detailed in his report, is one of the most instructive and interesting features of the present investigation. Mr. Babb found the total increase in 40 miles of the valley to be 153.8 second-feet, or 3.8 second-feet per mile. If this rate of percolation were maintained throughout the year, the annual volume thus returning to the river would be 111,400 acre-feet. This rate, however,

A. GILA RIVER CANYON, 15 MILES BELOW SAN CARLOS DAM SITE.

B. GILA RIVER CANYON, 8 MILES BELOW SAN CARLOS DAM SITE.

can not be expected to continue through the entire year, although the contribution to the stream probably never ceases entirely. If the addition from this source be assumed as averaging about 50,000 acre-feet per annum, its importance can not be overestimated. If the irrigation of the 20,000 acres is capable of producing results of such magnitude, the complete irrigation of the valley above San Carlos should yield a much greater supply.

Not the least important feature of this augmentation of the stream is the fact that the water comes back to it clear and free from silt. This fact may offer a partial future solution of the silt problem, for if the clear water could thus be gathered and the silt-laden river carried around the reservoir at times of maximum floods, the dilution of the water in the reservoirs by the clear seepage water would materially reduce the volume of silt which would have to be provided for. At present, however, the seepage water as it appears and augments in volume is successively diverted and applied to the land again and again, and the net gain to the river at low-water stage is not apparent at San Carlos.

CONCLUSIONS AND RECOMMENDATIONS.

Summarizing the net results of the investigation, the conclusions to be drawn are as follows:

First. That a minimum of 40,000 acre-feet of water annually should be stored for the supply of the Indian reservation.

Second. That it is not feasible to obtain this supply from Queen Creek, although the dam and reservoir proposed on the stream are feasible if a sufficient water supply were available.

Third. That Gila River is the only available source of permanent supply.

Fourth. That it is not feasible or advisable to build a dam and reservoir on the Gila for storing so small a quantity as 40,000 acre-feet, on account of the rapidity with which a small reservoir will fill with silt.

Fifth. That it is not feasible to construct a reservoir outside of the channel of the Gila of sufficient capacity to provide for the needs of the Indians, filling the same annually by a conduit from the river.

Sixth. That it is not advisable to build a dam and reservoir on the channel of the river of less capacity than half the total annual flow of the river in minimum years.

Seventh. That feasible reservoir and dam sites exist on the Gila at the Buttes, at Riverside, and at San Carlos.

Eighth. That it is not feasible to build a masonry dam at the Buttes, on account of the rotten quality of the rock, the great depth to bed rock, and the excessive height of dam required to obtain a storage of 174,000 acre-feet, or about half the minimum flow of the stream.

Ninth. That a combination rock-fill and masonry dam is feasible at the Buttes at a cost of $2,643,327, storing 170,040 acre-feet, but that it is not feasible to construct a dam of any type of greater height or capacity.

Tenth. That the Buttes reservoir of the stated capacity may be expected to fill with solid matter in eighteen years, unless dredged or sluiced out.

Eleventh. That it is feasible to construct a masonry dam at Riverside at a cost of $1,989,605, including damages for right of way and diversion dam at the head of the Florence canal, forming a reservoir with a capacity of 221,134 acre-feet.

Twelfth. That it is feasible to increase the height of the Riverside dam at least 70 feet above the one estimated upon, which would give an ultimate reservoir capacity of about 650,000 acre-feet, and would not fill with solid matter in less than sixty-seven years.

Thirteenth. That it is feasible to construct a masonry dam at San Carlos at a cost of $1,038,926, including damages for right of way and diversion dam at the head of the Florence canal, forming a reservoir of 241,396 acre-feet capacity; that the water supply is ample to fill such a reservoir in the years of minimum flow, and that the volume of storage will irrigate at least 100,000 acres in addition to the irrigation of the lands of the Indians.

Fourteenth. That it is feasible to construct a dam at San Carlos at least 70 feet higher than the one contemplated in the estimates, forming a reservoir with an ultimate capacity of approximately 550,000 acre-feet and a probable life of usefulness of sixty-three years.

Fifteenth. That provisions should be made in the working plans for the ultimate extensions suggested, and that public lands in the reservoir basin should be reserved for the additional area that may ultimately be flooded.

Sixteenth. That the San Carlos dam should be built as the first step to be taken for the storage of water upon the Gila, and that all other available sites should be permanently withdrawn from entry with a view to their ultimate utilization for storage purposes.

Seventeenth. That the working plans of the San Carlos dam should be drawn to permit of the complete utilization of all power which may be developed from the head of the water issuing from the reservoir, and that steps should be taken to realize upon the full commercial value of the power.

Eighteenth. That that portion of the public domain which can be irrigated and reclaimed from the surplus storage of Gila River reservoirs, over and above what is required for the Gila River Indian Reservation, should be withdrawn from entry, segregated into an irrigation district, provided with a system of canals of distribution, and only offered for sale at a rate commensurate to their true value as irrigable lands with water rights, the proceeds to be placed in a fund to be used only for continuing the improvement, extension, and care of reservoirs and storage dams on Gila River.

SEEPAGE MEASUREMENTS NEAR PHŒNIX, ARIZONA.[1]

In June, 1896, a series of measurements were made of Salt River and of the canals diverting water from it in the vicinity of Phœnix, Arizona. The first measurement was made on Salt River about a half mile above the mouth of Verde River, at the gaging station of the Hudson Reservoir and Canal Company. The discharge was 220 second-feet. The next measurement was of Verde River itself, a half mile above its mouth, and showed a discharge of 117 second-feet. The sum of these two measurements is 337 second-feet, being the total amount of water available at that time for the canals below. The dam of the Arizona canal is about a mile below the mouth of the Verde. It was measured just below its waste gate, or 2 miles below its head. At that point it was discharging 250 second-feet, Salt River, immediately opposite, was carrying 60 second-feet, and the Highland canal, which heads a short distance below the head of the Arizona canal, was discharging 4.2 second-feet. The total of these last three streams is 314 second-feet, which, compared with the total discharge of the Salt and Verde—337 second-feet—shows a loss of 23 second-feet.

The Mesa Consolidated canal was the next one considered. The head of this canal is about 2 miles below the Arizona canal waste gate, on the south side of the river. The measurement of it was made, however, 2 miles below, or at its waste gate. It here showed a discharge of 20.3 second-feet. Salt River, immediately opposite, was carrying 24.3 second-feet. Salt River opposite the Arizona waste gate, with a discharge, as already stated, of 60 second-feet, added to the discharge of the Highland canal, 4 second-feet, gives a total of 64 second-feet. The total discharge of the Mesa Consolidated canal and Salt River near by is 44.6 second-feet. Here is another loss of 19.4 second-feet. The head of the Tempe canal is about 4 miles below the waste gates of the Mesa Consolidated and on the same side of the river. The measurements showed a discharge of 114.2 second-feet. This, however, can not be used in an estimation of the seepage, for it is principally water from the Arizona canal, having been diverted from that canal by means of the Evergreen Crosscut, which discharges into the river a short distance above the head of the Tempe canal. In the main river opposite the head of this canal the amount escaping through its dam was 5.5 second-feet. In the table (p. 382) this amount is compared with the discharge of the river under the railroad bridge, which was 88.7 second-feet. As there were no canals diverting water

[1] Report of Cyrus C. Babb.

or tributaries entering between the points, the difference—83.2 second-feet—shows the gain in that distance. It is locally considered that the water comes to the surface opposite the little butte near the town of Tempe. The water under the railroad bridge was diverted about a mile below into the Joint Head, as it is called, which supplies the Maricopa canal and the Salt River Valley canal. No measurements were made below that point.

A second series of measurements were made in the summer of 1899, in order to compare with those made in 1896. Each series was begun on June 12, and the measurements were made as nearly as possible at the same points. On June 12, 1899, the combined discharges of Salt and Verde rivers, as shown on page 381, was 337 cubic feet per second. Compared with the total (323.4 second-feet) of the four following measurements—Arizona canal below the waste gate, 185 second-feet; Arizona canal waste water, 88 second-feet; Salt River immediately opposite, 18.7 second-feet; and the Highland canal, south side, 31.7 second-feet—this shows a loss of 13.6 second-feet. The 1896 measurements show a loss between the same points, as already stated, of 23 second-feet.

The next comparison is between the Arizona canal waste water, Salt River at that point, and the Highland canal. The total of these three measurements for 1899 is 138.4 second-feet. In the 1896 measurements the gaging on the river opposite the Arizona canal waste gate included the waste water from the canal itself. In the 1899 measurements they were made separately. The Highland canal diverts water, as already stated, a short distance below the head of the Arizona canal, but returns the water to the river immediately above the head of the Mesa Consolidated, which takes it up, the former canal having been enjoined a few years ago from diverting and using the water when the river was at low stages.

The total discharge of the Arizona canal waste, of Salt River at that waste gate, and of the Highland canal was 138.4 second-feet. At the Mesa Consolidated waste gate the main canal was carrying 67.7 second-feet, a small flume 1.8 second-feet, the canal waste water 15.3 second-feet, and the river 5.8 second-feet, a total of 90.6 second-feet. Subtracting this amount from the 138.4 second-feet shows a loss of 47.8 second-feet. The 1896 measurements showed a loss between these same points of 19.4 second-feet. The Arizona canal was still furnishing the Tempe canal with a certain amount of water through the Evergreen Crosscut. In 1899, as measured at the head of the Tempe canal, this amount was 70.6 second-feet. Salt River immediately below the dam of the Tempe canal was dry. At the railroad bridge below it was carrying 59.8 second-feet, which amount, then, represents the gain.

The second series of measurements in 1899 were continued farther down the river than the first. The water under the railroad bridge was all diverted a mile below into the Joint Head, and the river immediately below the dam was dry, which was the condition at the road crossing due south of Phœnix, on the township line between ranges 2 and 3 east.

The next measurement was made 8 miles below this point, on the St. John canal, and showed a discharge of 7.8 second-feet. There was escaping through the dam 23.9 second-feet. The sum of these two measurements, or 31.7 second-feet, shows the gain in the distance of 8 miles, or about 4 second-feet to the mile.

The Buckeye canal diverts water from the north side of Gila River 4 miles below the mouth of the Salt and 1 mile below the mouth of the Agua Fria. The measurement of June 15, 1899, showed a discharge of 102.3 second-feet. There was seeping through its dam 1 second-foot. Neither Gila River above Salt River nor Agua Fria River had any water in them at this time. Therefore, subtracting the 23.9 second-feet in the river below the head of the St. John canal from the combined flow of the Buckeye canal and the seepage through its dam, which is 103.3 second-feet, shows a gain of 79.4 second-feet in a distance of 8 miles, or 9.9 second-feet to the mile. The Buckeye canal is noted for its constant flow, and water rights under it are considered among the safest in the entire Phœnix Valley.

The results of the measurements near Phœnix for both seasons are given in the following tables. The location of the various places can be found on the map of Salt River Valley, Pl. XXX of Water-Supply and Irrigation Paper No. 2.

Discharge measurements near Phœnix, Arizona, 1896.

Date.	Stream.	Point of measurement.	Gage height.	Area.	Mean velocity.	Discharge.
			Feet.	*Sq. ft.*	*Ft. per sec.*	*Sec.-ft.*
June 12.	Salt River	Half mile above Verde River.	0.28	212	1.04	220
Do	Verde River	Half mile above mouth	4.24	70	1.66	117
June 13.	Arizona canal	Below waste gate		85	2.95	250
Do	Salt River	Opposite Arizona canal waste gate.		76	0.80	60
	Highland canal	do		10.3	0.41	4.2
	Mesa Consolidated canal.	At waste gate		52.4	0.39	20.3
	Salt River	Below Mesa Consolidated waste gate.		21.7	1.12	24.3
	Tempe canal	Half mile above waste gates.		74.6	1.53	114.2
	Salt River	Opposite head of Tempe canal.		14.7	0.40	5.5
	Do	At railroad bridge		55.7	1.60	88.7

Computations of seepage near Phœnix, Arizona, 1896.

Stream.	Discharge.	
	Second-feet.	
Salt River above Verde River	220	
Verde River at mouth	117	
		337
Arizona canal at waste gate	250	
Salt River opposite Arizona canal waste gate	60	
Highland canal	4	
		314
Loss	......	23
Salt River opposite Arizona canal waste gate	60.0	
Highland canal opposite Arizona canal waste gate	4.0	
		64.0
Mesa Consolidated canal	20.3	
Salt River below Mesa Consolidated waste gate	24.3	
		44.6
Loss	......	19.4
Salt River opposite head of Tempe canal	......	5.5
Salt River at railroad bridge	......	88.7
Gain	......	83.2

Discharge measurements near Phœnix, Arizona, 1899.

Date.	Stream.	Point of measurement.	Gage height.	Area.	Mean velocity.	Discharge.
			Feet.	*Sq. ft.*	*Ft. per second.*	*Sec.-ft.*
June 12.	Salt River	At gaging station	10.20	177.0	1.11	197.0
Do	Verde River	do	7.18	91.0	1.54	140.0
June 13.	Arizona canal	Below waste gate	....	93.0	2.00	185.0
Do	Arizona canal waste	At river	....	46.0	1.91	88.0
Do	Salt River	Opposite Arizona canal waste gate.	....	14.4	1.30	18.7
Do	Highland canal	do	....	22.6	1.40	31.7
Do	Mesa Consolidated canal.	Below waste gate	....	51.6	1.31	67.7
Do	Small flume	Mesa Consolidated waste gate.	....	2.8	0.64	1.8
Do	Mesa Consolidated waste.	Near gate	....	18.6	0.82	15.3
	Salt River	Opposite Mesa Consolidated waste gate.	....	17.2	0.34	5.8
June 13.	Tempe canal	Ford near head	....	58.8	1.20	70.6
	Salt River	Opposite Tempe canal head.	....	....	....	0.0
	Do	Railroad bridge	....	51.4	1.18	59.8
June 15.	do	South of Phœnix	....	....	....	0.0
	St. John canal	At head	....	14.2	0.55	7.8
	Salt River	Below head of St. John canal.	....	16.4	1.45	23.9
	Buckeye canal	At head	....	13.1	1.62	102.3
	Salt River	Below Buckeye canal	....	....	....	1.0

Computations of seepage near Phœnix, Arizona, 1899.

Stream.	Discharge.	
	Second-feet.	
Salt River at gaging station	197.0	
Verde River at gaging station	140.0	
		337.0
Arizona canal at waste gate	185.0	
Arizona canal waste	88.0	
Salt River at Arizona canal waste gate	18.7	
Highland canal	31.7	
		323.4
Loss		13.6
Arizona canal waste	88.0	
Salt River at Arizona canal waste gate	18.7	
Highland canal	31.7	
		138.4
Mesa Consolidated canal	67.7	
Small flume	1.8	
Mesa Consolidated waste	15.3	
Salt River opposite Mesa Consolidated waste gate	5.8	
		90.6
Loss		47.8
Salt River opposite Tempe canal		0.0
Salt River at railroad bridge		59.8
Gain		59.8
Salt River south of Phœnix		0.0
St. John canal	7.8	
Salt River opposite St. John canal	23.9	
		31.7
Gain		31.7
Salt River opposite St. John canal		23.9
Buckeye canal	102.3	
Salt River below Buckeye canal	1.0	
		103.3
Gain		79.4

QUEEN CREEK, ARIZONA.

Observations of the discharge of Queen Creek were commenced in 1895, at the time of the first investigation for water supply for the Gila River Indian Reservation. A gage rod was then placed and a gaging station established at Whitlow's ranch, at the dam site of the Queen Creek reservoir. During the year 1896 an observer was employed and located at the station. At the time of the establishment of the station there was a slight permanent flow, averaging about 2 second-feet, but the next year this failed. The principal water supply of Queen Creek consists of floods of one or two days' duration, occurring immediately after a rainfall in the basin. On this account, in order to obtain an accurate determination of the discharge a man must be constantly at the station to measure the discharge and to record its duration. Such a system was employed during 1896 and until April, 1897. The following table of the monthly discharge at this station for 1896 is reprinted from the Eighteenth Annual Report of the United States Geological Survey, Part IV, page 295. The total discharge for the year was 10,887 acre-feet.

Estimated monthly discharge of Queen Creek at Whitlow's ranch, Arizona.

[Drainage area, 143 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1896.						
January	2	2.0	2.0	123	0.014	0.016
February	2	2.0	2.0	115	0.014	0.015
March	2	2.0	2.0	123	0.014	0.016
April	2	1.0	1.5	89	0.010	0.011
May	1	1.0	1.0	61	0.007	0.008
June	1	1.0	1.0	60	0.007	0.008
July	9,000	0.0	121.6	7,477	0.850	0.980
August	1,433	0.6	13.1	805	0.092	0.106
September	3,428	0.5	17.1	1,016	0.120	0.134
October	1,188	0.5	13.3	818	0.093	0.108
November	80	0.6	1.3	77	0.009	0.010
December	207	0.6	2.0	123	0.014	0.016
The year	9,000	0.0	15.0	10,887	0.104	1.428

NOTE.—Miscellaneous discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 320.

The daily observations of Queen Creek for 1897 are published in the Nineteenth Annual Report, Part IV, page 417. The total discharge to April 6 is 8,020 acre-feet. The total discharge for the year has been estimated, based on the rainfall records, and is therefore only approximate. A rainfall record has been kept at Pinal ranch, within the drainage area, from 1895 to August, 1899, inclusive. The total precipitation for 1897 was 23.23 inches. For the period from January to March, inclusive, during the time in which measurements of discharge of the creek were made, the precipitation was 14.21 inches. The following proportion was therefore made: 14.21 is to 23.23 as 8,020 is to the total discharge for the year, viz, 13,110 acre-feet.

An observer was employed at this station for July, August, and September, 1898. He recorded the height of recurring floods on the gage rod, from which, in connection with occasional cross sections, an estimation of the discharge was made. The record of these observations will be found in Water-Supply and Irrigation Paper No. 28, page 132. The discharge for these three months has been computed as 5,140 acre-feet, including the one flood occurring in December of that year. The creek was reported dry from March 1 until the time the observer assumed his duties, and from September to the time of the measured flood, December 18. There was one flood, however, in January or February, of which no record was kept, but the quantity was not notably large. It is reported by people located within the basin that the year 1898 was characterized by an exceedingly small flow of the creek. The total discharge for the year is assumed to be 6,000 acre-feet. It probably did not materially exceed that amount.

The act of Congress authorizing the continuation of the investigation of the water supply of Gila River had a provision for continuing observations of the water supply of Queen Creek. The old gaging station was reestablished in December, 1898, and an observer was employed to record any floods that might occur. Meter measurements were not made, but gage records were taken on both the original gage and on a slope gage placed 431 feet above and referred to the same datum. Cross sections were also made of each flood. From this data the discharges of the creek were computed by means of the Kutter formula. From these computations the total discharge for the period—January 1 to August 11, 1899—is found to be 12,527 acre-feet.

Total annual discharge of Queen Creek at Whitlow's ranch, Arizona.

Year.	Discharge.
	Acre-feet.
1896	10,887
1897	13,110
1898	6,000
1899, January 1 to August 11	12,527

SALT RIVER.

This river is the principal tributary of Gila River. It rises in Graham County, Arizona, its headwater tributaries adjoining those of San Francisco River. It empties into the Gila at the northwest corner of the Gila River Indian Reservation. During ordinary seasons all of the water of Salt River is diverted, and at the present time there is a shortage in the summer months. Its principal tributary is Verde River, which enters it about 30 miles northeast of Phœnix, Arizona. Both the Salt and the Verde are measured at McDowell, Arizona, the gaging stations having been established April 20, 1897. Measurements are made by W. A. Farish.

Estimated monthly discharge of Salt River at McDowell, Arizona.

[Drainage area, 6,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	810	265	379	23,304	0.06	0.07
February	485	350	406	22,548	0.06	0.06
March	650	426	505	31,051	0.08	0.09
April	625	475	585	34,810	0.09	0.10
May	500	215	324	19,922	0.05	0.06
June	530	173	219	13,031	0.03	0.03
July	1,500	165	472	29,022	0.08	0.09
August	3,500	175	706	43,410	0.11	0.13
September	1,300	175	316	18,803	0.05	0.06
October	785	168	269	16,540	0.04	0.05
November	226	165	213	12,674	0.03	0.03

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 322; discharge measurements, page 321.

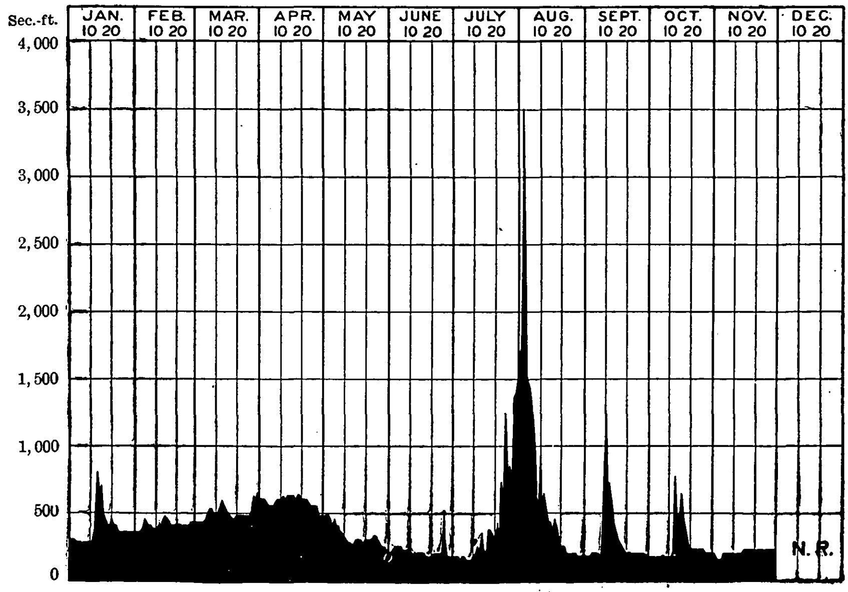


FIG. 211.—Discharge of Salt River at McDowell, Arizona, 1899.

Estimated monthly discharge of Verde River at McDowell, Arizona.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	560	295	350	21,521	0.06	0.07
February	375	295	344	19,105	0.06	0.06
March	325	225	260	15,987	0.04	0.05
April	230	170	205	12,198	0.03	0.03
May	210	118	152	9,346	0.03	0.03
June	230	118	152	9,045	0.03	0.03
July	1,400	118	365	22,443	0.06	0.07
August	2,170	100	434	26,686	0.07	0.08
September	2,500	135	357	21,243	0.06	0.07
October	3,770	160	549	33,757	0.09	0.10
November 1 to 11	250	235	249	14,817	0.04	0.04

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 324; discharge measurements, page 323.

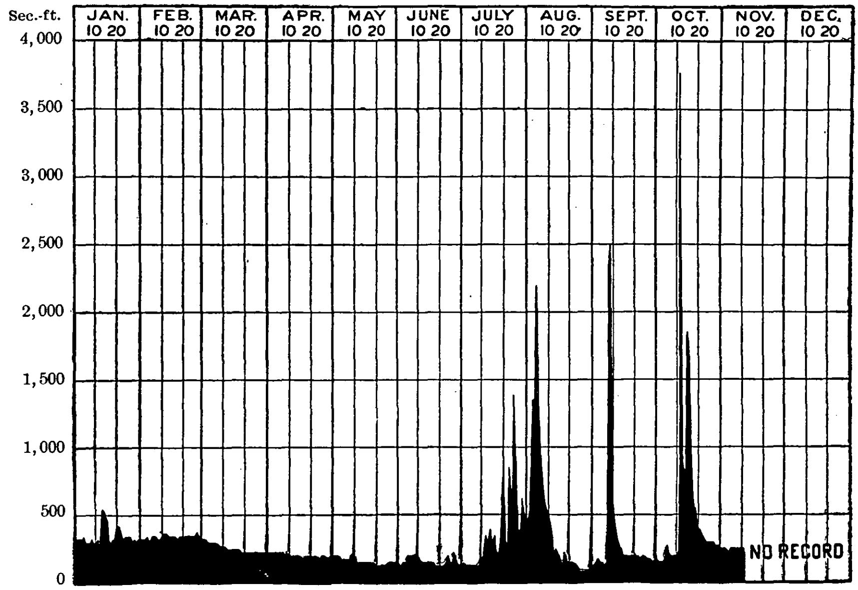
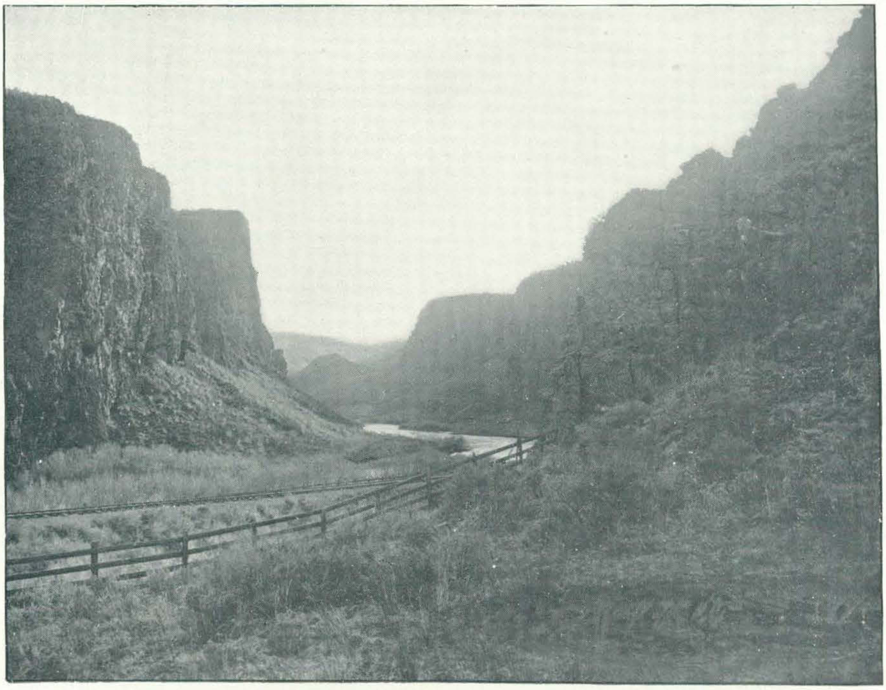


FIG. 212.—Discharge of Verde River at McDowell, Arizona, 1899.

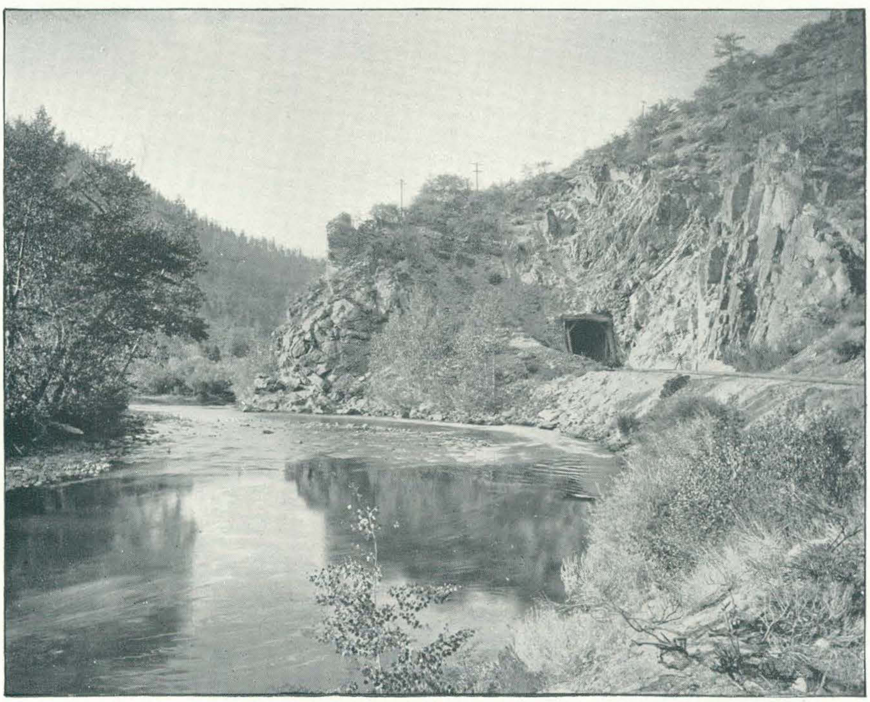
INTERIOR DRAINAGE BASIN.

HUMBOLDT RIVER.

This river rises in the extreme northeastern part of Nevada and flows in a general westerly and southerly direction, finally entering Humboldt Lake, whence its waters find their way into Humboldt and Carson sinks. The general direction of the mountain ranges of this basin is north and south, crossed at nearly right angles by the main Humboldt River. The tributaries flow in the general direction of the mountain ranges, and drain either to the north or to the south. During low stages the water of the river is almost wholly diverted. For the future development of the country recourse must be had to the construction of storage reservoirs. Of its tributaries, the North Fork, which enters it west of Peko, Nevada, is measured at Peko, and the South Fork, which enters it about 10 miles below Elko, is measured at Mason's ranch, Nevada. The station at Peko was established March 25, 1898; the one at Mason's ranch was established August 29, 1896. The main river is measured at Elko, Nevada, station established June 17, 1895; at Golconda, Nevada, station established October 24, 1894, and at Oreana, Nevada, station established January 27, 1896. Measurements at all of these stations are made by L. H. Taylor. Pl. XXXVII, *A*, is a view of the palisades on Humboldt River.



A. PALISADES ON HUMBOLDT RIVER, NEVADA.



B. TRUCKEE CANYON NEAR BRONCO, NEVADA.

Estimated monthly discharge of North Fork of Humboldt River at Peko, Nevada.

[Drainage area, 1,020 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	92	23	45	2,767	0.044	0.050
February	182	35	75	4,165	0.074	0.075
March	327	50	172	10,576	0.169	0.194
April	1,584	327	845	50,281	0.828	0.924
May	628	92	384	23,611	0.379	0.436
June	1,241	327	695	41,355	0.681	0.760
July	546	327	435	26,747	0.427	0.482
August	396	59	142	8,731	0.139	0.161
September	69	8	46	2,737	0.045	0.050
October	29	5	14	861	0.013	0.015
November	35	18	26	1,547	0.026	0.029
December	35	14	28	1,722	0.027	0.031
The year	1,584	5	243	175,100	0.237	3.207

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 326; discharge measurements, page 325; rating table in Paper No. 39, page 452.

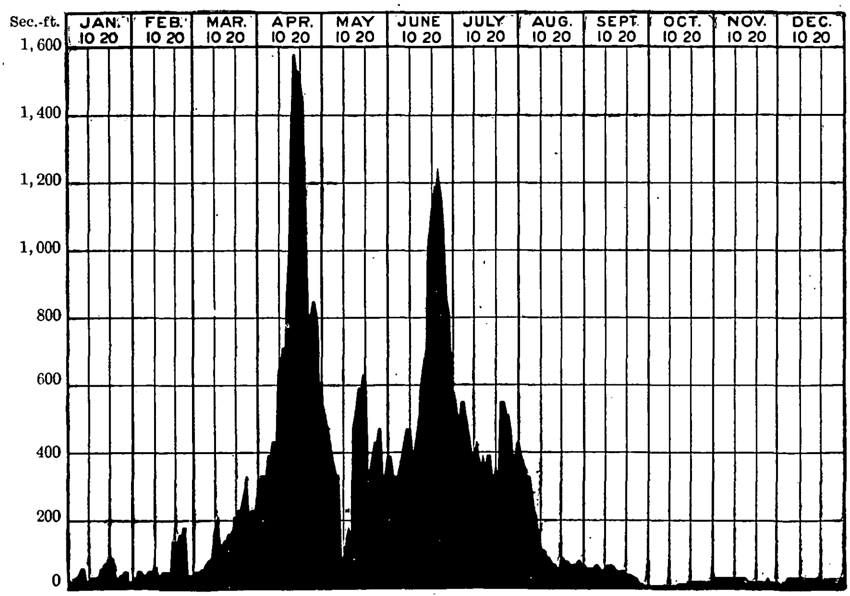


FIG. 213.—Discharge of North Fork of Humboldt River at Peko, Nevada, 1899.

Estimated monthly discharge of Humboldt River at Elko, Nevada.

[Drainage area, 2,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	63	14	28	1,722	0.010	0.011
February	134	56	81	4,498	0.028	0.029
March	667	134	296	18,200	0.104	0.120
April	1,929	525	1,206	71,762	0.424	0.473
May	1,655	862	1,156	71,079	0.407	0.469
June	2,339	1,121	1,665	99,075	0.586	0.654
July	1,873	402	1,007	61,918	0.354	0.408
August	374	86	175	10,760	0.062	0.071
September	144	32	107	6,378	0.037	0.042
October	306	37	176	10,822	0.062	0.071
November	366	166	330	19,636	0.116	0.129
December	144	63	96	5,903	0.034	0.039
The year	2,339	14	527	381,753	0.185	2.316

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 327; rating table in Paper No. 39, page 452.

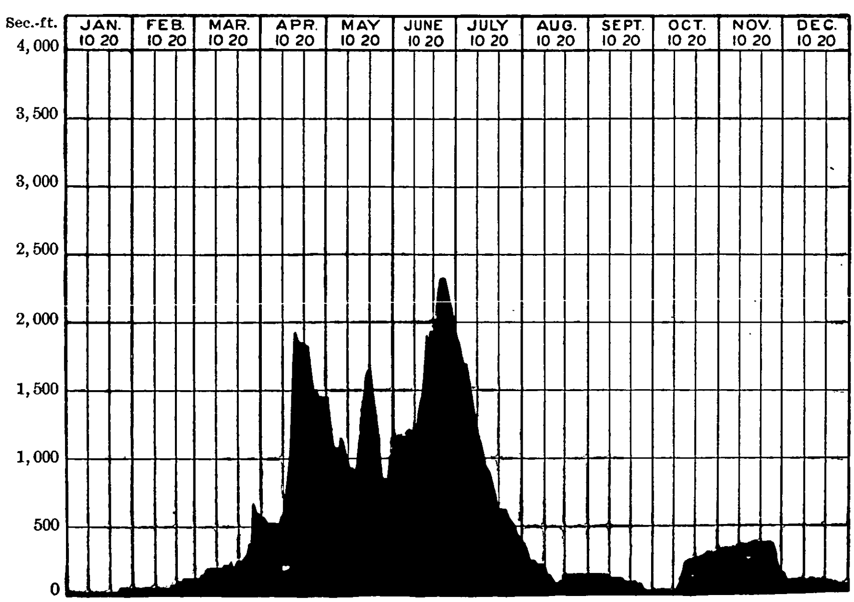


FIG. 214.—Discharge of Humboldt River at Elko, Nevada, 1899.

Estimated monthly discharge of South Fork of Humboldt River at Mason's ranch, Nevada.

[Drainage area, 1,150 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	122	74	98	6,026	0.086	0.099
February	327	97	172	9,552	0.150	0.156
March	469	105	186	11,437	0.162	0.187
April	529	227	401	23,861	0.349	0.389
May	454	193	300	18,446	0.261	0.300
June	1,370	354	852	50,698	0.741	0.827
July	937	227	531	32,650	0.462	0.532
August	216	24	111	6,825	0.097	0.111
September	24	19	20	1,190	0.017	0.019
October	54	24	38	2,337	0.033	0.038
November	60	47	54	3,213	0.047	0.053
December	60	35	54	3,320	0.046	0.057
The year	1,370	19	235	169,555	0.204	2.768

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 328; rating table in Paper No. 39, page 452.

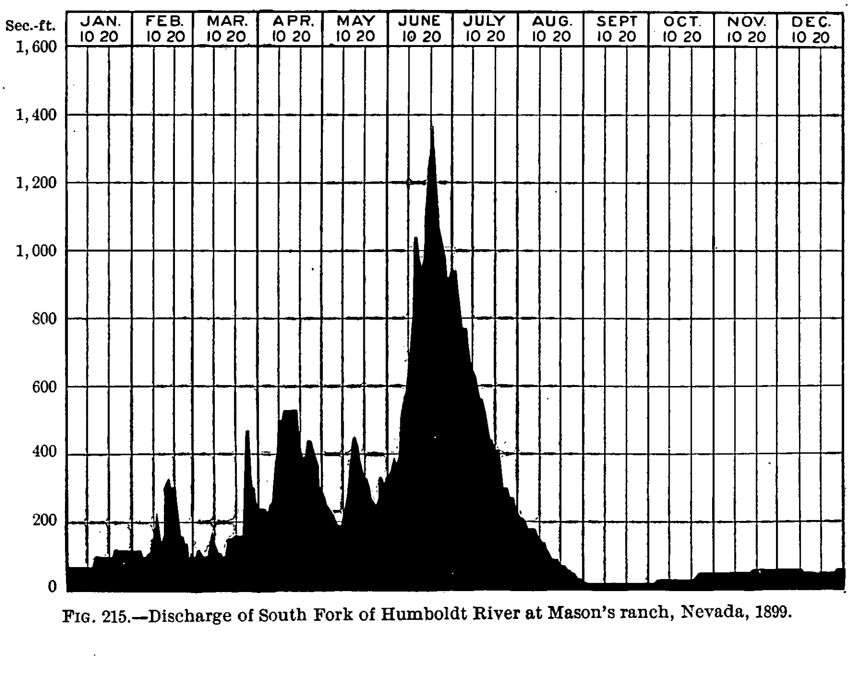


FIG. 215.—Discharge of South Fork of Humboldt River at Mason's ranch, Nevada, 1899.

Estimated monthly discharge of Humboldt River at Golconda, Nevada.

[Drainage area, 10,780 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	180	20	69	4,243	0.0064	0.0074
February	385	180	292	16,217	0.0271	0.0282
March	835	315	433	26,624	0.0402	0.0463
April	2,095	835	1,383	82,294	0.1283	0.1431
May	2,233	1,387	1,853	113,937	0.172	0.198
June	1,888	1,137	1,427	84,913	0.132	0.148
July	2,095	1,011	1,644	101,086	0.152	0.176
August	973	156	523	32,158	0.0485	0.056
September	134	38	56	3,332	0.0053	0.0058
October	51	29	36	2,213	0.0033	0.0038
November	114	54	93	5,534	0.0086	0.0096
December	134	114	126	7,747	0.0117	0.0134
The year	2,233	20	661	480,298	0.0613	0.8356

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 329; rating table in Paper No. 39, page 452.

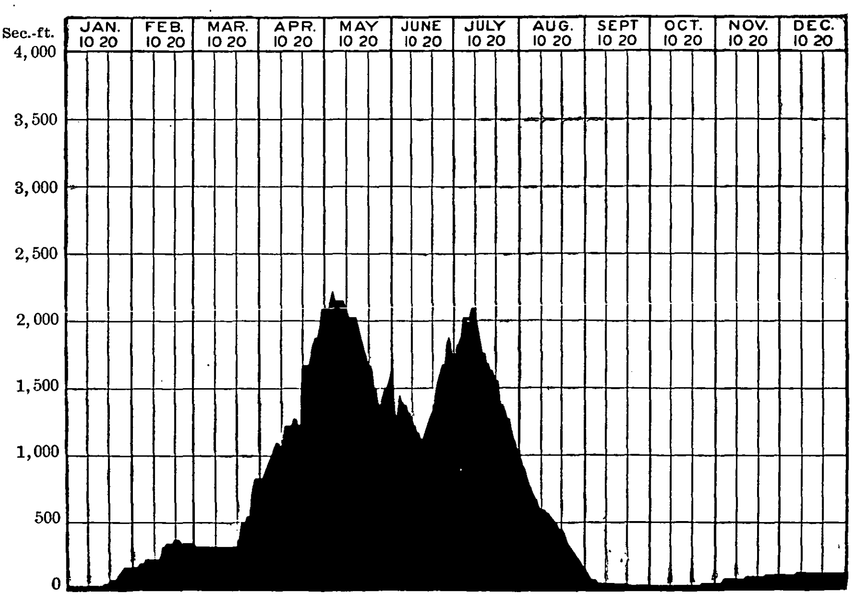


FIG. 216.—Discharge of Humboldt River at Golconda, Nevada, 1899.

Estimated monthly discharge of Humboldt River at Oreana, Nevada.

[Drainage area, 13,800 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
July	2,395	1,362	2,005	123,283	0.145	0.165
August	1,283	245	606	37,261	0.0439	0.0506
September	245	87	150	8,926	0.0109	0.0121
October	87	59	65	3,997	0.0047	0.0054
November	104	59	90	5,355	0.0065	0.0073
December	561	104	259	15,925	0.0187	0.0216

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 330; rating table in Paper No. 39, page 452.

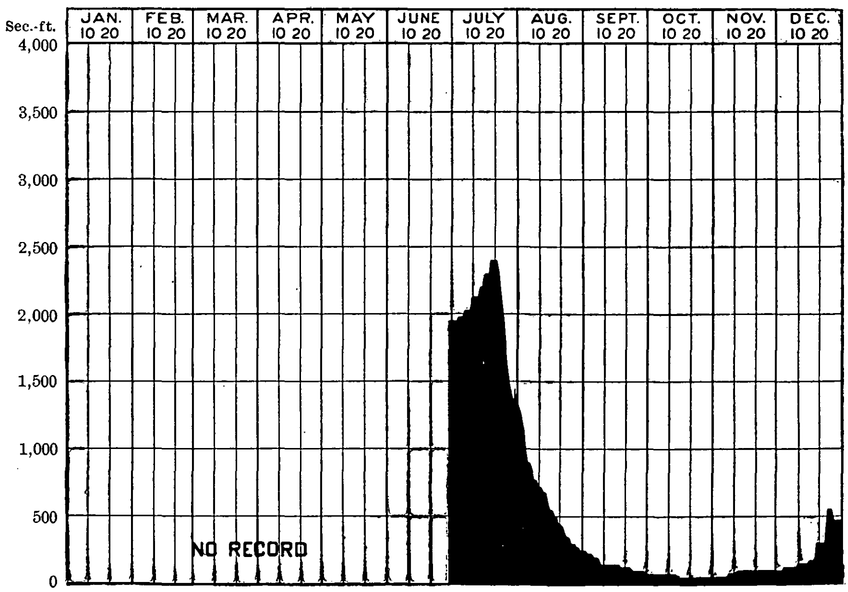


FIG. 217.—Discharge of Humboldt River at Oreana, Nevada, 1899.

TRUCKEE RIVER.

The Truckee has its source on the slopes of the Sierra Nevada in eastern California and flows northward, entering Lake Tahoe, which is at an elevation of 6,225 feet and the largest body of fresh water in the United States at this considerable altitude. The area of the lake is 193 square miles. Its outlet is at Tahoe, California, from which point Truckee River has a general northward course, receiving several important tributaries which contribute to its flow. There are a number of lakes at the headwaters of the branch streams which have been surveyed and recommended as reservoir sites. Two stations are maintained on Truckee River—one at the Nevada-California State line, established September 7, 1899, and the other at Vista, Nevada, established August 18, 1899. Measurements at both stations are made by L. H. Taylor. Pl. XXXVII, *B*, is a view of Truckee Canyon near Bronco, Nevada.

BEAR RIVER.

This river has its source on the northern slope of the Uinta Mountains in the northeastern part of Utah, and after a circuitous course, in which it leaves Utah and enters Wyoming, reenters Utah, appears again in Wyoming, then in Idaho, reenters Utah, it finally discharges its waters into Great Salt Lake. There are a number of reservoir sites in its upper basin, which have not, however, been examined in detail. Considerable irrigation is practiced on certain portions of the river. Logan River empties into Bear River in Cache Valley, Utah. A station is maintained on the Logan at Logan, Utah, and two stations are maintained on Bear River—one at Battlecreek, Idaho, and the other at Collinston, Utah. Measurements at all of the stations are made by J. S. Baker and G. L. Swendsen.

Estimated monthly discharge of Bear River at Battlecreek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	660	660	660	40,582	0.15	0.17
February	660	597	635	35,266	0.14	0.14
March	870	597	657	40,397	0.15	0.17
April	2,945	870	2,133	126,922	0.47	0.53
May	3,842	2,312	3,026	186,061	0.67	0.77
June 1 to 29	5,011	3,842	4,325	257,355	0.96	1.07
August 4 to 31	1,935	1,260	1,569	96,474	0.35	0.40
September, 23 days	1,200	1,140	1,182	70,334	0.26	0.29
October	1,325	1,140	1,227	75,445	0.27	0.31
November	1,390	1,260	1,310	77,950	0.29	0.32
December	1,325	980	1,149	70,649	0.26	0.30

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 334; discharge measurements, page 333; rating table in Paper No. 39, page 452.

Estimated monthly discharge of Bear River at Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,485	870	1,299	79,872	0.22	0.25
February	1,600	950	1,266	70,310	0.21	0.22
March	2,340	1,485	1,875	115,289	0.31	0.36
April	4,900	2,340	3,839	228,436	0.64	0.71
May	5,970	4,320	5,129	315,370	0.85	0.98
June	6,640	5,495	6,247	371,722	1.04	1.16
July	6,640	2,970	4,873	299,629	0.81	0.93
August	2,840	1,600	2,309	141,975	0.38	0.44
September	1,600	1,150	1,448	86,162	0.24	0.27
October	2,215	1,370	1,887	116,027	0.31	0.36
November	2,340	1,965	2,132	126,863	0.36	0.40
December	2,090	1,485	1,753	107,788	0.29	0.33
The year	6,640	870	2,839	2,059,443	0.47	6.41

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 336; rating table in Paper No. 39, page 453.

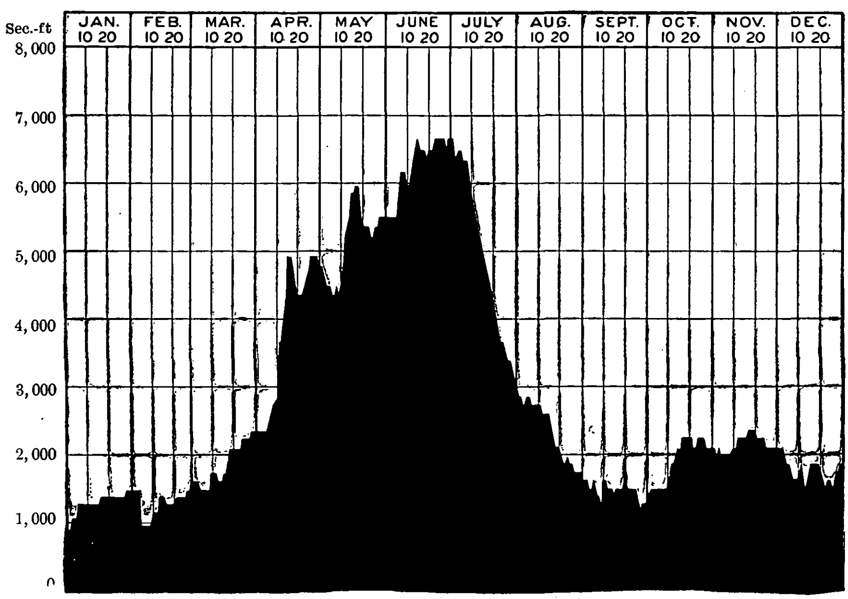


FIG. 218.—Discharge of Bear River at Collinston, Utah, 1899.

On the headwaters of Bear River and throughout the Wasatch and Uinta ranges are many localities where reservoirs can be constructed to hold a portion at least of the flood waters, which, as shown by the preceding diagrams, occur mainly in June. As typical of these, there is given herewith (fig. 219) a map of a small reservoir site on Big Cottonwood Creek, mention of the flow of which is made on page 403.

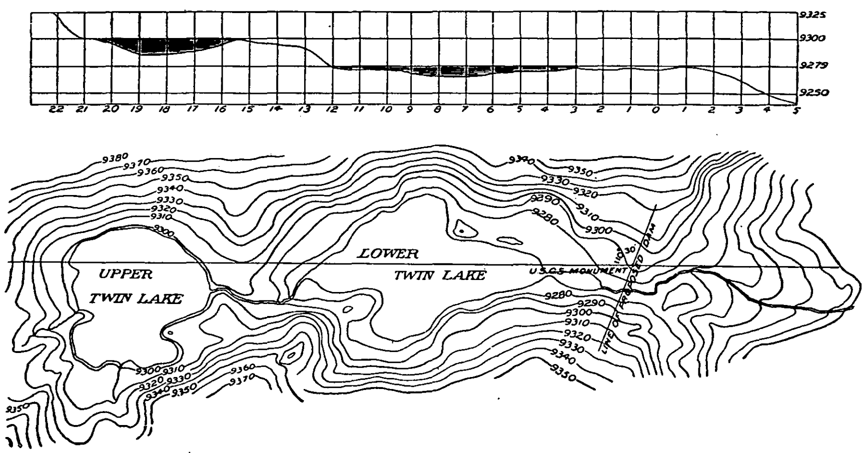


FIG. 219.—Map of Twin Lakes reservoir site, Big Cottonwood Canyon, Utah.

The lakes shown in fig. 219 are of glacial origin, their outlets having usually been cut through morainal material. Fig. 220 is a profile of the outlet, and shows the comparatively narrow gorge, which can be closed by the construction of a dam.

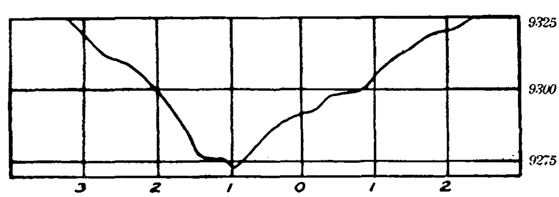


FIG. 220.—Profile of dam site of Twin Lakes reservoir, Utah.

Further data in connection with this reservoir site will be found on page 460 of the Thirteenth Annual Report.

LOGAN RIVER.

Logan River rises in the elevated region west of Bear Lake and flows in a general southwesterly direction until it enters Cache Valley, when it bends northward and enters Bear River before the latter reaches its lower canyon. Logan River has a good water supply, and as soon as it appears from its canyon a number of canals divert its waters for the irrigation of a large portion of Cache Valley. The station is at Logan, Utah. It was established June 1, 1896. Measurements are made by J. S. Baker and G. L. Swendsen.

Estimated monthly discharge of Logan River at Logan, Utah.

[Drainage area, 218 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	243	210	229	14,081	1.05	1.21
February	310	200	226	12,551	1.04	1.08
March	268	210	231	14,204	1.06	1.22
April	570	243	369	21,957	1.69	1.89
May	890	380	660	40,582	3.03	3.49
June	1,930	765	1,470	87,471	6.74	7.51
July	1,703	663	1,100	67,636	5.05	5.82
August	663	420	518	31,851	2.38	2.75
September	420	345	379	22,552	1.74	1.94
October	345	310	338	20,783	1.55	1.79
November	310	295	304	18,089	1.39	1.55
December	295	255	283	17,401	1.30	1.50
The year	1,930	200	509	369,158	2.34	31.75

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 335; rating table in Paper No. 39, page 453.

WEBER RIVER.

Like the Ogden, its principal tributary, this river rises in the high country east of the Wasatch Mountains. Passing through this range, it appears in the plains region in the vicinity of Ogden, where, after it receives the waters of Ogden River, it discharges into Great Salt Lake. There are a number of good reservoir sites on its upper tributaries, some of which have been utilized within the last half year. The station, which was established in October, 1899, is at Uinta, Utah. The station on Ogden River is at Ogden, Utah. It was established in the spring of 1897. Measurements at both of these stations are made by J. S. Baker and W. B. Dougall.

Estimated monthly discharge of Weber River at Uinta, Utah.

[Drainage area, 1,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	445	445	445	27,362	0.28	0.32
February	520	445	491	27,269	0.31	0.32
March	1,721	520	780	47,960	0.49	0.56
April	3,723	1,403	2,642	157,210	1.65	1.84
May	4,770	2,768	3,556	218,650	2.22	2.56
June	4,588	2,677	3,693	219,749	2.31	2.58
July	2,586	445	1,183	72,740	0.74	0.85
August	445	375	412	25,333	0.26	0.30
September	375	320	322	19,160	0.20	0.22
October 1 to 15	520	320	393	24,165	0.25	0.29

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 338; rating table in Paper No. 39, page 453.

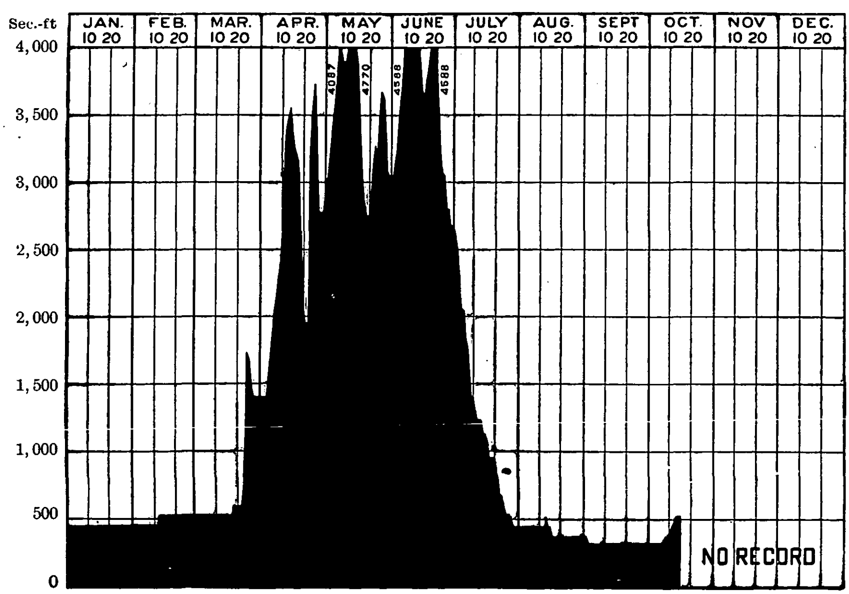


FIG. 221.—Discharge of Weber River at Uinta, Utah, 1899.

PROVO RIVER.

This river rises on the western slope of the Uinta Mountains, and after receiving a number of tributaries enters what is known as Heber Valley, where considerable irrigation is practiced. After crossing this valley it passes through the Wasatch Mountains in a picturesque canyon, and finally enters Utah Valley, where its summer flow is completely diverted for irrigation purposes. Its flood waters discharge into Utah Lake. The station, which was established July 27, 1889, is at Provo, Utah. Measurements are made by W. B. Dougall and J. S. Baker.

Estimated monthly discharge of Provo River at Provo, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	287	287	287	17,647	0.45	0.52
February	287	190	267	14,828	0.42	0.43
March	1,052	336	564	34,679	0.88	1.01
April	1,052	582	855	50,876	1.34	1.50
May	1,454	652	1,169	71,879	1.83	2.11
June	3,310	1,454	2,345	139,537	3.66	4.07
July	1,890	330	679	41,750	1.06	1.22
August	350	330	337	20,721	0.53	0.61
September 1 to 23	330	330	330	19,636	0.52	0.58
October 1 to 21	370	370	370	22,750	0.58	0.67

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 339; rating tables in Paper No. 39, page 453.

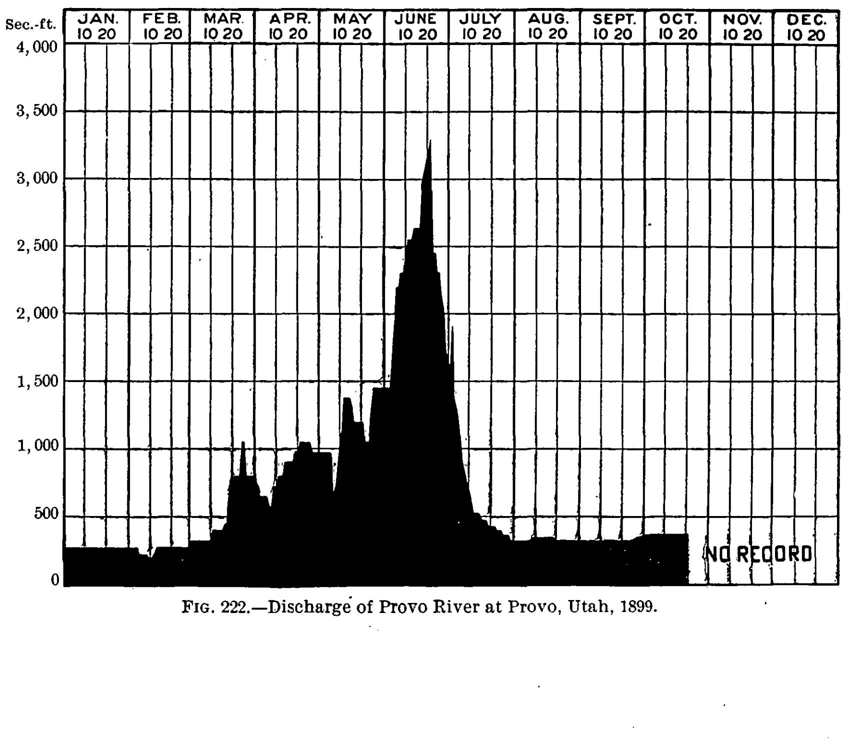


FIG. 222.—Discharge of Provo River at Provo, Utah, 1899.

UTAH LAKE.

This fresh-water lake receives the surplus waters and seepage of a number of streams that receive their water supply from the Wasatch Mountains, the principal ones being Currant Creek, Spanish Fork, Hobble Creek, Provo River, and American Fork. The ordinary flow of these streams is diverted on their appearance from their canyons to irrigate the lands in Utah Valley. Utah Lake discharges toward the north through Jordan River, which empties into Great Salt Lake. The gaging station is at Geneva, where has been recorded the rise and fall of the water surface since November 6, 1896. The city of Salt Lake is about to erect a new station at the outlet of Utah Lake. This is shown in plan and section in figs. 223 and 224.

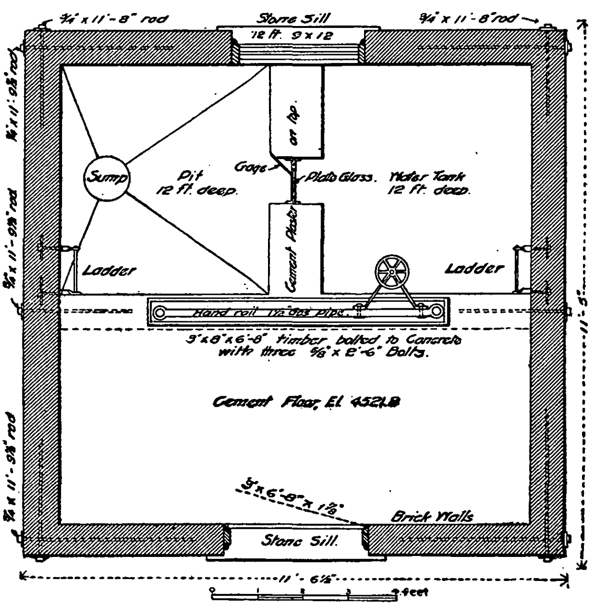
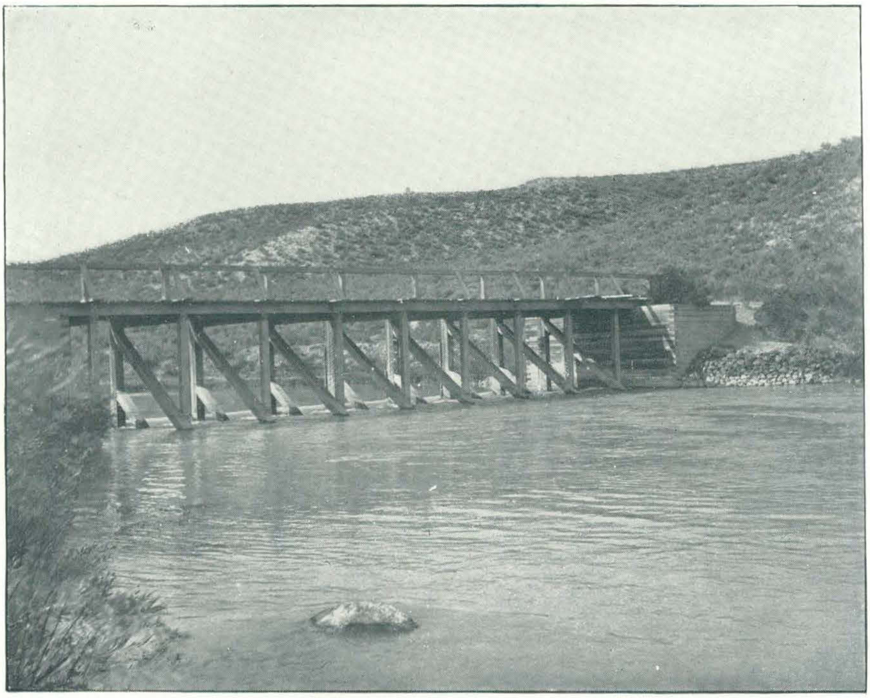


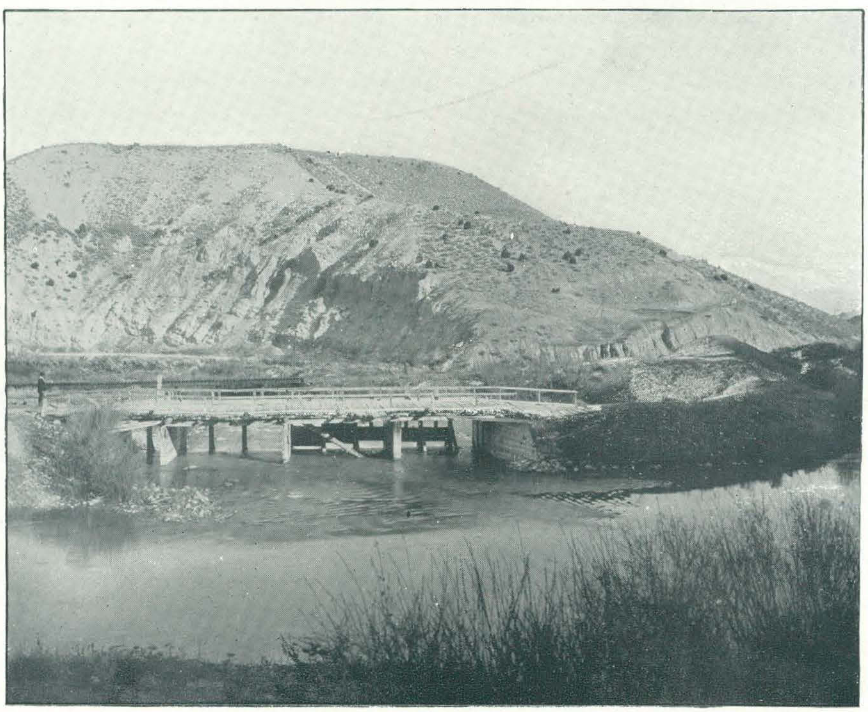
FIG. 223.—Plan of Utah Lake gaging station, Utah.

JORDAN RIVER.

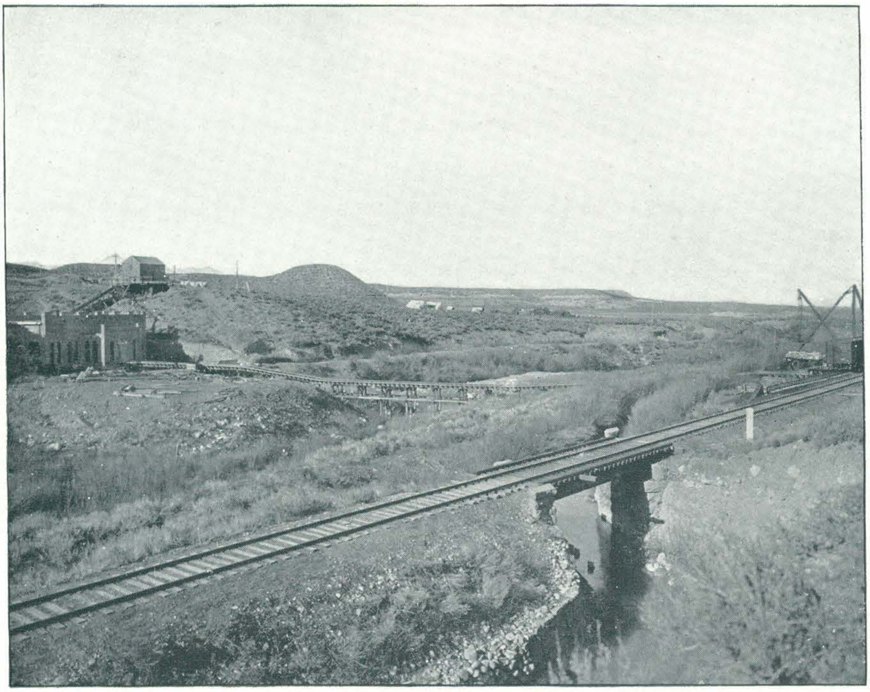
Utah Lake discharges toward the north through Jordan River, which empties into Great Salt Lake. A number of large canals divert the waters of this stream and supply lands in Salt Lake County, one of them carrying water to Salt Lake City. Measurements of the flow of Jordan River and of the water diverted into the canals have not been made systematically, owing largely to conservatism or distrust. When the hydrographic investigations were begun, in 1889, an attempt was made on behalf of the Geological Survey to secure cooperation, or at least the sympathy, of those interested, but there appeared to be a sentiment against furnishing records of this character, due, possibly,



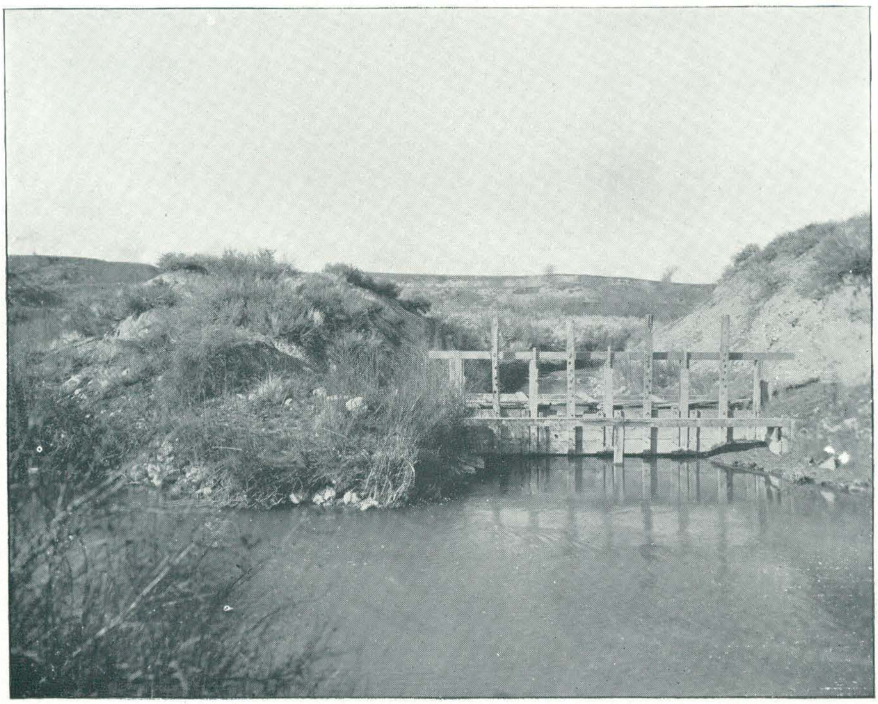
A. NEW DAM ON JORDAN RIVER, UTAH.



B. OLD DAM AT JORDAN NARROWS, UTAH.



A. POWER PLANT OF SALT LAKE CITY WATER AND ELECTRICAL POWER COMPANY AND JORDAN AND SALT LAKE CITY CANAL AT JORDAN NARROWS, UTAH.



B. HEAD GATE OF JORDAN AND SALT LAKE CITY CANAL.

to the fear that private interests might be injured. There was a tacit agreement at least that it was better not to meddle with the systems

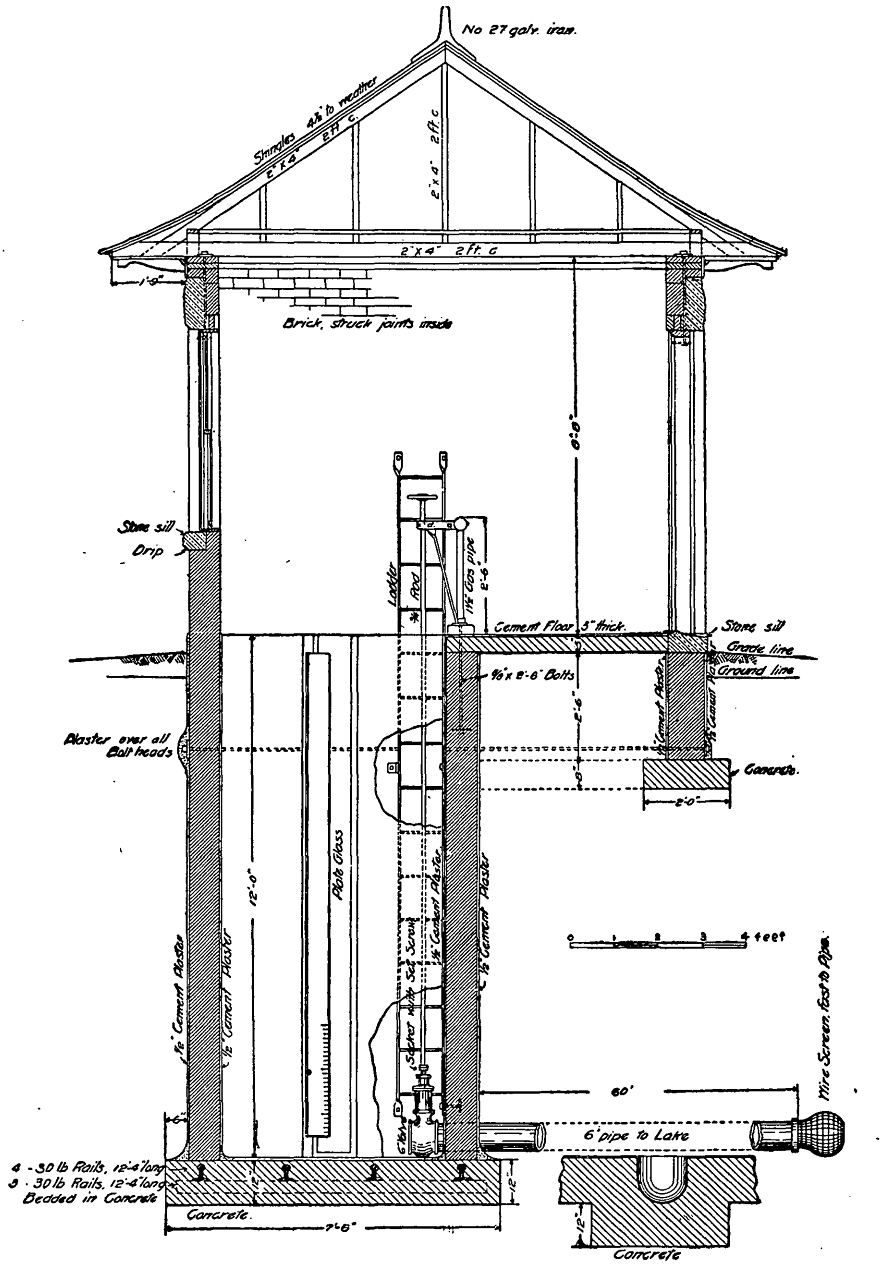


FIG. 224.—Section of Utah Lake gaging station, Utah.

in vogue. Ten years later attempts were made by the city engineer to obtain weir measurements of the canals, but he was opposed and the weirs were destroyed. The conditions, however, became so onerous that a private corporation finally undertook the measurement of the river, systematic observations being begun in May, 1899.

The plant of the Salt Lake City Water and Electrical Power Company was completed in 1899, and is developing electric power, which is used in the mining camps of Bingham and Mercur, Utah. It is located on Jordan River, about 20 miles south of Salt Lake City and 12 miles below the outlet of Utah Lake. (See Pl. XXXIX, *A*.) This water-power company has been keeping a record of the discharge of Jordan River and of the various canals diverting water immediately above, but on account of pending lawsuits the data are not at present available. The water necessary to develop the power of this plant is diverted from Utah and Salt Lake canal, which heads about 2 miles above the plant, at what is known as the Point of the Mountain. It is taken from the west side of the river, at the point where the East Jordan canal diverts water to the east side. When the power

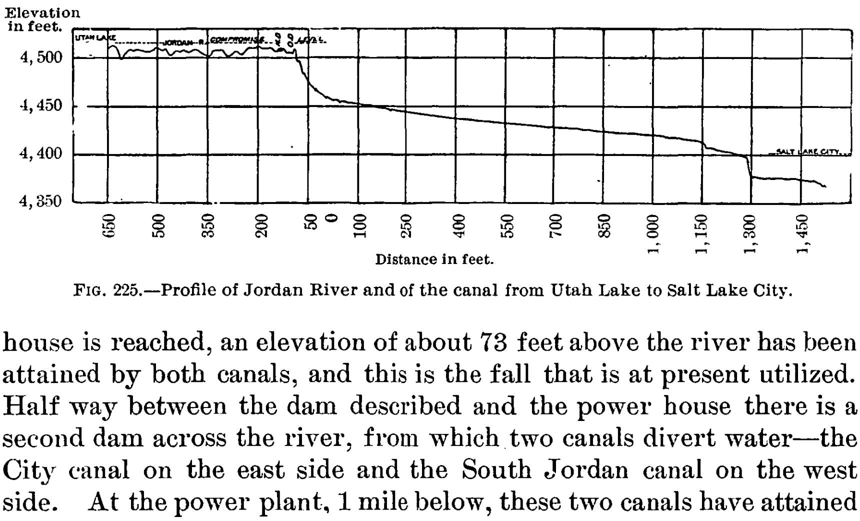
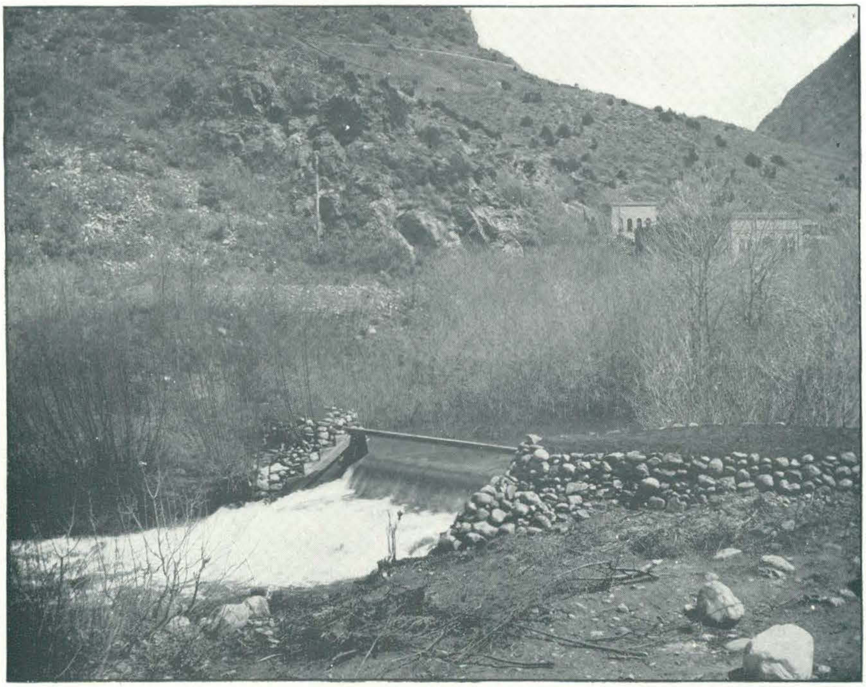


FIG. 225.—Profile of Jordan River and of the canal from Utah Lake to Salt Lake City.

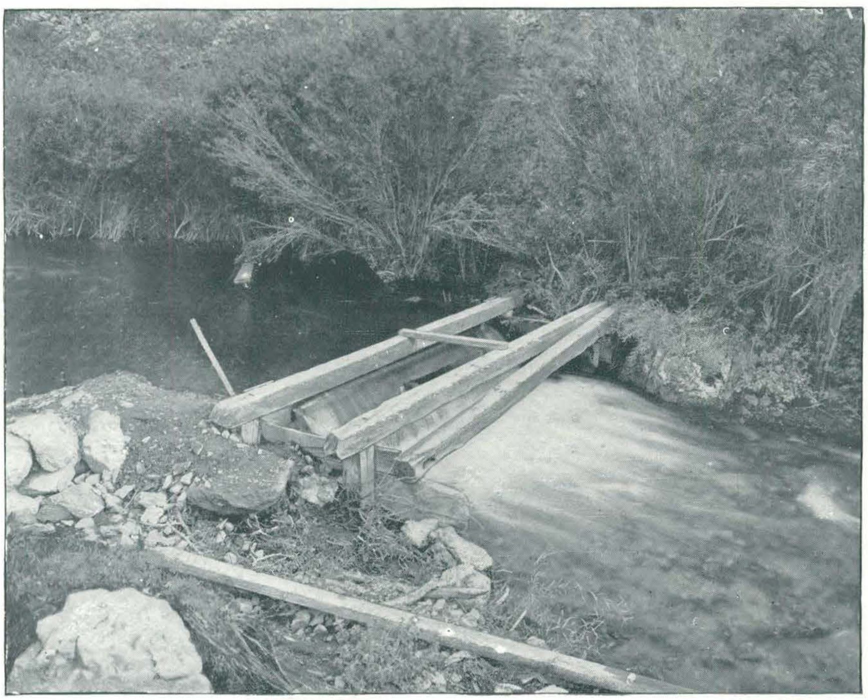
house is reached, an elevation of about 73 feet above the river has been attained by both canals, and this is the fall that is at present utilized. Half way between the dam described and the power house there is a second dam across the river, from which two canals divert water—the City canal on the east side and the South Jordan canal on the west side. At the power plant, 1 mile below, these two canals have attained elevations of about 20 feet above the river. On December 6, 1899, measurements of the discharge of these canals, as well as of Jordan River, were made at the stations of the Salt Lake City and Electrical Power Company. Utah and Salt Lake canal below the power company's diversion, at a gage height of 2.40 feet, was discharging 27 second-feet; Utah and Salt Lake canal above the power company's diversion, at a gage height of 4.13 feet, was discharging 80 second-feet; the South Jordan canal, at a gage height of 2.33 feet, was discharging 19 second-feet; Jordan canal, at a gage height of 4.15 feet, was carrying 111 second-feet; City canal, at a gage height of 3.20 feet, was discharging 45 second-feet; East Jordan canal, with a gage



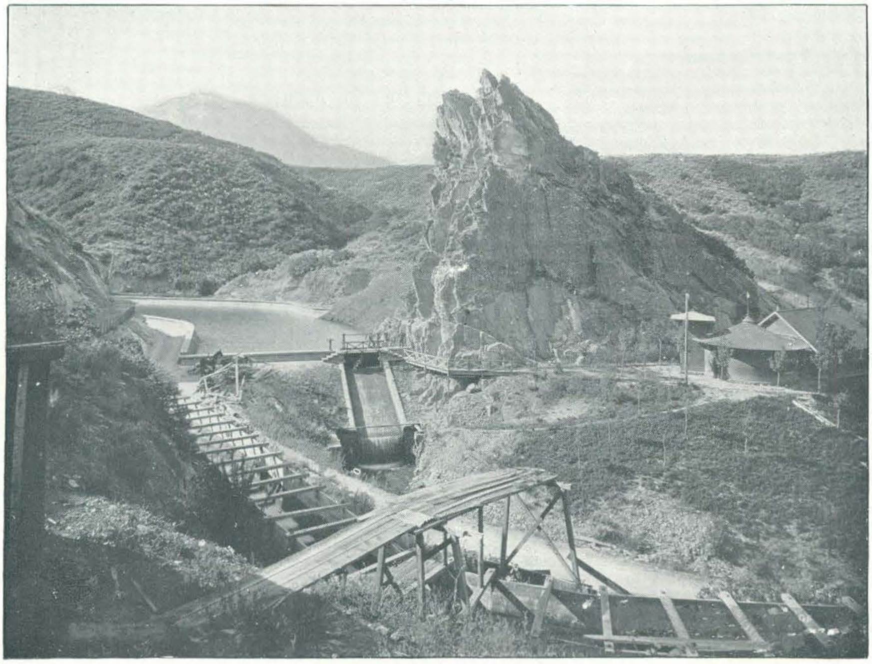
A. CIPPOLETTI WEIR ON BIG COTTONWOOD CREEK, NEAR MOUTH OF CANYON, UTAH.

B. CIPPOLETTI WEIR DURING HIGH WATER.

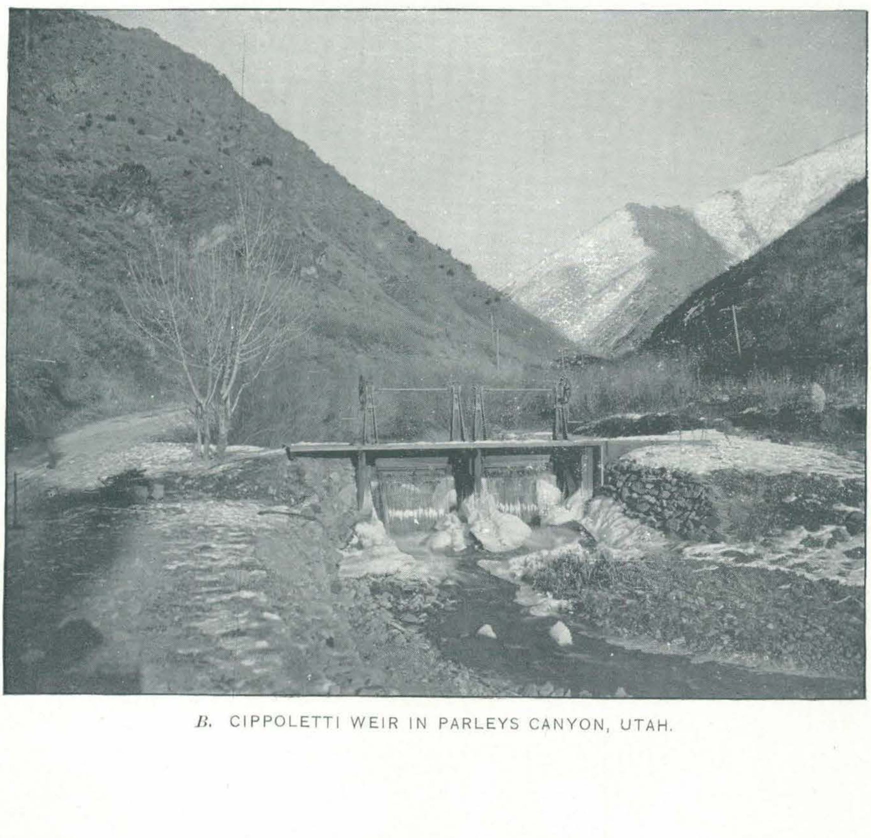
A. CIPPOLETTI WEIR ON LITTLE COTTONWOOD CREEK, UTAH.



B. CIPPOLETTI WEIR ON MILL CREEK, UTAH.



A. SALT LAKE CITY WATERWORKS, AT MOUTH OF PARLEYS CANYON, UTAH.



B. CIPPOLETTI WEIR IN PARLEYS CANYON, UTAH.

height of 1.02 feet, was discharging 6 second-feet. A measurement was also made of the tailrace of the power plant, in order to compare it with the difference between the two measurements of Utah and Salt Lake canal, and a discharge of 56 second-feet was found.

The city engineer of Salt Lake City, Mr. Frank C. Kelsey, has been keeping a record of the discharge of various small streams in the vicinity of that city, in connection with the municipal water supply. The following are the creeks, with the drainage areas in their respective canyons: Little Cottonwood Creek, 27.72 square miles; Big Cottonwood Creek, 48.47 square miles; Mill Creek, 21.29 square miles; Parleys Creek, 50.14 square miles; Emigration Creek, 18.92 square miles; Red Butte Creek, 11.59 square miles; City Creek, 19.15 square miles. The results of these measurements are given in Water-Supply Paper No. 38, pages 343 to 345.

The station on Big Cottonwood Creek is placed below the Utah Power Company's building. A record was commenced on October 30, 1898, the measurements being made over a rectangular weir 16 feet long. Pl. XL, *A*, is a view of a Cippoletti weir in Big Cottonwood Creek near mouth of canyon; Pl. XL, *B*, a view of Cippoletti weir during high water.

On Little Cottonwood Creek measurements are taken twice a day of the height of water passing over a Cippoletti weir 18 feet long. (See Pl. XLI, *A*.) The record is from November 11, 1898, to May 20, 1899. At the latter date the weir was washed out by a flood and funds could not be procured to replace it.

The measurements on Mill Creek were started September 8, 1898, and are made over a Cippoletti weir placed in the canyon. (See Pl. XLI, *B*.) April 10, 1899, this weir was removed by the water master of the district, but was replaced on the 30th of the same month.

There is an interesting double Cippoletti weir in the canyon on Parleys Creek (see Pl. XLII, *B*), which is so controlled that the entire weir can be lifted, allowing the gravel and deposit from above to be washed out from time to time. Pl. XLII, *A*, is a view of Salt Lake City waterworks at the mouth of Parleys Canyon.

COLUMBIA RIVER DRAINAGE.

SNAKE RIVER.

Snake River, which is the largest affluent of the Columbia, rises on the southern slope of the Continental Divide in the Yellowstone National Park, draining the country west and southwest of Yellowstone Lake. From Shoshone, Lewes, and Heart Lakes, near its head, the river flows in a southerly direction through a timbered and mountainous country, resulting in a long period of high water. After continuing through this area for about 20 miles it broadens into Jackson Lake, a deep body of water about 3 miles wide and 8 miles long. Below the lake the river flows through Jackson Hole Valley—about

40 miles long and 8 miles wide—and then enters a long canyon near the Idaho-Wyoming line. All of the large tributaries come from the east, receiving their waters from the Wind River Range. The west side of the valley is bounded by the high Teton Mountains, from which most of the drainage flows westward through Teton River into North Fork of Snake River. Two stations are maintained on Snake River, one at Grovant, Wyoming, established April 2, 1899, and the other at Montgomery Ferry, Idaho, established August 5, 1895. Stations are also maintained on the following tributaries of the Snake, in order downstream: On Portneuf River at Pocatello, Idaho, established May 8, 1897; on Little Wood River (a tributary of Malade River) at Toponis, Idaho, established August 29, 1899; on Malade River at Toponis, Idaho, established June 2, 1896; and at Bliss, Idaho, established March 27, 1899; on Bruneau River at Grandview, Idaho; on Boise River at Boise, Idaho, established December 15, 1894; on Weiser River at Weiser, Idaho, established December 6, 1894; and on Palouse River at Hooper, Washington, established September 9, 1897. Measurements at these stations are made by F. S. Shirley and N. S. Dils.

Pl. XLIII, *A*, is a view of Twin Falls of Snake River, in Idaho. Pl. XLIII, *B*, shows the top of Shoshone Falls, Idaho.

Estimated monthly discharge of Portneuf River at Pocatello, Idaho.

[Drainage area, 1,130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	270	210	235	14,450	0.21	0.24
February	270	190	214	11,885	0.19	0.20
March	395	190	235	14,450	0.21	0.24
April	545	285	443	26,360	0.39	0.44
May, 25 days	820	457	610	37,507	0.54	0.62
June	775	370	638	37,964	0.56	0.62
July	370	85	262	16,110	0.23	0.26
September	180	85	131	7,795	0.12	0.13
October 1 to 14	170	130	150	9,223	0.13	0.15

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 351; discharge measurements, page 350; rating table in Paper No. 39, page 453.

A. TWIN FALLS OF SNAKE RIVER, IDAHO.

B. TOP OF SHOSHONE FALLS, IDAHO.

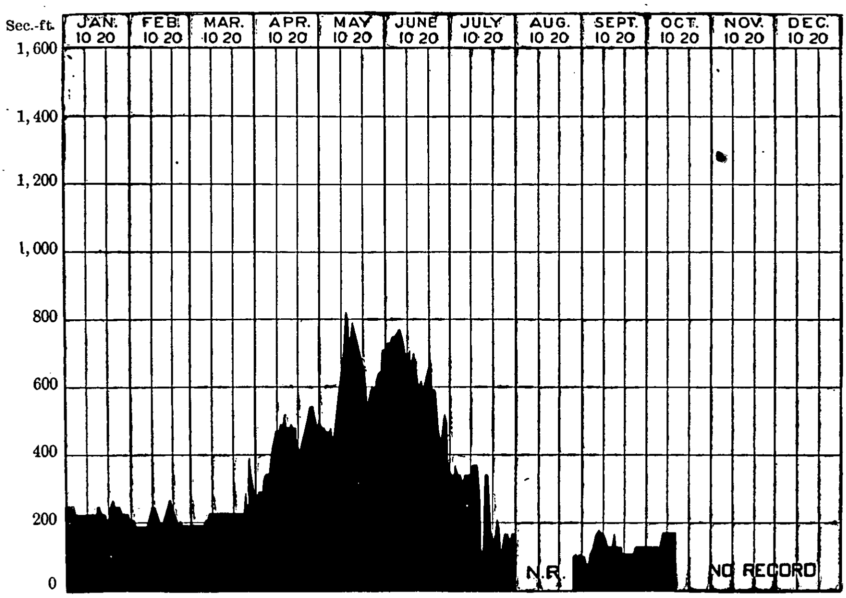


FIG. 226.—Discharge of Portneuf River at Pocatello, Idaho, 1899.

Estimated monthly discharge of Snake River at Montgomery Ferry, Idaho.

[Drainage area, 22,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	9,200	5,150	6,973	428,753	0.31	0.36
February	7,625	4,850	5,972	331,668	0.26	0.27
March	5,600	4,950	5,410	332,648	0.24	0.28
April	9,725	5,225	6,196	368,688	0.27	0.30
May	20,655	7,000	13,717	843,426	0.61	0.70
June	39,220	21,125	29,138	1,733,832	1.29	1.44
July	37,340	14,000	26,221	1,612,267	1.11	1.28
August	13,400	6,900	8,772	539,369	0.39	0.45
September	6,800	5,600	6,010	357,620	0.27	0.30
October 1 to 15	5,900	5,700	5,787	355,829	0.26	0.30

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 352; rating table in Paper No. 39, page 453.

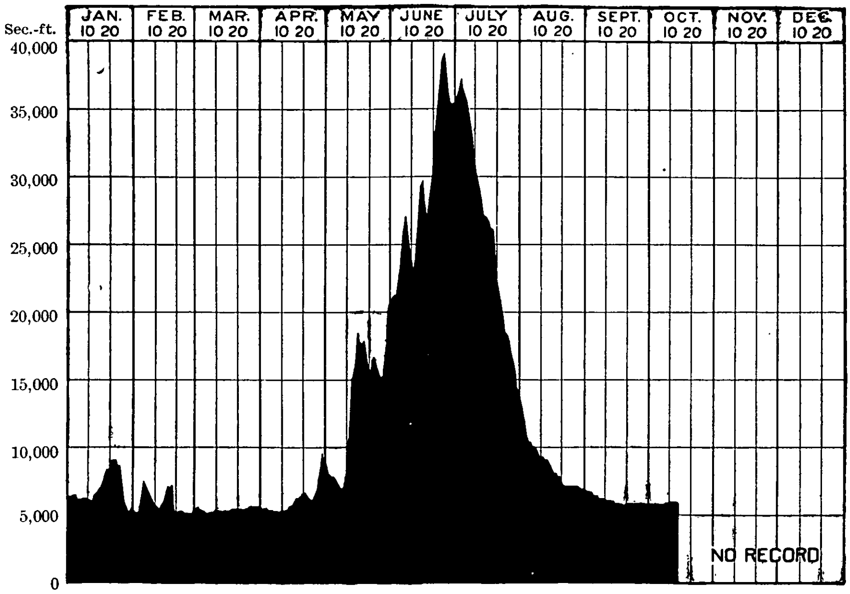


FIG. 227.—Discharge of Snake River at Montgomery Ferry, Idaho, 1899.

Estimated monthly discharge of Little Wood River at Toponis, Idaho.

[Drainage area, 1,270 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March	303	109	173	10,637	0.136	0.16
April	164	52	114	6,783	0.089	0.099
May	64	0.5	20	1,230	0.016	0.018
June	12	0.1	4	238	0.003	0.003
July	9	2	6	369	0.005	0.006
August	14	0.5	6	369	0.005	0.006
September	30	2	11	655	0.009	0.010
October 1 to 14	61	2	46	2,828	0.036	0.042

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 353; rating table in Paper No. 39, page 453.

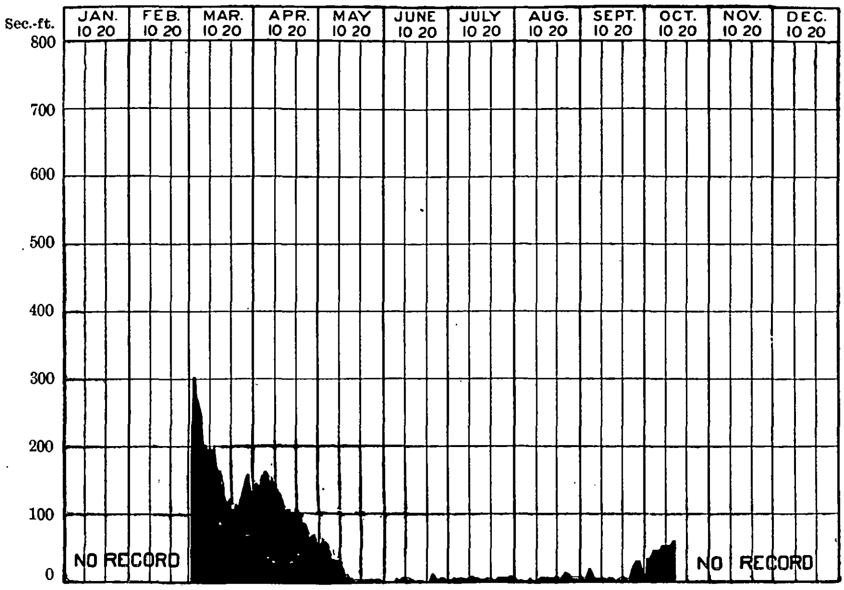


FIG. 228.—Discharge of Little Wood River at Toponis, Idaho, 1899.

Estimated monthly discharge of Malade River at Toponis, Idaho.

[Drainage area, 2,190 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
February 18 to 28	....	....	80	4,443	0.036	0.037
March	470	7	60	3,689	0.027	0.031
April	2,390	85	910	54,149	0.415	0.47
May	1,370	280	723	44,456	0.330	0.38
June	1,690	710	1,065	63,372	0.486	0.55
July	1,060	65	408	25,087	0.186	0.22
August	65	5	14	861	0.006	0.007
September	12	5	9	536	0.004	0.004
October	12	10	11	676	0.005	0.006

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 354; rating table in Paper No. 39, page 453.

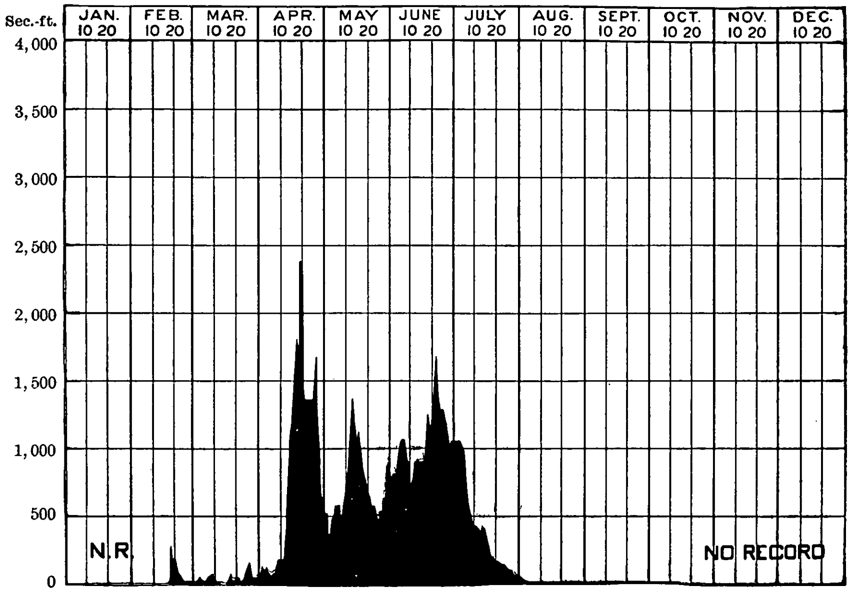


FIG. 229.—Discharge of Malade River at Toponis, Idaho, 1899.

Estimated monthly discharge of Malade River at Bliss, Idaho.

[Drainage area, 3,550 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	3,625	1,300	2,299	136,800	0.65	0.72
May	2,875	1,410	1,890	116,212	0.53	0.61
June	3,325	1,975	2,300	136,859	0.65	0.72
July	2,125	1,120	1,517	93,277	0.43	0.49
August	1,120	1,090	1,095	67,329	0.31	0.36
September	1,120	1,090	1,093	65,038	0.31	0.35
October 1 to 14	1,120	1,120	1,120	68,866	0.32	0.37

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 355; rating table in Paper No. 39, page 453.

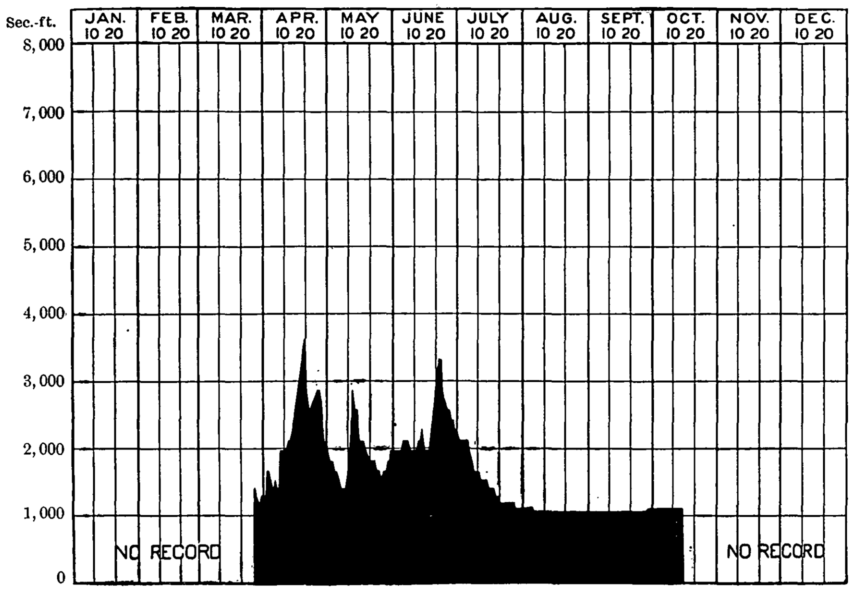


FIG. 230.—Discharge of Malade River at Bliss, Idaho, 1899.

Malade River, or Big Wood River, as it is sometimes called, has its source in the high mountainous area north of Ketchum, Idaho, and flows southerly into Snake River. After receiving the waters of its principal tributary, Camas Creek, which enters from the west, the main stream flows across the broken lava-covered country from which there apparently is no drainage. The rain which falls upon this ground percolates downward through passages in the lava, and unites to form springs, some of which discharge directly into Snake River. A considerable amount of irrigation is practiced in the drainage basin of Malade River, and a number of ditches divert water from it at a point above Toponis. The second point of measurement, at Bliss, is about 15 miles below the upper station, and in that distance the flow is considerably augmented by spring water.

BRUNEAU RIVER.

This river has its source in northern Nevada and flows in a general northerly direction, entering Snake River in Owyhee County, Idaho. Its basin is of a rolling character and is devoted to stock raising. Systematic measurements on this river have been maintained by Andrew J. Wiley for the Owyhee Land and Irrigation Company immediately below the headworks of their canal system, 10 miles east of Grandview, Idaho.

Estimated monthly discharge of Bruneau River at Grandview, Idaho.

[Drainage area, 1,800 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,464	80	182	11,191	0.101	0.12
February	420	45	152	8,442	0.084	0.087
March	1,844	120	333	20,475	0.185	0.22
April	2,452	360	1,397	83,127	0.776	0.87
May	2,300	630	1,383	85,037	0.768	0.89
June	2,452	1,350	1,983	117,997	1.101	1.23
July	1,350	170	617	37,938	0.342	0.39
August	170	80	121	7,440	0.067	0.077
September	80	65	70	4,165	0.038	0.043
October	130	72	105	6,456	0.058	0.067
November	140	120	123	7,319	0.068	0.075
December	120	80	103	6,333	0.057	0.066
The year	2,452	45	547	395,920	0.304	4.135

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 356; rating table in Paper No. 39, page 453.

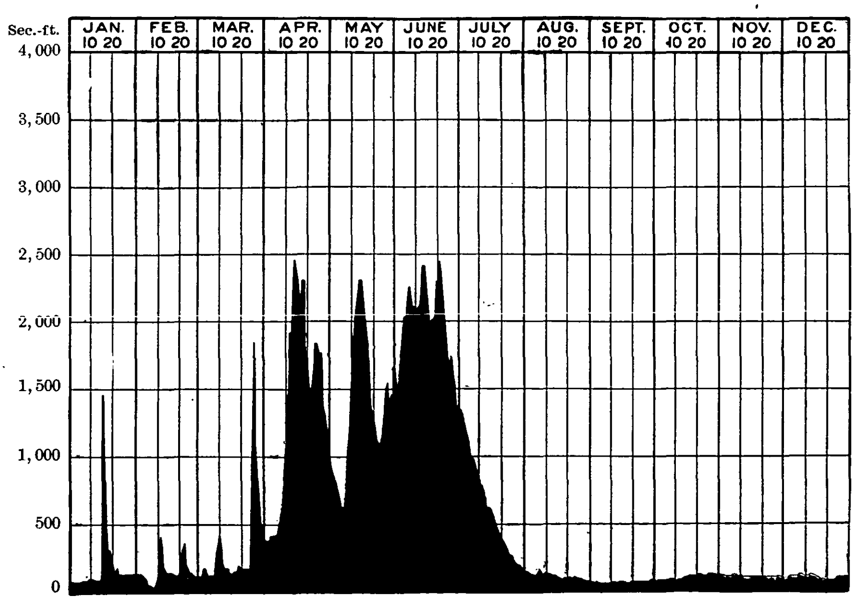


FIG. 231.—Discharge of Bruneau River at Grandview, Idaho, 1899.

BOISE RIVER.

The Boise drains a mountainous and well-wooded country in Elmore County, Idaho. The effects of the forests are shown in the high flow that is maintained throughout the summer season, in contrast to the discharge of Weiser River, farther to the west, which drains a more barren country. Below the gaging station, which is located in the canyon, a large number of canals divert water to irrigate lands in Boise Valley. The diversion of the water is now so great that frequent complaints of scarcity are heard. It is estimated that 13,000 acres of land are irrigated by canals fed by Boise River. The station, established December 15, 1894, is about 9 miles above Boise, Idaho, at the mouth of the canyon. Measurements are made by F. S. Shirley and N. S. Dils.

Estimated monthly discharge of Boise River at Boise, Idaho.

[Drainage area, 2,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,975	1,224	2,590	159,253	1.06	1.22
February	1,938	1,105	1,407	78,141	0.57	0.59
March	3,755	1,343	1,838	113,014	0.75	0.86
April	13,130	2,780	7,095	422,182	2.89	3.22
May	19,050	4,820	9,810	603,193	4.00	4.61
June	18,680	9,800	12,186	725,118	4.97	5.54
July	11,280	2,390	5,742	353,062	2.34	2.70
August	2,390	1,105	1,773	109,017	0.72	0.83
September	1,343	986	1,150	68,430	0.47	0.53
October	2,390	986	1,350	83,008	0.55	0.63
November	2,057	1,224	1,504	89,494	0.61	0.68
December	2,057	1,224	1,566	96,290	0.64	0.74
The year	19,050	986	4,001	2,900,202	1.63	22.15

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 357; rating table in Paper No. 39, page 453.

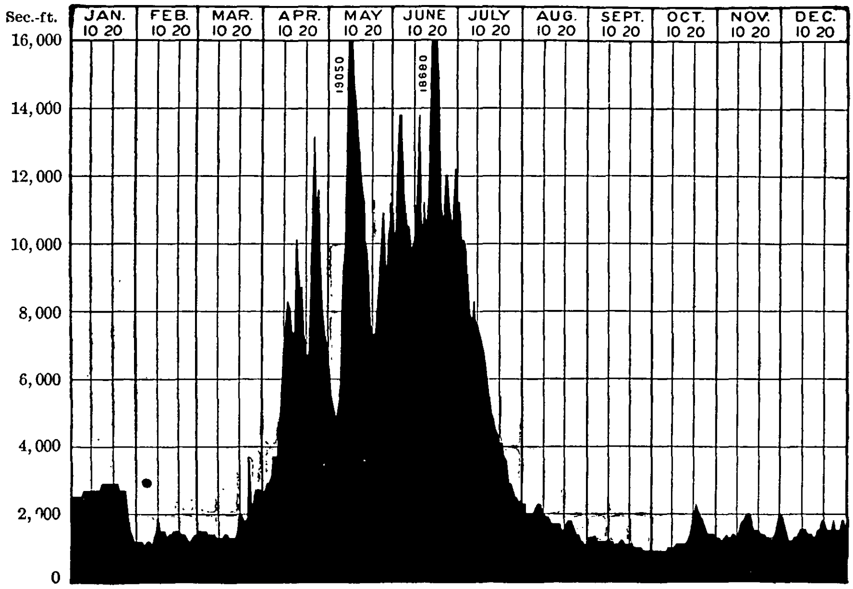


FIG. 232.—Discharge of Boise River at Boise, Idaho, 1899.

The table on the foregoing page (411) is a continuation of that on page 483 of the Twentieth Annual Report, Part IV. A series of measurements for computation of seepage were made along the river below the gaging station, the results of which are given in the report just mentioned, beginning on page 484. These were supplemented by a second series made in 1899, the results of which are given in Water-Supply Paper No. 38, beginning on page 358.

WEISER RIVER.

The drainage basin of this river is mountainous and rocky, in contrast to the well-wooded areas of the Boise and Payette basins, the effect being shown in the high flood discharges and the low summer flow. A number of small ditches divert water from the river for irrigation. The station, which was established December 6, 1894, is located in the canyon of the river about 10 miles from Weiser. Measurements are made by F. S. Shirley and N. S. Dils.

Estimated monthly discharge of Weiser River at Weiser, Idaho.

[Drainage area, 1,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	5,020	660	1,556	95,675	0.93	1.07
February	875	470	605	33,600	0.36	0.37
March	6,580	950	2,776	170,690	1.66	1.91
April	5,020	2,570	3,799	226,056	2.27	2.53
May	4,630	1,780	3,014	185,324	1.80	2.08
June	4,110	2,110	3,071	182,737	1.84	2.05
July	2,000	415	1,003	61,672	0.60	0.69
August	360	175	236	14,511	0.14	0.16
September	175	75	137	8,152	0.08	0.09
October	470	75	215	13,220	0.13	0.15
November	3,330	310	948	56,410	0.57	0.63

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 360; rating table in Paper No. 39, page 454.

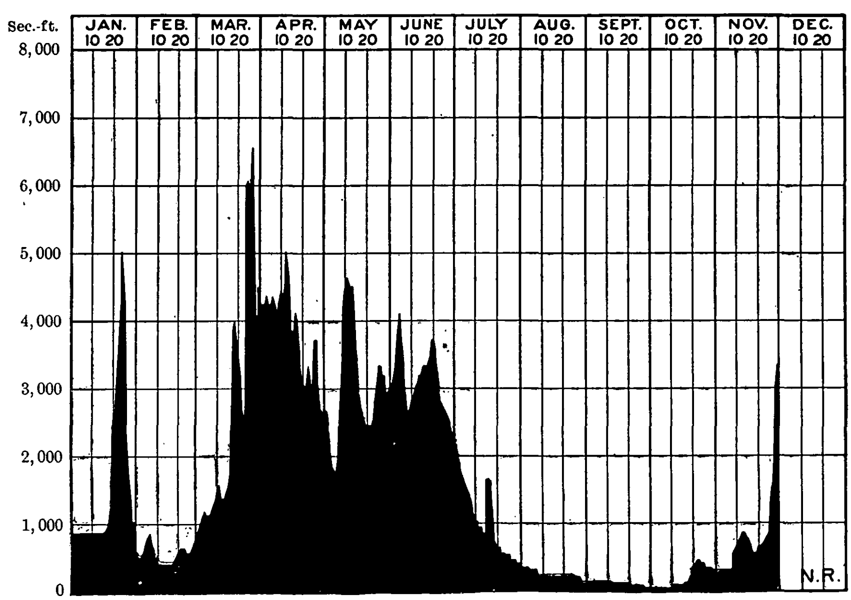


FIG. 233.—Discharge of Weiser River at Weiser, Idaho, 1899.

PALOUSE RIVER.

The headwater tributaries of this river have their sources in western Idaho, adjoining the headwater streams of Potlatch River, a tributary of Clearwater River. After passing into Washington they unite to form the main Palouse, which has a general southwesterly course, passing through a rolling country. Six miles below Hooper, Washington, the river bends suddenly to the south and enters its canyon, through which it continues until its junction with Snake River. A short distance above the mouth of the river are the Palouse Falls, which are approximately 130 feet in height. The station, which was established September 9, 1897, is located near Hooper, Washington.

Estimated monthly discharge of Palouse River at Hooper, Washington.

[Drainage area, 2,210 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	3,440	73	1,126	69,235	0.51	0.59
February	3,209	446	1,357	75,364	0.61	0.64
March	2,120	932	1,374	83,439	0.62	0.71
April	4,199	1,130	1,894	112,701	0.86	0.95
May	1,724	333	827	50,850	0.37	0.43
June	333	79	176	10,473	0.08	0.09
July	107	20	51	3,136	0.02	0.02
August	29	20	24	1,476	0.01	0.01
September	32	22	27	1,607	0.01	0.01
October	148	22	49	3,013	0.02	0.02
November	377	50	110	6,545	0.05	0.06
December	1,658	248	718	44,148	0.32	0.37
The year	4,199	20	644	461,987	0.29	3.90

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 361; rating table in Paper No. 39, page 454.

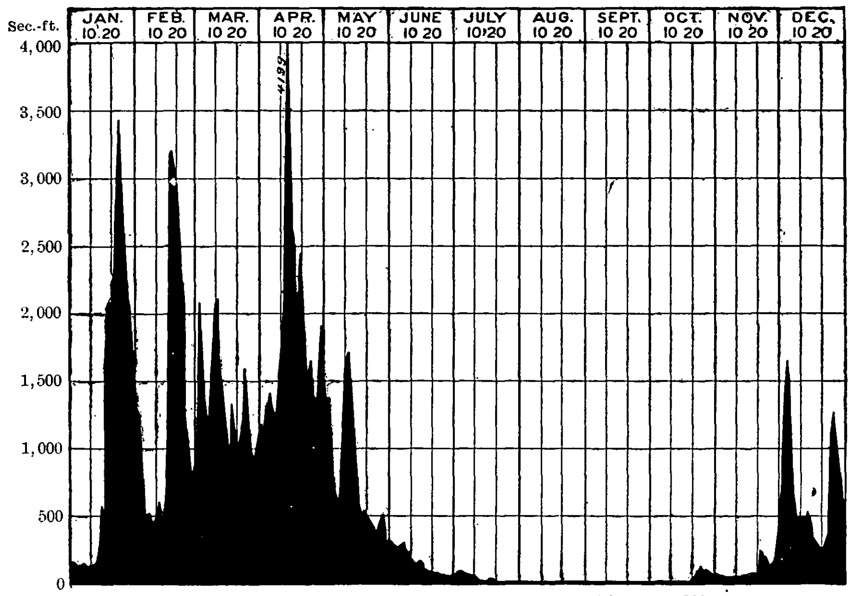


FIG. 234.—Discharge of Palouse River at Hooper, Washington, 1899.

BIG BLACKFOOT RIVER.

This river has its source on the western slope of the main divide of the Rocky Mountains, in Deerlodge County, Montana. Its drainage basin is mountainous and well wooded, and little cultivation is possible within the area. The Clearwater Lakes, near the head, serve as a reservoir, giving the stream a relatively constant flow. The principal industrial applications of the river are found near its mouth, where the water can be used for power purposes as well as for the irrigation of the adjacent lands. It unites with Hellgate River to form the Missoula. The station, which was established July 7, 1898, is at Bonner, Montana. Measurements are made under the direction of Prof. F. D. Smith.

Estimated monthly discharge of Big Blackfoot River at Bonner, Montana.

[Drainage area, 2,465 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March 3 to 31	1,390	730	831	51,096	0.34	0.39
April	7,416	740	2,516	149,712	1.02	1.14
May	14,598	2,112	7,699	473,393	3.12	3.60
June	17,244	10,818	13,615	810,149	5.52	6.16
July	12,078	2,810	6,557	403,174	2.66	3.07
August	2,810	1,420	1,921	118,117	0.78	0.90
September	1,460	1,050	1,250	74,380	0.51	0.57
October	1,205	965	1,073	65,977	0.44	0.51
November	1,275	990	1,074	63,907	0.44	0.49
December	1,420	865	1,012	62,226	0.41	0.47

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 363; discharge measurements, page 362; rating table in Paper No. 39, page 454.

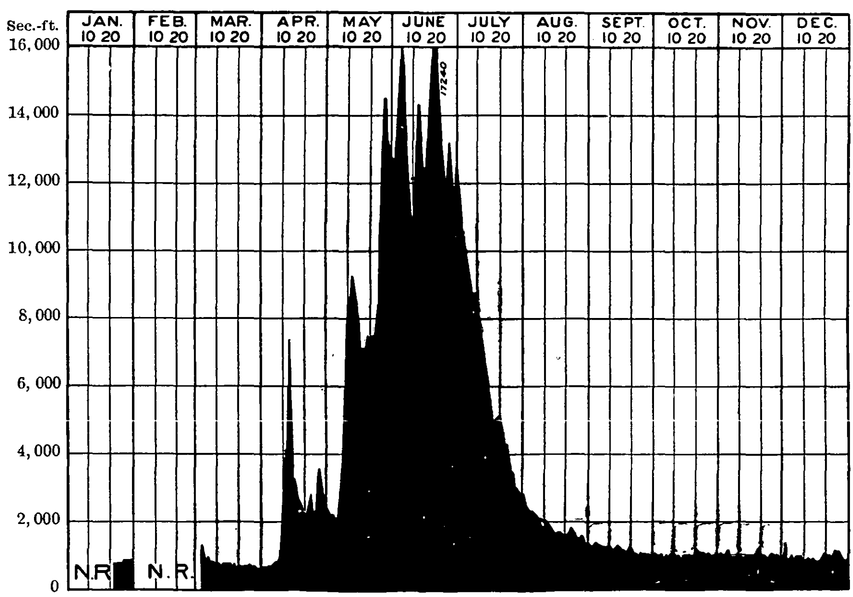


FIG. 235.—Discharge of Big Blackfoot River at Bonner, Montana, 1899.

RATTLESNAKE CREEK.

Rattlesnake Creek has its source north of Missoula and drains a small extent of country. It enters Missoula River in the city of Missoula. The most important application of this stream is for the water supply of the city of Missoula. The station was established May 27, 1899. It is at Missoula. Measurements are made under the direction of F. D. Smith.

Estimated monthly discharge of Rattlesnake Creek at Missoula, Montana.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1899.				
May 27 to 31			846	
June	2,047	490	1,197	71,227
July	1,200	94	511	31,420
August	87	52	63	3,874
September	72	46	57	3,392
October	80	44	70	4,304
November	94	52	64	3,808
December	94	36	74	4,550

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 364; rating table in Paper No. 39, page 454.

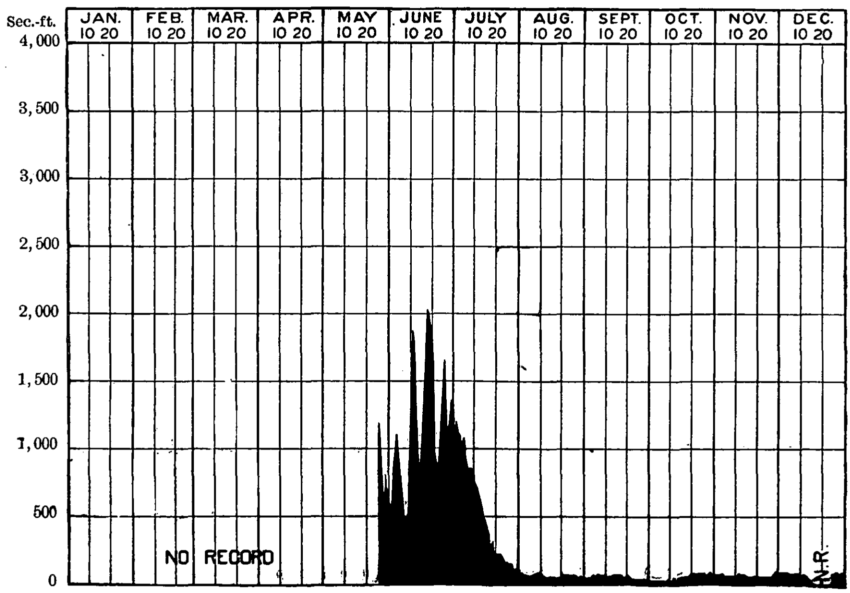


FIG. 236.—Discharge of Rattlesnake Creek at Missoula, Montana, 1899.

MISSOULA RIVER.

The Missoula has its source in Silverbow County, Montana, and flows northerly until it receives the waters of Little Blackfoot River, when it takes a more northwesterly course. The name Missoula is usually applied to that section of the river between the junction of Blackfoot and Hellgate rivers and the mouth of Pend Oreille River. From this point to its junction with Columbia River it is called Clark Fork of Columbia. Rattlesnake Creek and Bitterroot River are the important tributaries. A station was established at Missoula July 10, 1898. Measurements are made under the direction of F. D. Smith.

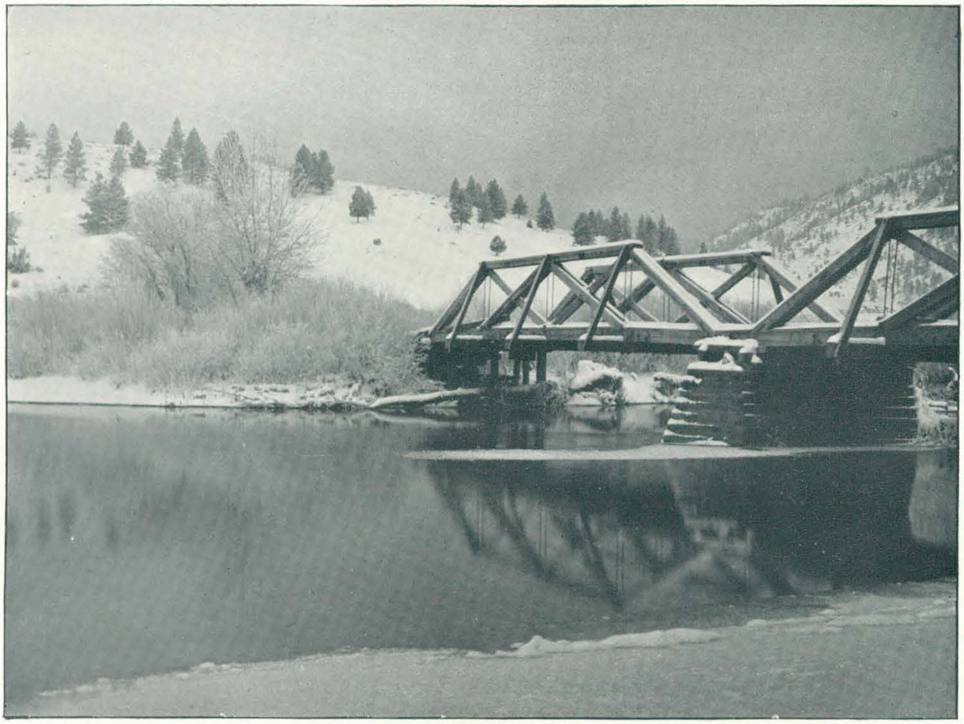
Pl. XLIV, *A*, shows Missoula River at Bearmouth, Montana, above Blackfoot River, Rock Creek, Flint Creek, and other important tributaries. Pl. XLIV, *B*, shows the gage on Missoula River at Missoula, Montana, looking upstream toward the city. This gage was erected in May, 1899, by F. D. Smith, to take the place of a post gage which was located under the Higgins avenue bridge, shown in the center of the background. Discharge measurements are made from the Northern Pacific Railroad bridge, 150 yards below the gage.

Estimated monthly discharge of Missoula River at Missoula, Montana, rod No. 3.

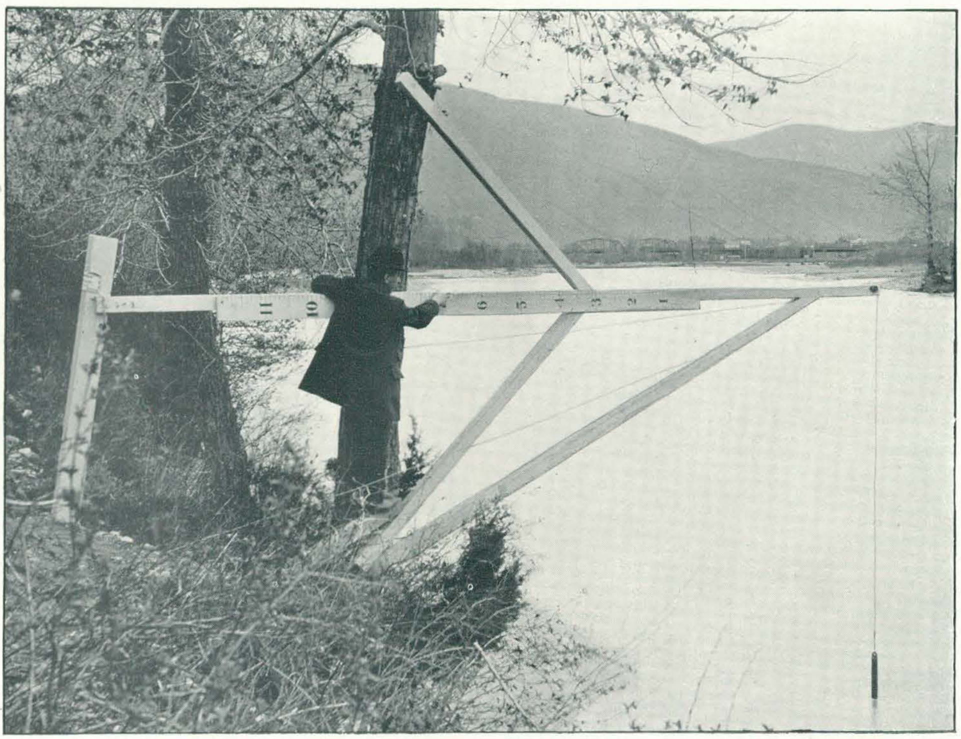
[Drainage area, 5,960 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
June	35,800	18,700	25,858	1,538,658	4.34	4.84
July	22,400	4,900	11,208	689,154	1.88	2.17
August	4,900	2,650	3,592	220,864	0.60	0.69
September	2,725	1,950	2,287	136,086	0.38	0.42
October	2,500	1,900	2,153	132,383	0.36	0.42
November	2,240	1,850	2,138	127,220	0.36	0.40
December 1 to 15	2,180	1,750	1,946	119,654	0.33	0.38

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, pages 366 and 367; discharge measurements, page 365; rating table in Paper No. 39, page 454.



A. MISSOULA RIVER AT BEARMOUTH, MONTANA.



B. GAGE ON MISSOULA RIVER AT MISSOULA, MONTANA.

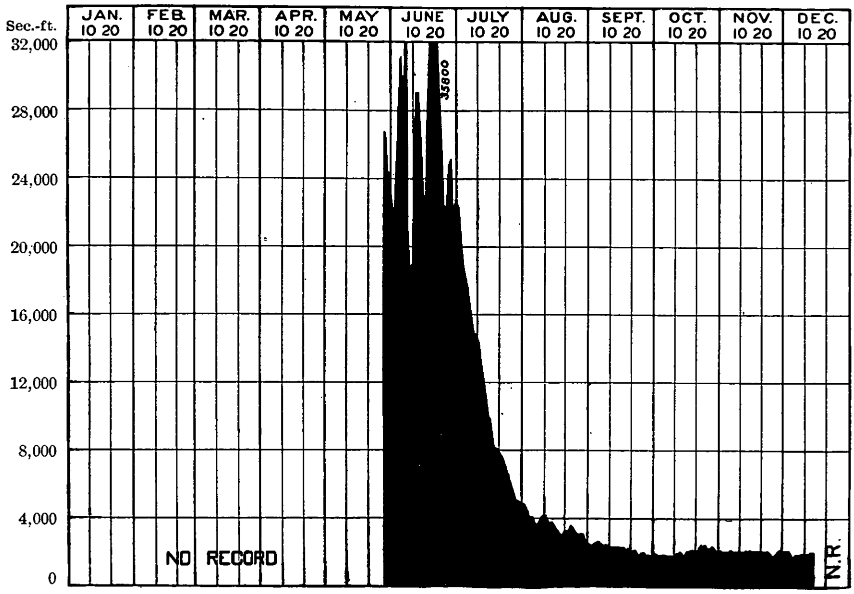


FIG. 237.—Discharge of Missoula River at Missoula, Montana, 1899.

BITTERROOT RIVER.

The source of this river is in the high mountains forming the boundary line between Montana and Idaho. It flows in a northerly direction, entering Missoula River a short distance below the city of Missoula. The tributaries on the east side drain comparatively low hills and contribute little to the supply of the river. The west-side branches, on the contrary, are numerous, draining the precipitous and heavily wooded area. Their discharges are regulated by many small lakes fed by banks of snow, which continue far into the summer before disappearing altogether. From Hamilton to Missoula, a distance of 48 miles, the fall of the river is 350 feet, or 7.3 feet per mile. Two stations are maintained on the river, one at Como, Montana, established in October, 1898, and the other at Missoula, Montana, established July 6, 1898. Measurements at the latter station are made under the direction of F. D. Smith.

Estimated monthly discharge of Bitterroot River at Missoula, Montana.

[Drainage area, 3,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January *a*			1,200	73,785	0.37	0.43
February *a*			1,000	55,537	0.31	0.32
March	1,255	930	1,070	65,792	0.33	0.38
April	4,230	1,122	2,842	169,111	0.87	0.97
May	15,800	2,680	7,729	475,237	2.37	2.73
June	37,437	11,400	21,876	1,301,713	6.71	7.49
July	23,600	5,440	14,497	891,385	4.45	5.13
August	5,330	1,985	3,411	209,734	1.05	1.21
September	2,160	1,122	1,622	96,516	0.50	0.56
October	2,160	1,122	1,470	90,387	0.45	0.52
November	1,830	1,165	1,477	87,888	0.45	0.50
December	1,540	1,165	1,351	83,070	0.41	0.47

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 369; discharge measurements, page 368; rating table in Paper No. 39, page 454.

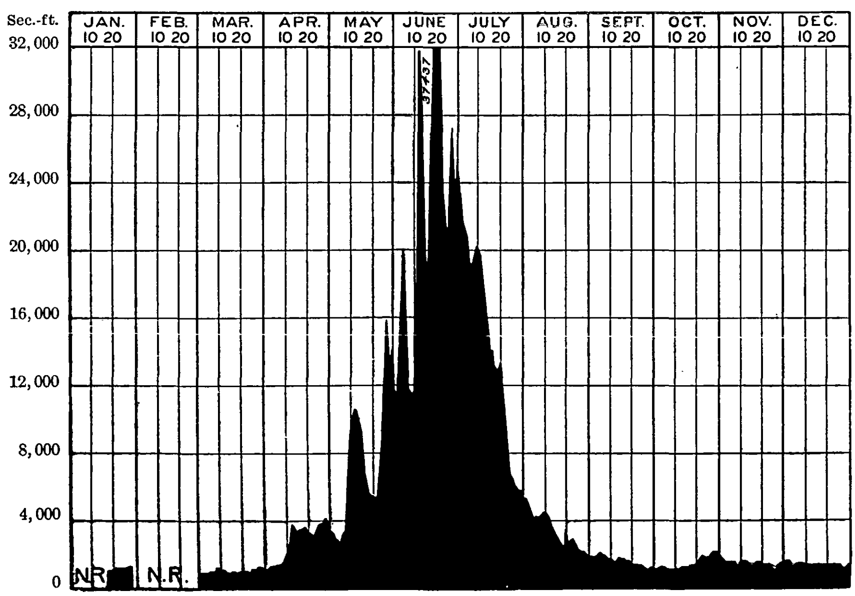


FIG. 238.—Discharge of Bitterroot River at Missoula, Montana, 1899.

FLATHEAD LAKE, MONTANA.[1]

Flathead Lake, in northwestern Montana, occupies the lowest portions of an extensive valley which extends from the Jocko Mountains on the south, northward across the international boundary between the United States and British Columbia, a distance of over 100 miles. The lake proper is about 35 miles long and 15 miles across in the widest places. The plains at the southern end of the lake are about 36 miles long and from 5 to 8 miles wide, nearly level and very fertile. These plains are a part of the Flathead Indian Reservation, and are not cultivated to any considerable extent. At the northern end of the lake, the valley is from 4 to 8 miles wide and 50 miles long, level and fertile, abundantly watered by rainfall, and altogether one of the most valuable valleys in the Northwest.

The lake is a part of the drainage system of that portion of north western Montana between the Rocky Mountains on the east and the Cabinet and Kootenai River mountains on the west. The two paral lel ranges, the Mission and the Kootenai mountains, send all of their drainage from both slopes into Flathead Lake. At the head of the lake streams from the north and west also flow into it, bringing the drainage from that territory and from portions of British Columbia. The main inlet to the lake is Flathead River, which receives practically all of the water of the other streams mentioned, and, with one exception, is the only inflow of any importance. The river receives the waters of these tributaries in the vicinity of Kalispell, at which place Stillwater River empties into the Flathead, bringing water from the northwestern and northern parts of the valley, from the region of Tobacco Plains.

At Columbia Falls, 7 miles from Kalispell, Flathead River receives three streams of importance the confluence of which may be said to give rise to the river. These streams are: North Fork, which drains the Rocky Mountains on their northwestern slope, Middle Fork, which drains the western slope of the Rocky Mountains, and South Fork, which drains a range between the Kootenai Mountains and the Rocky Mountains. The latter two flow in a northerly direction until about opposite Columbia Falls, when they change their course and flow south into Flathead River, which has a general southerly course.

From Kalispell Flathead River pursues a circuitous course through the valley bottom, with a barely perceptible current. Its total length is about 35 miles—measured in a straight line it is only 15 miles. Its width varies from 300 to 600 feet; its depth at high water is nowhere less than 20 feet and it often reaches 75 feet. It is navigable through its entire length. It is more properly an arm of Flathead Lake than a

[1] From notes on the hydrography and economic importance of the lake, prepared by Prof. F. D. Smith, B. S., University of Montana, Missoula, Montana.

river, since its level is that of the lake, except for the slight difference necessary to produce flow. The river is simply a remnant of the old lake, as is plainly shown by the slight elevation of the banks above the water, and by the fact that the surrounding valley bottom is but a few feet above the level of the river.

The only other tributary of this lake is Swan River, which enters near the head, within a mile of the mouth of Flathead River. Pl. XLV is a view of Swan River about a half mile above Flathead Lake.

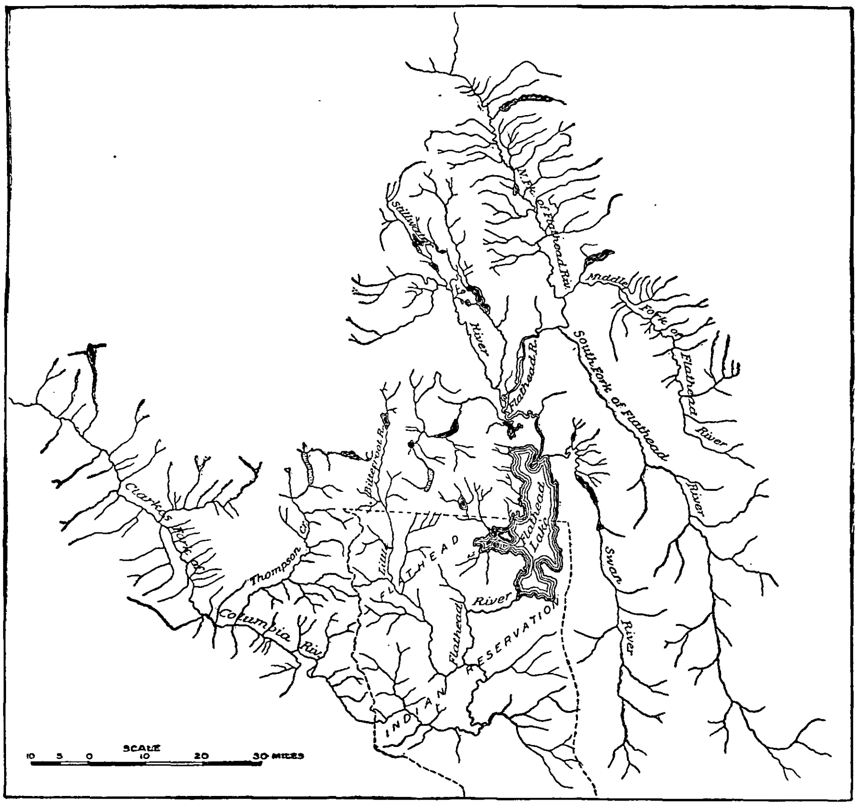
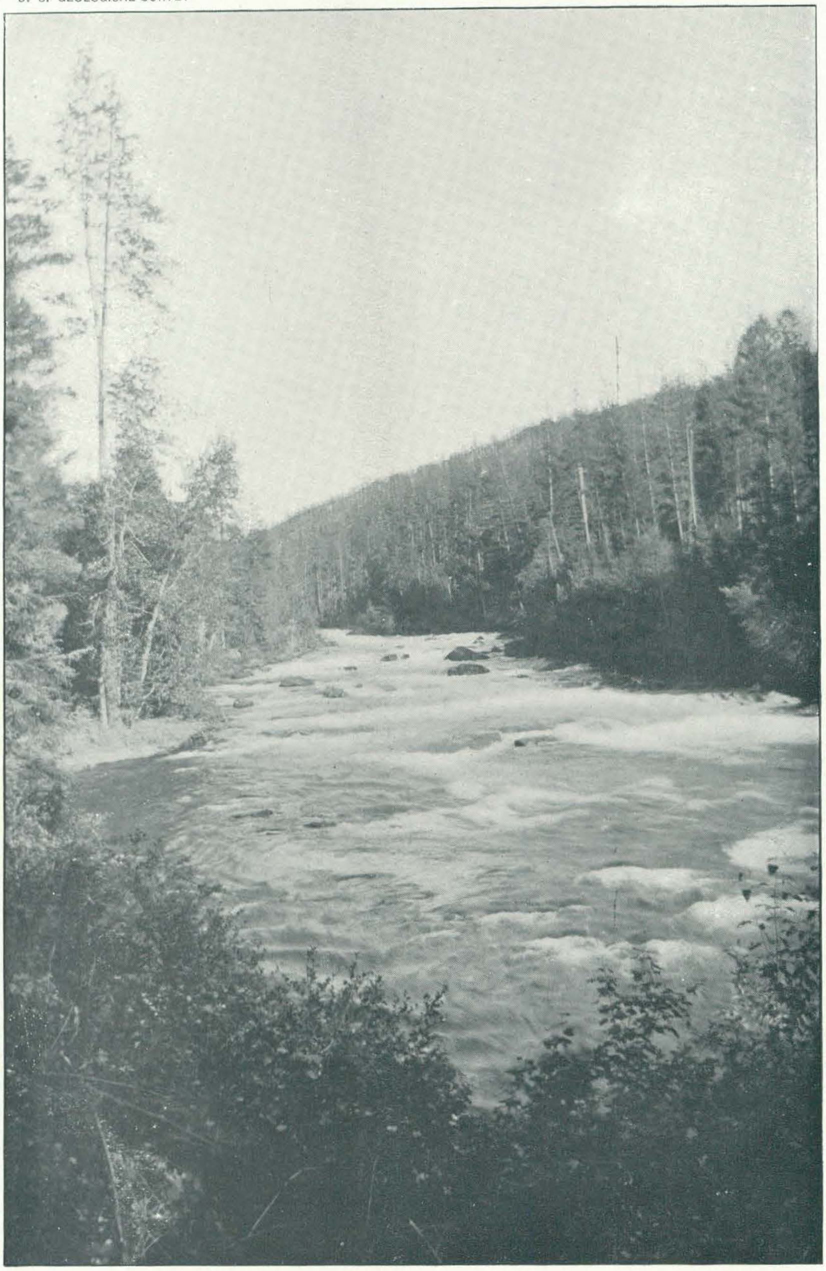


FIG. 239.—Drainage basin of Flathead Lake, Montana.

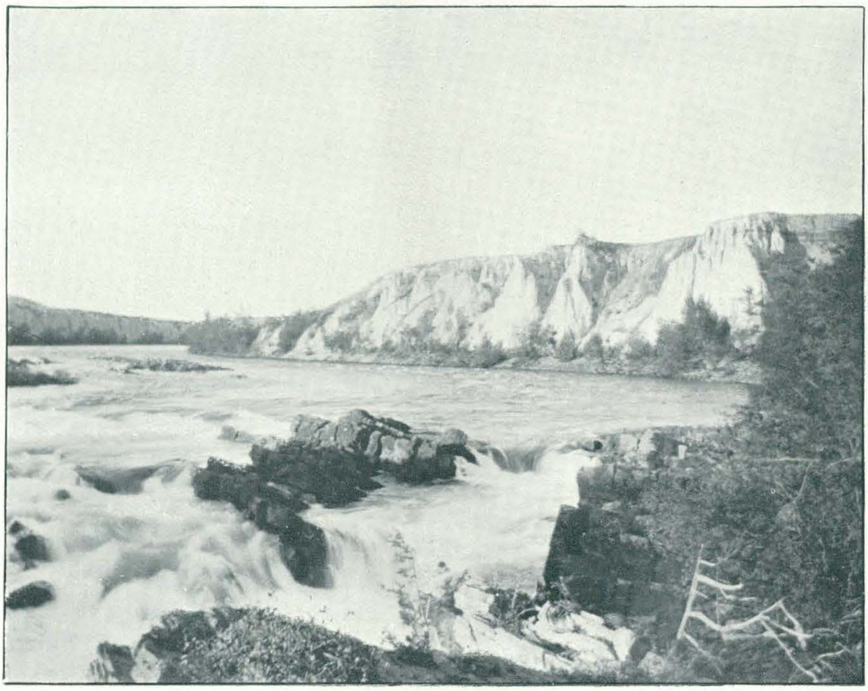
Swan River is sometimes called Big Fork, presumably to correlate with the other forks already enumerated.

These waters, which enter the lake at the northern end, find an outlet at the southern end, through Pend Oreille River, near the town of Polson, Montana. Pl. XLVI, *A*, is a view of Flathead Lake at Polson. Pl. XLVI, *B*, shows the rapids in Pend Oreille River, a half mile below the outlet of Flathead Lake. The Pend Oreille, sometimes called Flathead River, flows south and empties into Missoula River near the town of Olive. It is a stream with rapid slope, forming in many places beautiful rapids and waterfalls, particularly near its head



SWAN RIVER ABOUT A HALF MILE ABOVE FLATHEAD LAKE, MONTANA.

A. FLATHEAD LAKE AT POLSON, MONTANA.



B. RAPIDS IN PEND OREILLE RIVER, MONTANA, A HALF MILE BELOW THE OUTLET OF FLATHEAD LAKE.

at Polson. When the Flathead Indian Reservation is opened for settlement, the town of Polson will become a center of agricultural industries and of manufacturing business, owing to its peculiarly advantageous situation at the foot of a waterway and near this abundant water power.

From the map, fig. 239, it will be seen that Flathead Lake is a nearly rectangular body of water, at the lower end of which a chain of islands and a peninsula nearly divide it into two parts. It is, in fact, an enlargement of the river of the same name, and must be considered an element in the drainage system of that region. Its ability to hold the waters brought into it by tributaries is affected by several conditions. The long stretch of water, unprotected on the south by high mountains, is materially affected by the winds, which blow up the lake, creating waves from 8 to 12 feet in height. The wind at times holds back the water instead of allowing it to flow to the south. Again, the islands and peninsula at the foot must also retard the waters that flow in that direction.

The amounts of water flowing into and out of the lake could only be estimated. In September, 1899, Swan River carried about 2,000 second-feet and Pend Oreille River about 12,000 second-feet. Soundings of the lake in 1899 showed in places a depth of 150 or 175 feet. The level of the lake is reported to change about 10 feet in a season. The amount of change and its rate are dependent upon the relative inflow from Flathead and Swan rivers, as compared with the outflow at Pend Oreille River. When the inflow is rapid, the tracts along Flathead River, now occupied as ranches, are overflowed and much valuable land is submerged. A large tract of level tillable land on the banks of this river is kept in a semiswampy condition, making it unfit for either habitation or agriculture. This land is overgrown with timber or brush, and for a portion of the summer is covered with stagnant pools of water in which mosquitoes breed in great numbers.

It is believed that if the level of the water in the lake could be kept at the point reached at low-water stage (about September 30) this tract of land would be entirely dry and fit for settlement. Should this control of the lake be gained, the danger of overflow during sudden thaws would be lessened and greater security afforded the ranchers at present in that portion of the valley. The land thus redeemed and insured would be several thousand acres.

The sixth legislature of Montana prepared a memorial to the United States Congress in which the foregoing conditions were set forth, and asked for an appropriation of money to enlarge the channel of Pend Oreille River. It was the opinion of the petitioners to the legislature that a large rock, of some 40,000 cubic yards volume, which stands in the center of the river at a point 1 mile below the outlet of the lake, was responsible for the deficient discharge of the river. The removal of this rock would, in their opinion, secure the control of the lake.

An examination of the conditions, made in the summer of 1899, results, however, in doubt of the necessity, or even the wisdom, of the removal of this rock. It is believed that it in no way affects the outflow of the lake, since there is a great fall in the river above the rock, which is sufficient to counteract the tendency of the latter to retard the flow of the waters. It is important, though, that a careful record be kept of the levels of the lake at the Biological Survey station on one end and at Polson on the other, in order that the rate of flow of water through the lake may be determined.

SPOKANE RIVER.

This river rises in the northern part of Idaho, being an outlet of Lake Cœur d'Alene. It passes into Washington, flows in a northwesterly direction, and enters Columbia River near latitude 47° 52′ north. It is about 120 miles long. The station, which was established October 17, 1896, is at Spokane, Washington. Measurements are made by Sydney Arnold.

Estimated monthly discharge of Spokane River at Spokane, Washington.

[Drainage area, 4,005 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	11,243	3,566	5,955	366,159	1.49	1.72
February	10,957	6,523	7,784	432,301	1.94	2.02
March	6,642	6,059	6,320	388,602	1.57	1.81
April	21,281	6,174	14,388	856,146	3.59	4.00
May	29,024	17,828	23,955	1,472,936	5.98	6.89
June	28,644	20,228	25,256	1,502,836	6.31	7.04
July	19,880	6,406	12,209	750,702	3.04	3.50
August	6,406	3,660	4,663	286,717	1.16	1.34
September	3,566	2,938	3,330	198,149	0.83	0.92
October	3,566	2,682	2,954	181,634	0.73	0.84
November	5,832	3,474	3,912	232,780	0.97	1.08
December	10,673	6,523	8,631	530,700	2.15	2.48
The year	29,024	2,682	9,946	7,199,662	2.48	33.64

NOTE.—Gage heights and discharge measurement for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 371; rating table in Paper No. 39, page 454.

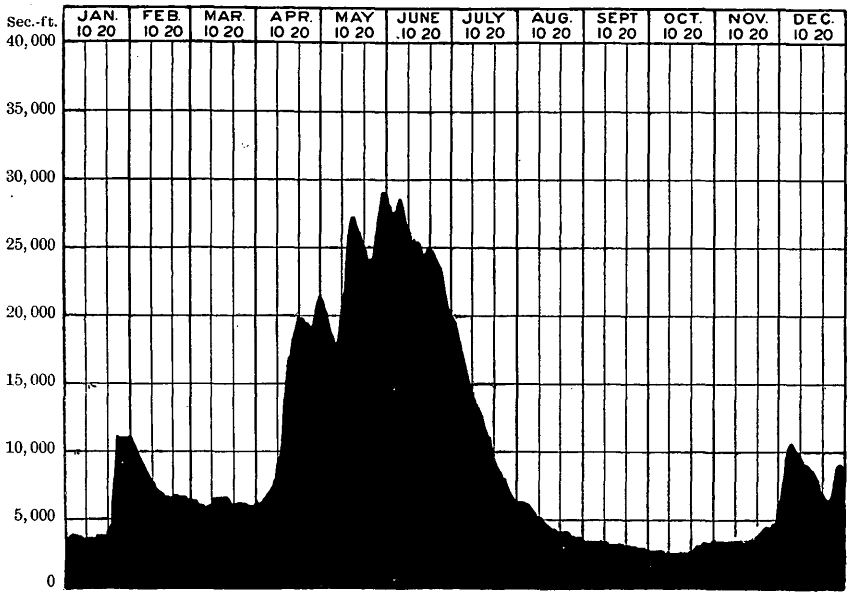


FIG. 240.—Discharge of Spokane River at Spokane, Washington, 1899.

NACHES RIVER.

This river has its source on the eastern slope of the Cascade Mountains, in Yakima County, Washington. It flows in a general southeasterly direction, entering Yakima River a short distance above the town of North Yakima. Irrigation is practiced in the narrow valley along the lower course of the river, but its waters are of greater value for the irrigation of lands west of North Yakima. The river has considerable fall and the water can be easily diverted by means of comparatively short canals. For this reason it is of more value for irrigation purposes than Yakima River, which has less fall. The station at North Yakima was originally established August 14, 1893, but was abandoned in 1897. It was reestablished February 1, 1898. Measurements are made by Sydney Arnold.

Estimated monthly discharge of Naches River at North Yakima, Washington.

[Drainage area, 1,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	4,325	600	1,458	89,649	1.46	1.68
February	2,675	1,350	1,827	101,466	1.83	1.91
March	1,500	950	1,115	68,559	1.12	1.29
April	3,050	1,200	2,246	133,646	2.25	2.51
May	6,700	2,500	4,534	278,785	4.53	5.22
June	6,700	5,500	6,220	370,116	6.22	6.94
July	5,800	2,850	4,606	283,212	4.00	4.61
August	2,675	950	1,605	98,688	1.60	1.84
September	950	500	666	39,630	0.67	0.74
October	1,500	425	728	44,763	0.73	0.84
November	7,300	700	2,612	155,425	2.61	2.91
December	5,500	1,200	2,941	180,835	2.94	3.39
The year	7,300	425	2,546	1,844,774	2.50	33.88

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 373; rating table in Paper No. 39, page 454.

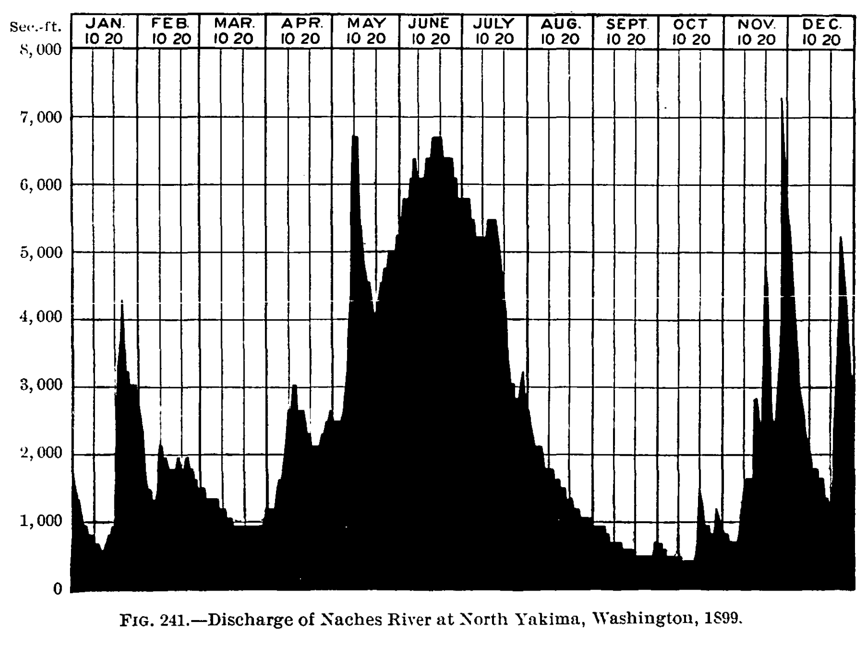


FIG. 241.—Discharge of Naches River at North Yakima, Washington, 1899.

YAKIMA RIVER.

Yakima River has its source in Keechelus Lake, on the eastern slope of the Cascade Mountains, in Kittitas County, Washington. Within a short distance it receives the waters of Kachess Lake, and 2½ miles above Clealum it receives the outlet of the last of the three large head-water lakes. The river enters Columbia River 23 miles below Kiona, Washington. Two stations are maintained on the river; one at Union Gap, Washington, established August 14, 1893. and the other at Kiona, Washington, established August 20, 1895. Measurements at both stations are made by Sydney Arnold. The Sunnyside canal is one of the principal diversions of the water of Yakima River. Pls. XLVII and XLVIII are views of the canal and lands irrigated by it.

Estimated monthly discharge of Yakima River at Union Gap, Washington.

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	10,500	2,000	4,813	295,940	1.46	1.68
February	8,050	3,500	4,810	267,134	1.45	1.51
March	3,900	2,450	3,006	184,832	0.91	1.05
April	6,300	2,600	4,273	254,261	1.29	1.44
May	13,750	4,525	9,424	579,459	2.85	3.29
June	17,011	9,800	13,346	794,142	4.04	4.52
July	9,800	4,525	7,554	464,477	2.28	2.62
August	4,525	2,600	3,299	202,848	0.99	1.14
September	2,450	1,605	1,920	114,248	0.58	0.64
October	2,900	1,355	1,888	116,089	0.57	0.66
November	12,030	2,300	4,711	280,324	1.42	1.58
December	14,180	2,150	5,951	365,913	1.80	2.08
The year	17,011	1,355	5,416	3,919,667	1.64	22.21

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 374; rating table in Paper No. 39, page 454.

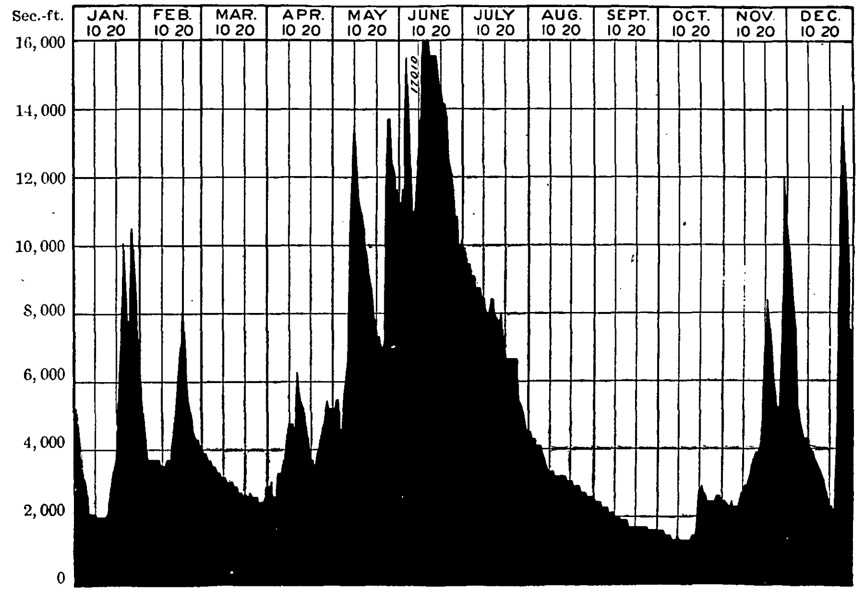


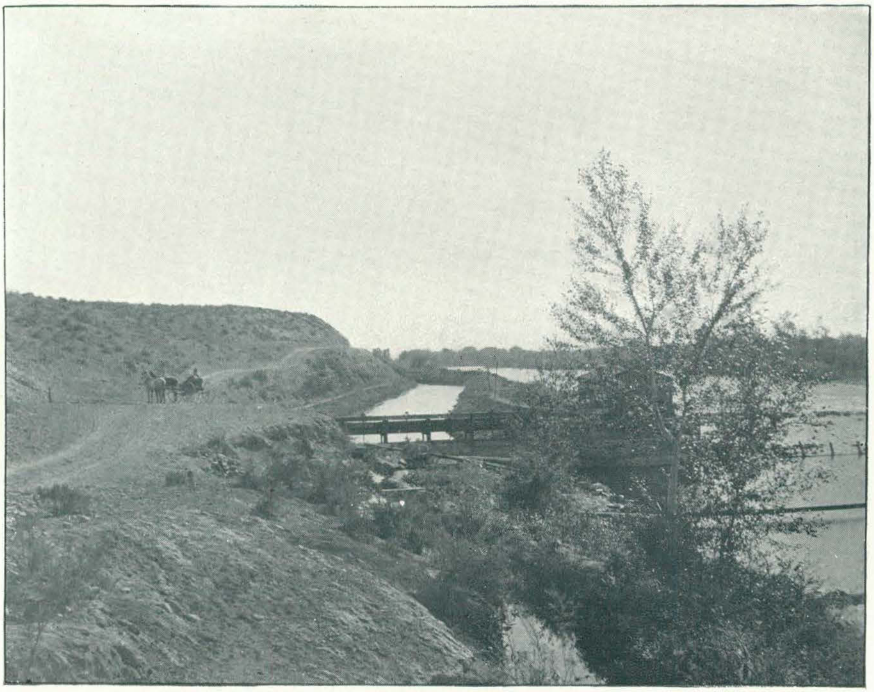
FIG. 242.—Discharge of Yakima River at Union Gap, Washington, 1899.

Estimated monthly discharge of Yakima River at Kiona, Washington.

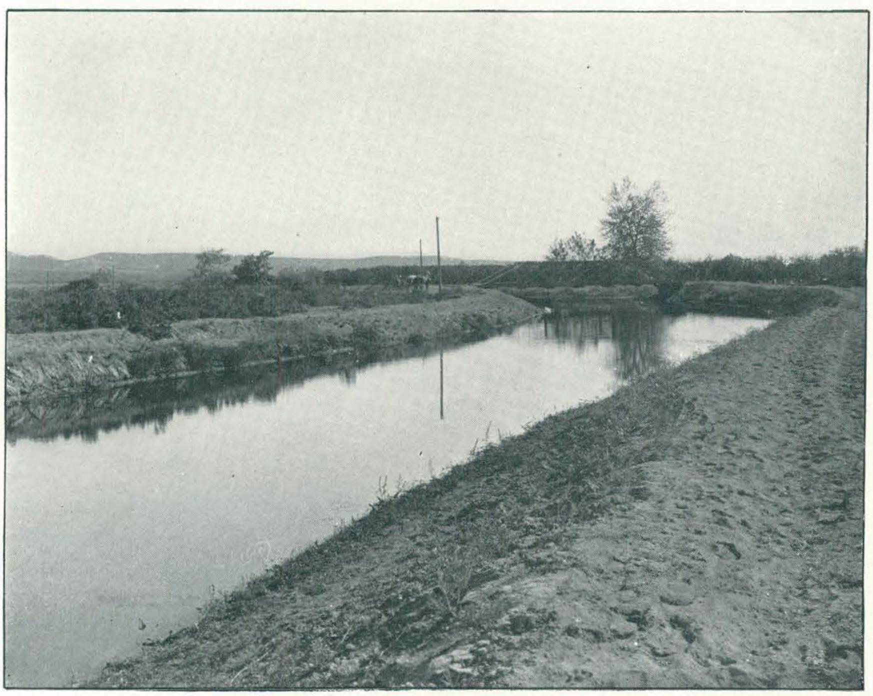
[Drainage area, 5,230 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	10,752	2,030	5,314	326,745	1.02	1.18
February	9,900	3,307	5,397	299,734	1.03	1.07
March	4,612	2,534	3,180	195,531	0.60	0.69
April	7,105	2,719	4,982	296,450	0.95	1.05
May	13,695	4,935	9,432	579,951	1.80	2.08
June	16,395	10,614	13,522	804,615	2.59	2.98
July	12,045	5,326	9,041	555,909	1.73	1.99
August	5,228	2,126	3,241	199,281	0.62	0.71
September	2,098	1,223	1,670	99,372	0.31	0.35
October	2,564	1,091	1,651	101,516	0.31	0.36
November	9,445	1,832	4,456	265,150	0.85	0.94
December	14,745	2,887	7,770	477,759	1.49	1.72
The year	16,395	1,091	5,805	4,202,013	1.11	15.12

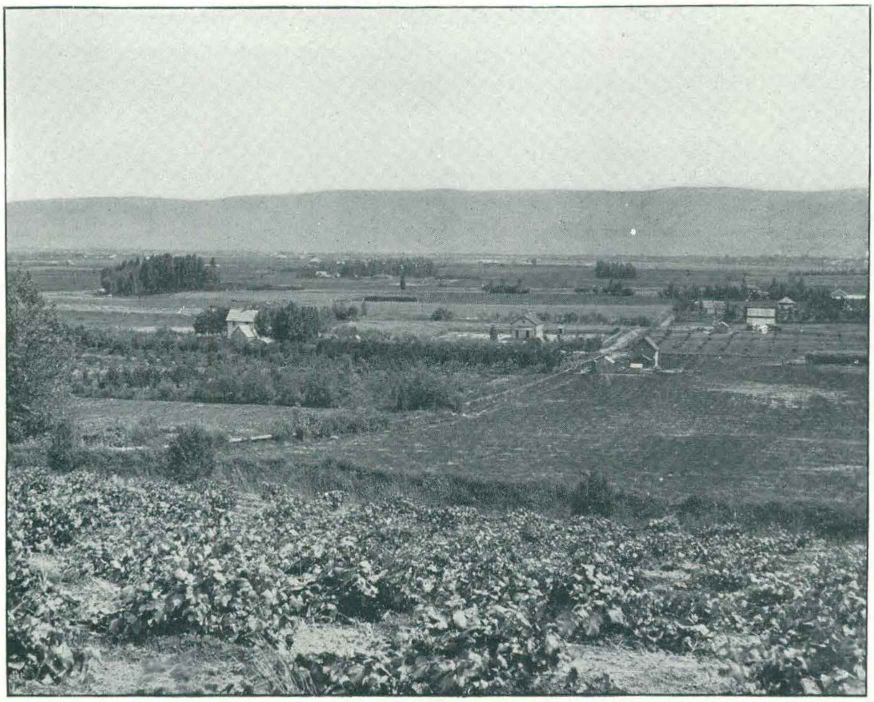
NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 375; rating table in Paper No. 39, page 454.



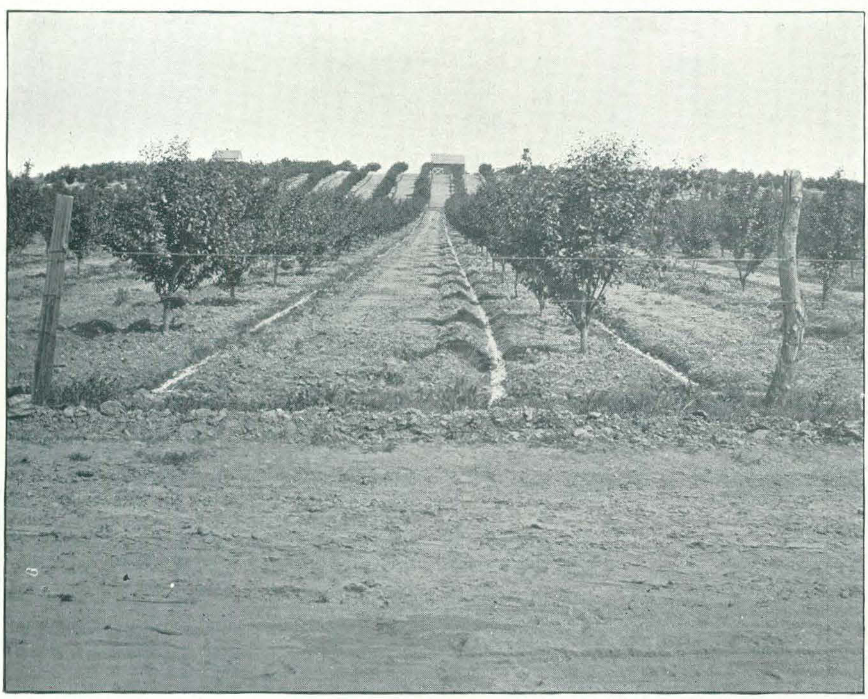
A. HEAD OF SUNNYSIDE CANAL, WASHINGTON.



B. ALONG THE LINE OF SUNNYSIDE CANAL, WASHINGTON.



A. IRRIGATED FARMS IN ATANUM VALLEY, WASHINGTON.



B. SUNNYSIDE FRUIT ORCHARD, YAKIMA VALLEY, WASHINGTON.

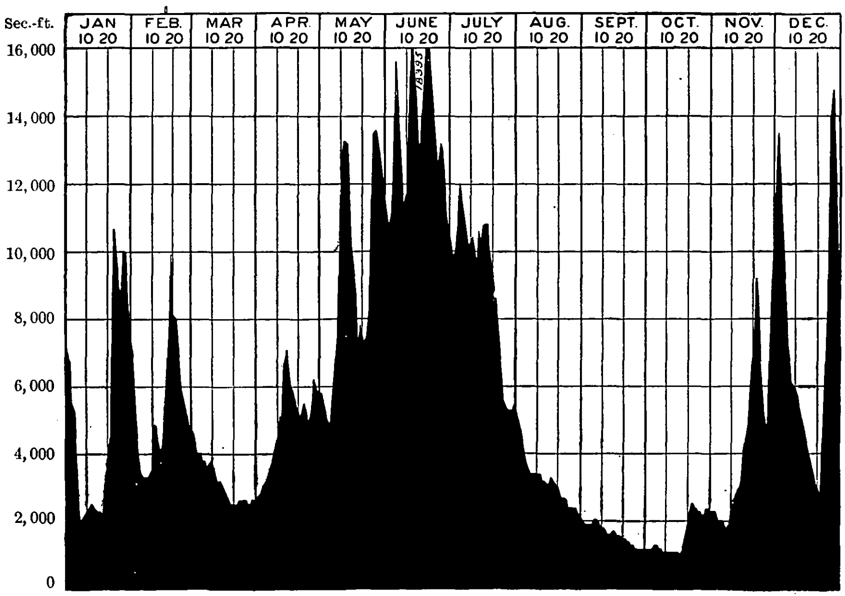


FIG. 243.—Discharge of Yakima River at Kiona, Washington, 1899.

A comparison of figs. 242 and 243 shows the relatively small increase in discharge of Yakima River at the lower point of measurement, and illustrates the fact that the greater part of the water of that stream is derived from the mountain catchment area above Union Gap. The low-water flow at Kiona is less than that at the upper gaging station, because of the fact that diversions for purposes of irrigation are made at intervening points. The foregoing tables and diagrams are a continuation of those contained in the Twentieth Annual Report, Part IV, beginning on page 496. The locations of the river stations are shown in fig. 194 of that report.

UMATILLA RIVER.

This river rises in the well-wooded country in northeastern Oregon and flows in a general westerly direction, entering Columbia River below the mouth of Wallawalla River. The country north of Umatilla is high and rolling. Agriculture is practiced to a considerable extent, cereals being the principal crops raised. A number of canals divert water from the lower course of the stream to irrigate lands on either side. The station is at Gibbon, Oregon. It was established July 22, 1896.

Estimated monthly discharge of Umatilla River at Gibbon, Oregon.

[Drainage area, 353 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	2,533	202	829	50,973	2.34	2.70
February	1,972	521	1,089	60,480	3.08	3.21
March	1,081	694	866	53,248	2.45	2.83
April	3,052	984	1,618	96,278	4.58	5.11
May	2,945	922	1,790	110,063	5.07	5.84
June	1,928	592	1,163	69,203	3.29	3.67
July	592	264	376	23,119	1.07	1.23
August	353	217	245	15,064	0.69	0.79
September	298	233	240	14,281	0.68	0.75
October	521	233	339	20,844	0.96	1.10
November	1,361	372	515	30,645	1.45	1.62
December	1,398	642	785	48,268	2.22	2.56
The year	3,052	202	821	592,466	2.32	31.41

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 377; rating table in Paper No. 39, page 454.

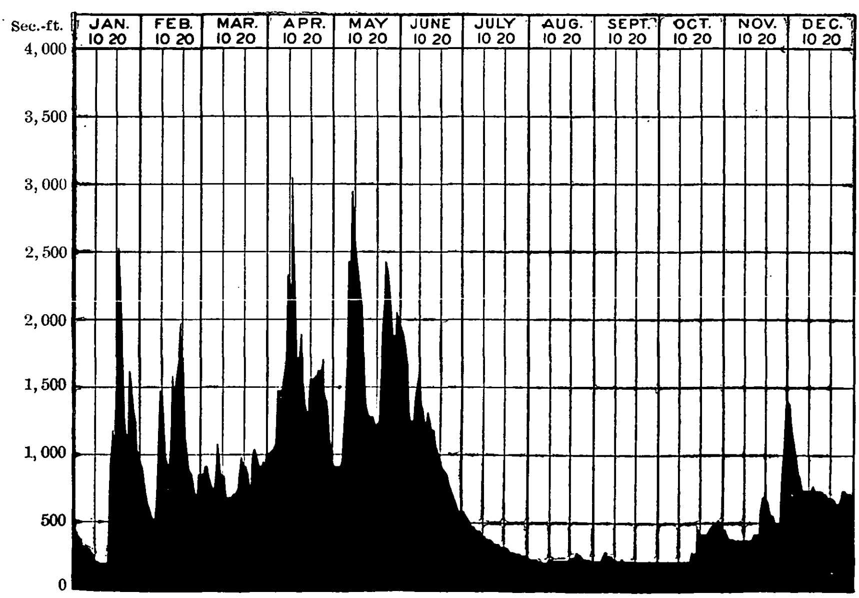


FIG. 244.—Discharge of Umatilla River at Gibbon, Oregon, 1899.

DESCHUTES RIVER.

This river drains a large area in central Oregon, and flows in a general northerly direction, entering Columbia River about 15 miles east of The Dalles, Oregon. The headwater tributaries have their sources in the snow-clad peaks of the Cascade Mountains. The plains region on which they enter upon their appearance from the mountain canyons is of a very porous lava formation, which has a tendency to regu-

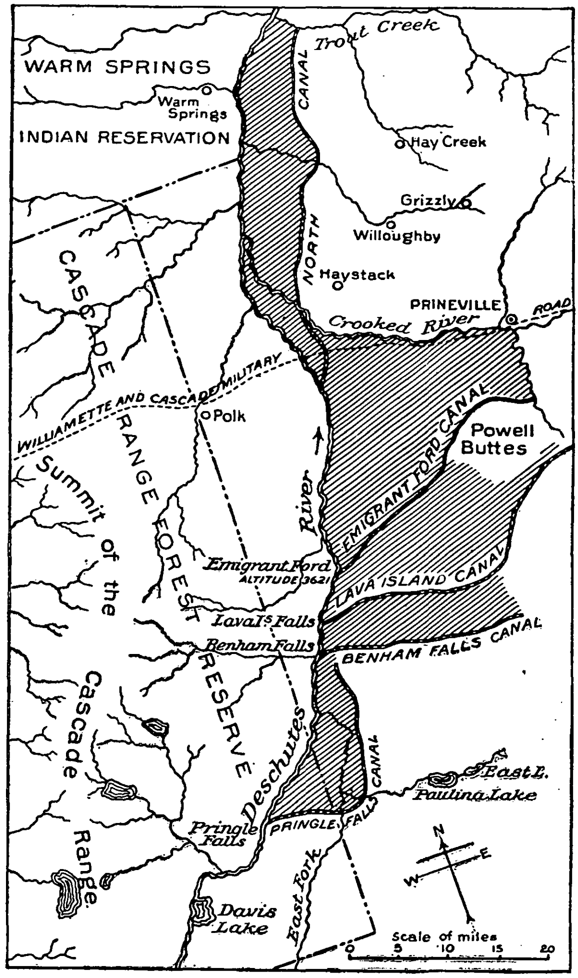


FIG. 245.—Map showing proposed canals from Deschutes River.

late the flow of the river. The rains and snows of the winter are absorbed by the porous rocks and slowly discharged into the river later. The general character of the lower basin of Deschutes River is high and rolling, and it is difficult to irrigate except from its high tributaries. Crooked River is an important tributary, entering it from the east. Considerable irrigation, principally for forage crops, is practiced in its basin above Prineville. The station, which was established October 19, 1897, is located at Moro, Oregon, 16 miles east of The Dalles. Measurements are made by Sydney Arnold.

A survey of a portion of Deschutes River, from Pringle Falls, above the East Fork, down to and including the country around Prineville, on Crooked River, and below Warmspring, was made during May and June, 1899, by Mr. G. F. Allardt, civil engineer for the Oregon Irrigation Company. Sufficient information was obtained to locate the general routes of the main irrigating canals and to determine the limits of the country that could be watered. The following details are taken from the report by Mr. Allardt:

Measurements of the river were made on May 27, 1899, at Sizemore Bridge, about 1 mile above Emigrant Ford, giving a flow of 3,014 second-feet. At the time of measurement the river was somewhat above its ordinary stage and was 380 feet wide, with an average depth of about 3 feet and a mean velocity of nearly 3 feet per second. At its lowest stage the discharge of the river was estimated, from marks pointed out by the oldest settlers, to amount to 1,740 second-feet. It is stated that the difference between the high and low water marks does not exceed 2 feet in the wider portions of the river.

The low banks of the river make possible the diversion of water into canals by means of open cuts from the river channel at points a short distance above the various falls or rapids, thus dispensing with dams. The slight fluctuations in surface level reduce the cost of head works to a minimum, and as the river never freezes it is unnecessary to adopt precautionary measures against ice.

Five principal canals were surveyed, leading out in succession from the east or right-hand side of the river. The first of these heads at Pringle Falls, and has a length of 30 miles; the next heads at Benham Falls, 18 miles below, and has a length of 15 miles; the third heads at Lava Island, 4 miles below, and has a length of 34 miles; the fourth heads at Emigrant Ford, 5 miles below, and has a length of 33 miles; the fifth, or North Canal, heads 20 miles below, and has a length of 47 miles, extending to Trout Creek. The following table gives the principal facts concerning the acreage irrigable and the altitude of the lands. Of the total acreage about one-fourth, or 92,000 acres, is timbered.

Proposed canals from Deschutes River.

Name.	Length.	Area irrigable.	Altitude.
	Miles.	*Acres.*	*Feet.*
Pringle Falls Canal	30	36, 000	4, 100–4, 300
Benham Falls Canal	15	22, 000	3, 800–4, 100
Lava Island Canal	34	103, 000	3, 600–3, 800
Emigrant Ford Canal	33	168, 000	2, 900–3, 600
North Canal	47	58, 000	2, 400–2, 900
Total	159	387, 000	

The slope of the irrigable country from south to north is fairly uniform, averaging about 23 feet to the mile. The soil is mainly composed of volcanic ash or finely disintegrated lava, easily cultivated, and when wet of a dark or chocolate color. About one-fourth of the irrigable land is somewhat stony or broken by outcroppings of lava. The rainfall at Prineville averages about 9 inches per annum.

A large amount of power can be created by the use of the surplus waters of the river, as the total fall of the river is 1,360 feet between Pringle Falls and Crooked River. It is estimated that more than 50,000 effective horsepower can be produced by diverting the water by means of short flumes and without the construction of dams.

Fig. 245 shows the proposed canals. The hatched portion shows the irrigable area.

Estimated monthly discharge of Deschutes River at Moro, Oregon.

[Drainage area, 9,900 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January	8,200	5,960	6,610	406,433	0.67	0.77
February	10,720	6,240	7,880	437,633	0.80	0.83
March	8,200	5,750	6,924	425,740	0.70	0.81
April	8,760	5,750	7,502	446,400	0.76	0.85
May	7,640	6,520	7,071	434,779	0.71	0.82
June	7,360	5,750	6,450	383,802	0.65	0.72
July	6,520	5,415	5,622	345,683	0.57	0.66
August	5,500	5,330	5,388	331,295	0.54	0.62
September	5,415	5,265	5,346	318,109	0.54	0.60
October	5,330	5,265	5,278	324,532	0.53	0.61
November	7,080	5,265	5,635	335,306	0.57	0.63
December	5,625	5,050	5,324	327,360	0.54	0.62
The year	10,720	5,050	6,253	4,517,072	0.63	8.54
1899.						
January	11,560	5,100	6,881	423,096	0.70	0.81
February	14,080	5,200	7,624	423,415	0.77	0.80
March	15,480	6,520	7,920	486,982	0.80	0.92
April	13,800	7,640	10,832	644,549	1.09	1.22
May	12,400	8,760	10,440	641,931	1.05	1.21
June	11,280	9,600	10,543	627,352	1.06	1.18
July	9,600	7,080	8,570	526,949	0.87	1.00
August	7,080	5,960	6,628	407,540	0.67	0.77
September	7,080	5,625	6,263	372,674	0.63	0.70
October	8,760	5,625	6,265	385,220	0.63	0.72
November	11,560	6,240	7,127	424,086	0.72	0.80
December	11,560	8,760	9,907	609,158	1.00	1.15
The year	15,480	5,100	8,250	5,972,952	0.83	11.28

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 167; discharge measurement, page 169. Gage heights and discharge measurements for 1899 are given in Water-Supply Paper No. 38, page 378; rating table in Paper No. 39, page 455.

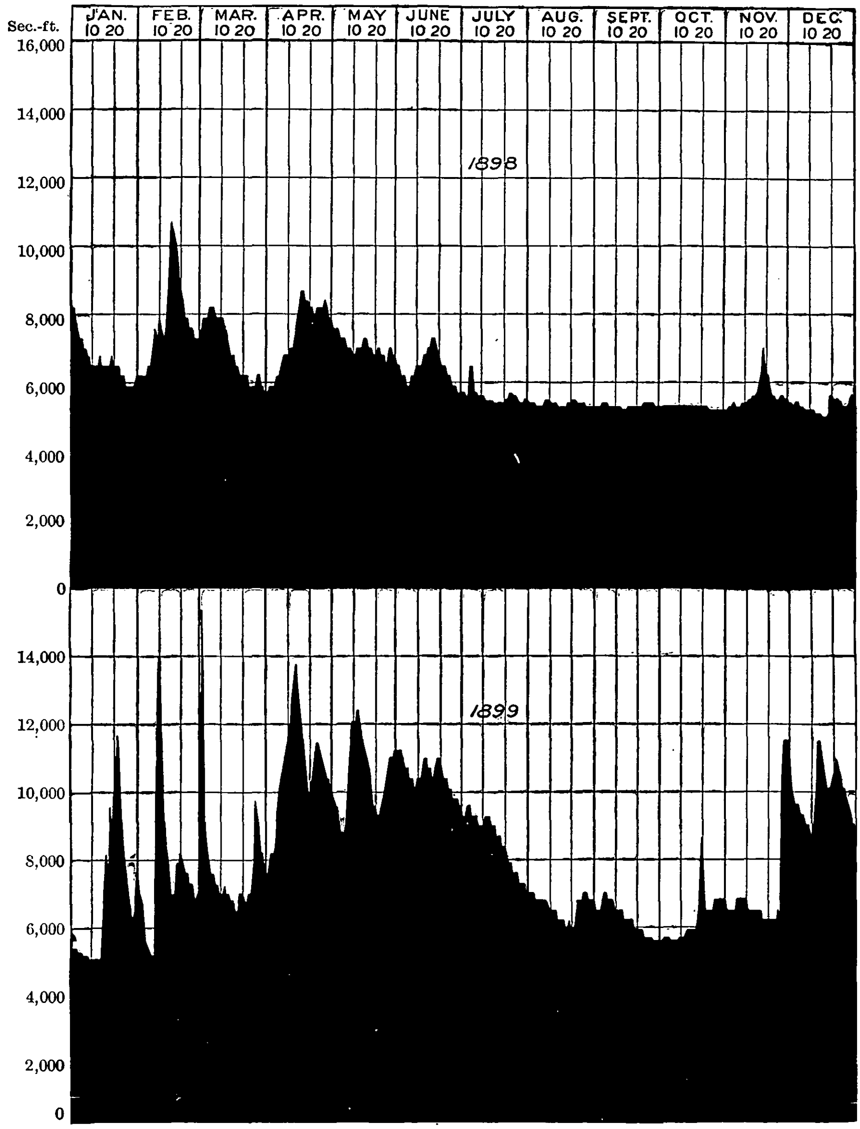


FIG. 246.—Discharge of Deschutes River at Moro, Oregon, 1898 and 1899.

HOOD RIVER.

This river rises at the base of Mount Hood, which has an elevation of 11,225 feet and is covered with snow throughout the year. The upper part of its basin is mountainous and well wooded. The river flows in a very narrow valley throughout its entire course, and empties into Columbia River almost opposite White Salmon River, which enters from the State of Washington. The river in its 30-mile course has a heavy fall, so that canals diverting water from it can, in a short distance, attain considerable elevation above the river. The station is at Tucker, Oregon. It was established October 20, 1897. Measurements are made by Sydney Arnold.

Estimated monthly discharge of Hood River at Tucker, Oregon.

[Drainage area, 350 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
January	2,550	936	1,434	88,173	4.10	4.73
February	8,700	882	2,867	159,225	8.19	8.53
March	1,512	830	1,165	71,663	3.33	3.84
April	2,700	830	1,352	80,450	3.86	4.30
May	1,586	1,172	1,426	87,681	4.07	4.69
June	1,512	882	1,242	73,904	3.55	3.96
July	992	732	852	52,387	2.43	2.80
August	830	522	684	42,058	1.95	2.25
September	1,302	486	583	34,691	1.67	1.86
October	1,370	486	668	41,074	1.91	2.20
November	4,650	486	1,191	70,869	3.40	3.80
December	3,150	642	1,297	79,749	3.70	4.27
The year	8,700	486	1,230	881,894	3.51	47.23
1899.						
January	12,150	642	2,944	181,019	8.41	9.69
February	5,400	1,302	2,452	136,177	7.01	7.30
March	6,900	992	1,719	105,697	4.91	5.66
April	5,550	1,050	2,418	143,881	6.91	7.70
May	3,000	1,440	1,842	113,260	5.26	6.06
June	3,900	1,810	2,438	145,071	6.97	7.77
July	2,000	1,302	1,687	103,730	4.82	5.55
August	1,900	936	1,087	66,837	3.11	3.59
September	992	686	804	47,841	2.30	2.56
October	3,300	522	928	57,060	2.65	3.06
November	6,450	642	1,785	106,215	5.10	5.69
December	9,150	1,302	2,428	149,292	6.94	8.00
The year	12,150	522	1,872	1,356,080	5.37	71.93

NOTE.—Gage heights for 1898 are given in Water-Supply and Irrigation Paper No. 28, page 168; discharge measurement, page 169. Gage heights and discharge measurement for 1899 are given in Water-Supply Paper No. 38, page 380; rating table in Paper No. 39, page 455.

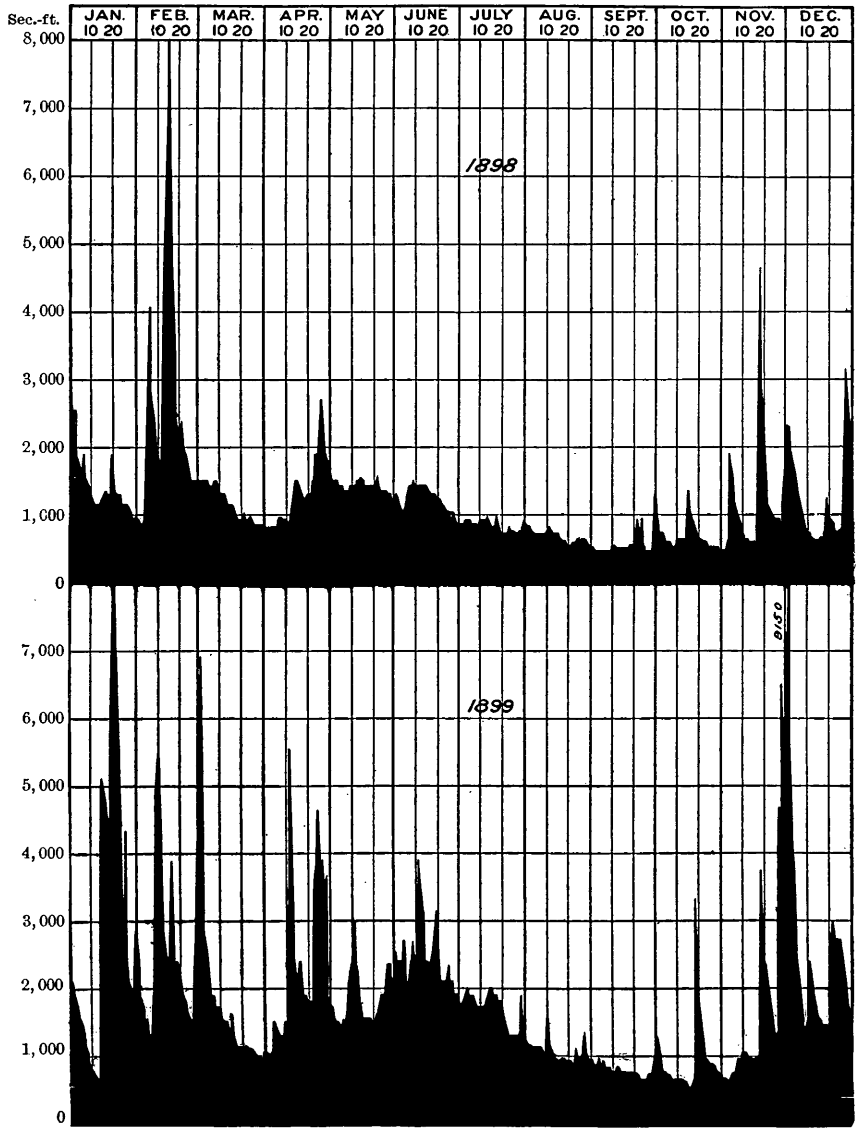


FIG. 247.—Discharge of Hood River at Tucker, Oregon, 1898 and 1899.

NORTHERN PACIFIC COAST DRAINAGE.

WHITE RIVER.

This river has its source in the glaciers of Mount Rainier, in the Cascade Range in Washington, and flows in a general northwesterly direction, entering Puget Sound at Seattle. Its mountainous collecting area is densely forested, and owing to the great precipitation on the western slope of the Cascade Mountains the basin has a high run-off. On account of the great fall of the rivers on the western slope of the Cascade Mountains in Washington, there are a number of fine water powers, which have lately been under investigation. The station, which is at Buckley, Washington, was established April 22, 1899. Measurements are made by Sydney Arnold.

Estimated monthly discharge of White River at Buckley, Washington.

[Drainage area, 450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April *a*			1,530	91,041	3.40	3.80
May	4,100	1,180	2,719	167,185	6.04	6.96
June	6,100	3,000	4,133	245,931	9.18	10.24
July	4,400	2,200	3,232	198,728	7.18	8.28
August	3,200	1,225	1,662	102,192	3.69	4.25
September	1,500	980	1,129	67,180	2.51	2.80
October	3,700	915	1,429	87,866	3.19	3.68
November	6,500	1,000	2,654	157,924	5.90	6.58
December	9,100	1,102	3,198	196,637	7.11	8.20

a Approximate.

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 382; discharge measurements, page 381; rating table in Paper No. 39, page 455.

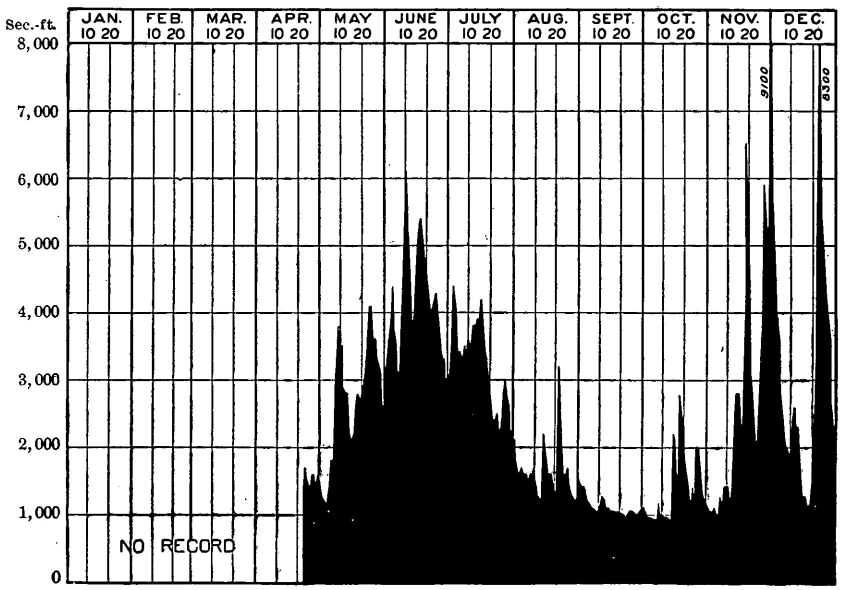


FIG. 248.—Discharge of White River at Buckley, Washington, 1899.

DUNGENESS RIVER.

The Dungeness rises on the eastern slope of the Olympic Mountains and flows in a general northeasterly direction, entering the Strait of Juan de Fuca at the town of Dungeness, Washington. Its mountainous drainage basin is highly picturesque and very heavily timbered. Although this section of the country receives a heavy precipitation, it occurs when least needed, and in certain sections recourse must be had to irrigation during the summer. The station is at Dungeness, Washington. It was established July 5, 1897. Measurements are made by W. J. Ware.

Estimated monthly discharge of Dungeness River at Dungeness, Washington.

[Drainage area, 145 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,180	203	478	29,391	3.30	3.81
February	640	255	375	20,826	2.59	2.70
March	310	203	240	14,757	1.66	1.91
April	505	205	261	15,531	1.80	2.01
May	850	215	463	28,469	3.19	3.68
June	1,090	612	810	48,198	5.59	6.23
July	880	480	682	41,935	4.70	5.42
August	531	185	299	18,385	2.06	2.38
September	255	207	229	13,626	1.58	1.76
October	760	197	278	17,094	1.92	2.21
November	3,460	382	1,339	79,676	9.23	10.30
December	2,920	310	941	57,860	6.49	7.48
The year	3,460	185	533	385,748	3.68	49.89

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 384; discharge measurements, page 383; rating table in Paper No. 39, page 455.

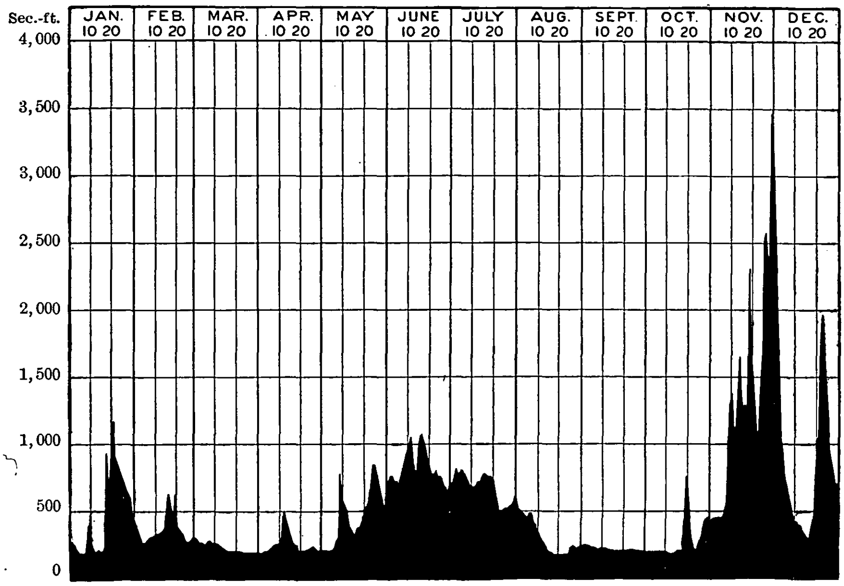


FIG. 249.—Discharge of Dungeness River at Dungeness, Washington, 1899.

Estimated monthly discharge of Elwha River at McDonald, Washington.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	3,320	660	1,512	92,969	8.04	9.27
February	3,320	770	1,370	76,086	7.29	7.59
March	1,210	510	684	42,058	3.64	4.20
April	1,920	520	763	45,402	4.06	4.53
May	2,020	575	1,249	76,798	6.64	7.66
June	2,820	1,630	2,124	126,387	11.30	12.61
July	2,470	1,630	2,037	125,250	10.83	12.49
August	1,630	575	999	61,426	5.31	6.12
September	805	510	570	33,917	3.03	3.38
October	1,677	475	742	45,623	3.95	4.55
November	8,320	595	3,338	198,625	17.75	19.81
December	6,870	1,000	2,502	153,842	13.31	15.35
The year	8,320	475	1,491	1,078,383	7.93	107.56

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 385; rating table in Paper No. 39, page 455.

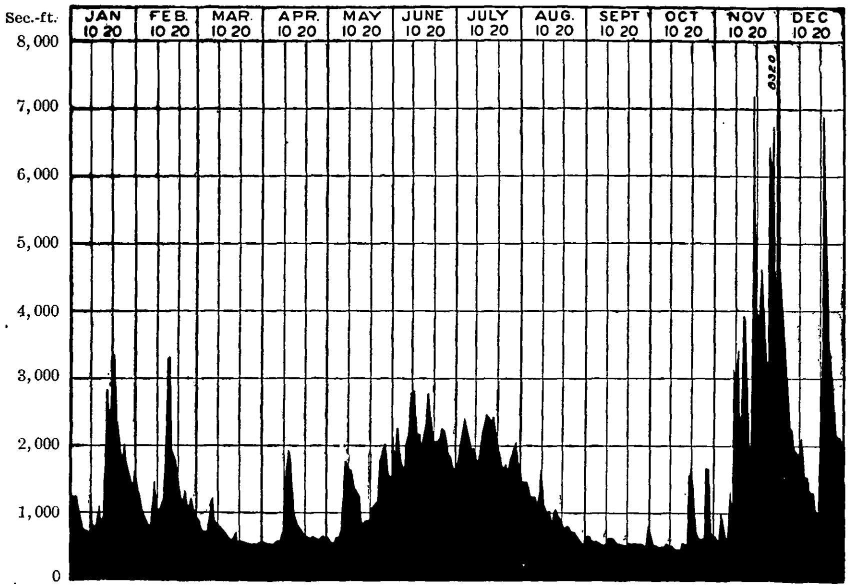


FIG. 250.—Discharge of Elwha River at McDonald, Washington, 1899.

ELWHA RIVER.

This river rises in the Olympic Mountains, and flows northerly, entering the Strait of Juan de Fuca. Its upper basin is very heavily wooded, and is almost inaccessible on account of its rugged character and the dense undergrowth that covers the mountain slopes. In the lower course of the river a number of falls occur, where power could be advantageously developed, and within the last half year surveys having this object in view have been made. The station, established October 8, 1897, is 9 miles southwest of Port Angeles, Washington. Measurements of discharge are made at McDonald, Washington, by W. J. Ware.

Pl. XLIX, *A*, is a view of the drainage basin of Morse River, Washington, a small area east of Elwha River. The river flows to the north and enters the Strait of Juan de Fuca 4 miles east of Port Angeles. In the foreground is Port Angeles; in the background are the Olympic Mountains. The depression in the foothills is the pass through which Morse River flows. The drainage basin extends east and west. Back and south of the mountains lies the drainage basin of Elwha River, which flows in a northwesterly direction from its source to within about 15 miles of its mouth, when it takes a course generally north.

Pl. XLIX, *B*, is a view looking north up Elwha River from McDonald, Washington, about 10 miles southwest of Port Angeles.

A. DRAINAGE BASIN OF MORSE RIVER, WASHINGTON; OLYMPIC MOUNTAINS IN BACKGROUND.

B. ELWHA RIVER AT McDONALD, WASHINGTON.

The McDonald observation station is located on the bridge shown, which is about 35 feet above the water. The banks upon which it rests, also the bed of the river, are of solid rock.

KALAWA RIVER.

This river has its source on the western slopes of the Olympic Mountains and flows in a general westerly and southerly direction, uniting with the Soleduck and Bogachiel rivers to form Quillayute River, which enters the Pacific Ocean at Lapush, Washington. The station, which is near Forks, Washington, was established November 12, 1897. Measurements are made by W. J. Ware.

Estimated monthly discharge of Kalawa River at Forks, Washington.

[Drainage area, 213 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	10,608	740	3,020	185,692	14.18	16.35
February	6,256	621	2,187	121,460	10.27	10.69
March	3,536	554	1,237	76,060	5.81	6.70
April	6,256	426	1,233	73,369	5.79	6.46
May	1,150	689	823	50,604	3.86	4.45
June	689	301	483	28,741	2.27	2.53
July	286	80	194	11,929	0.91	1.05
August	180	70	116	7,133	0.55	0.63
September	193	20	67	3,987	0.31	0.35
October	2,071	80	576	35,417	2.70	3.11
November	11,424	474	3,766	224,092	17.68	19.73
December	15,776	835	2,929	180,097	13.75	15.85
The year	15,776	20	1,386	998,581	6.51	87.90

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 386; rating table in Paper No. 39, page 455.

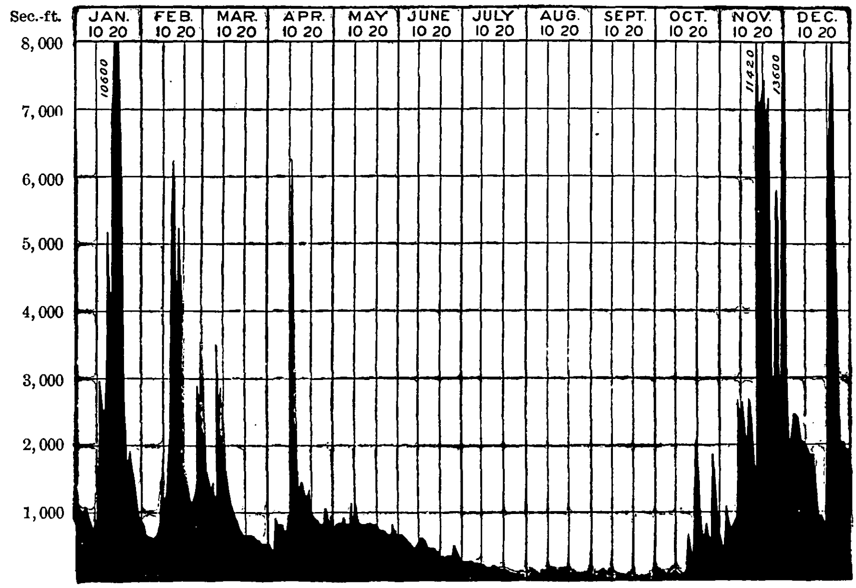


FIG. 251.—Discharge of Kalawa River at Forks, Washington, 1899.

The above diagram is a continuation of that on page 522 of the Twentieth Annual Report, Part IV. The location of this and other streams is shown on a small map (fig. 179) in the Nineteenth Annual Report, Part IV. In that report is a general description of the rivers of the Olympic Peninsula and a number of views illustrating the character of the catchment area. An examination of the forests covering the drainage basin of these streams is being made under the direction of Mr. Henry Gannett, results of which are given in Part V of the annual reports of this survey.

SOLEDUCK RIVER.

The Soleduck has its source on the high western slope of the Olympic Mountains, and drains the country immediately north of the Kalawa, joining it to form Quillayute River. The drainage basin is very heavily wooded, the greater portion of it being included in the Olympic Forest Reserve. The station, which was established November 13, 1897, is near Quillayute, Washington. Measurements are made by W. J. Ware.

Estimated monthly discharge of Soleduck River at Quillayute, Washington.

[Drainage area, 272 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	5,960	870	2,109	129,677	7.75	8.94
February	5,560	990	1,844	102,409	6.78	7.06
March	2,160	682	1,170	71,940	4.30	4.96
April	4,060	682	1,192	70,929	4.38	4.89
May	1,720	870	1,040	63,947	3.82	4.40
June	1,112	735	939	55,874	3.45	3.85
July	950	612	723	44,455	2.66	3.07
August	612	335	466	28,653	1.71	1.97
September	335	240	283	16,840	1.04	1.16
October	1,690	272	607	37,323	2.23	2.57
November	8,960	665	2,857	170,004	10.50	11.72
December	7,460	1,270	2,894	177,945	10.64	12.27
The year	8,960	240	1,344	969,996	4.94	66.86

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 387; rating table in Paper No. 39, page 455.

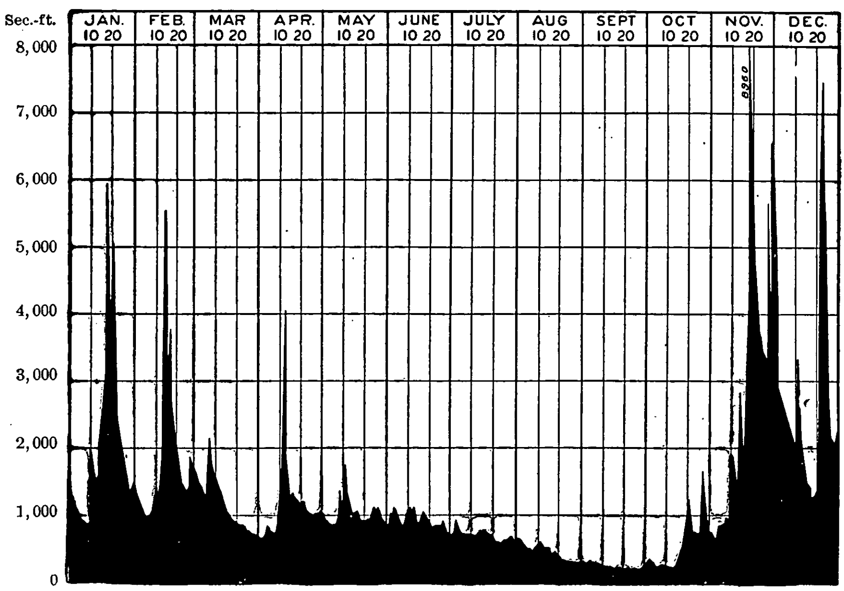


FIG. 252.—Discharge of Soleduck River at Quillayute, Washington, 1899

SAN FRANCISCO BAY DRAINAGE.

SACRAMENTO RIVER.

This river derives its water supply largely from Mount Shasta and the surrounding high ranges in the extreme northern portion of California. The stream does not have the same regular annual fluctuations that characterize the rivers discharging from the higher Sierra Nevada, in that a large portion of its basin is not at an elevation sufficient to cause the winter snows to remain unmelted until the summer months. The greatest floods of this basin usually occur in January and February, when the snow is accompanied or followed by rain. These floods are exceedingly destructive to the farming lands on the lower portion of the stream. The bed of the river, particularly below the mouth of Feather River, has been largely filled with débris produced by the hydraulic mining higher up that stream. The floods discharging in the channel, the section of which has been diminished, break through the banks of the stream, cutting new channels and overflowing vast areas of level farm lands. A law has been passed in California for reclaiming and protecting these bottom lands by the building of dikes. It is known as the Reclamation act. Districts are formed in much the same manner as for irrigation purposes under the Wright act. Floods occurring on the upper Sacramento River, above Redbluff, do not reach Sacramento for several days, and during the high stage of the stream river heights are telegraphed by the Weather Bureau observers at Redbluff to points lower down the river, thus giving warning of impending disaster. Numerous plans for the prevention of these floods have been proposed by State engineers. The records of the Geological Survey, therefore, are of special value in the case of this stream, in connection with the study of these questions of overflow.

Redbluff is the head of navigation on Sacramento River, and during the winter and spring boats occasionally carry freight to that point. Numerous petitions have been presented requesting appropriations for the deepening of the channel on the higher portion of the stream, but while the subject has been studied by Army engineers, no construction work has yet been done above Redbluff. A great deal of work, however, has been done on the lower portion of the stream between Sacramento and San Francisco Bay, the records of which have been frequently used by engineers for the study of these problems.

Irrigation in the upper portion of Sacramento Valley has been largely carried on from the smaller tributaries of the river, the waters of which can be more readily diverted onto the valley. The greater portion of the valley, however, is still in a semiarid condition, requiring irrigation for the successful growth of crops other than the cereals, and at some future time the water of the river will undoubtedly be used for irrigation.

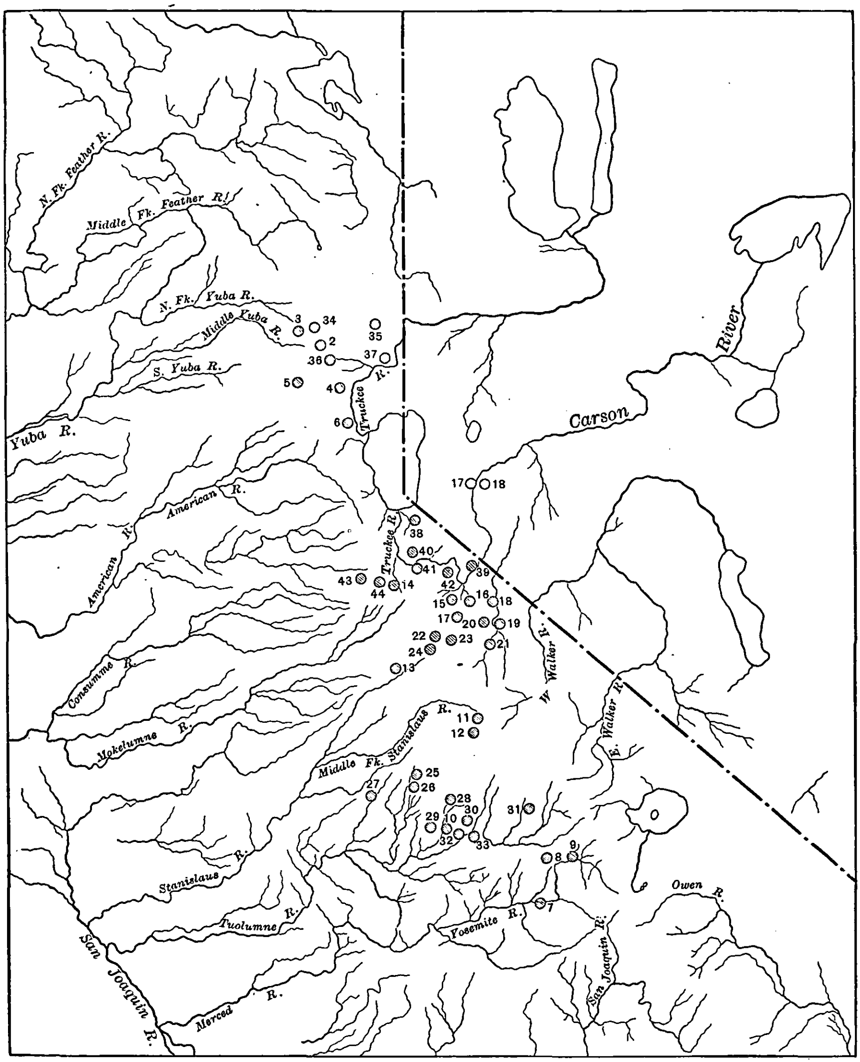


FIG. 253.—Reservoir sites surveyed in California and Nevada.

Reservoir sites:
1. Clear Lake.
2. Independence Lake.
3. Webber Lake.
4. Donner Lake.
5. Yuba River.
6. Squaw Creek.
7. Little Yosemite.
8. Lake Tenaya.
9. Tuolumne Meadows.
10. Lake Eleanor.
11. Kennedy Meadow.
12. Kennedy Lake.
13. Bear Valley on Bloods Creek.
14. Red Lake.
15. Markleeville Creek.
16. East Carson River.
17. Deer Creek.
18. Heenan Lake.
19. Silver Creek.
20. Wolf Creek.
21. East Carson.
22. Mokelumne River.
23. Mokelumne River.
24. Pacific Valley Creek.
25. Big Canyon Creek.
26. Big Canyon Creek.
27. Hull Creek.
28. Granite Creek.
29. Cherry Creek.
30. Lake Vernon.
31. Big Meadow.
32. Errars Meadow.
33. Tuolumne River.
34. Little Truckee River.
35. Little Truckee River.
36. Prosser Creek.
37. Little Truckee River.
38. Monument Peak.
39. Near East Carson River.
40. Grass Lake.
41. West Fork Carson River.
42. Near West Fork Carson River.
43. Silver Fork American River.
44. Near Silver Fork American River.

A number of reservoir sites have been surveyed in California and Nevada, those being selected which were considered the most favorable for development as storage basins for the irrigation of adjacent lands. The object of the surveys was to determine the possible capacity of the reservoirs, the height of dam required to impound the water, and the cost and practicability of construction. The sites surveyed are numbered on the map, fig. 253. In addition to these is the important Hetch Hetchy reservoir site, a full description of the survey of which begins on page 450. A general description of the methods of operation and the results obtained may be found in the reports of the United States Geological Survey, as follows: Tenth Annual Report, Part II, page 65; Eleventh Annual Report, Part II, pages 63 and 293; Twelfth Annual Report, Part II, pages 9 and 316; Thirteenth Annual Report, Part III, pages 284, 387, and 398; Twentieth Annual Report, Part IV, page 25. Irrigation in California is also discussed in Water-Supply and Irrigation Papers of the United States Geological Survey, Nos. 17, 18, and 19.

Estimated monthly discharge of Sacramento River at Jellys Ferry, California.

[Drainage area, 9,134 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	42,600	5,065	13,498	829,965	1.48	1.71
February	8,644	5,810	6,646	369,100	0.73	0.76
March	83,400	6,750	20,915	1,286,022	2.29	2.64
April	16,100	7,800	10,837	344,845	1.19	1.33
May	7,530	6,030	6,908	424,759	0.76	0.87
June	15,200	4,965	6,199	368,865	0.68	0.75
July	4,760	4,170	4,531	278,592	0.50	0.58
August	4,170	3,980	3,986	245,061	0.44	0.51
September	3,980	3,980	3,980	236,826	0.44	0.49
October	10,550	3,980	5,063	311,314	0.55	0.63
November	53,480	4,760	14,532	864,712	1.59	1.77
December	45,600	8,915	14,519	892,744	1.59	1.83
The year	83,400	3,980	9,301	6,752,805	1.02	13.87

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 389; discharge measurements, page 388; rating table in Paper No. 39, page 455.

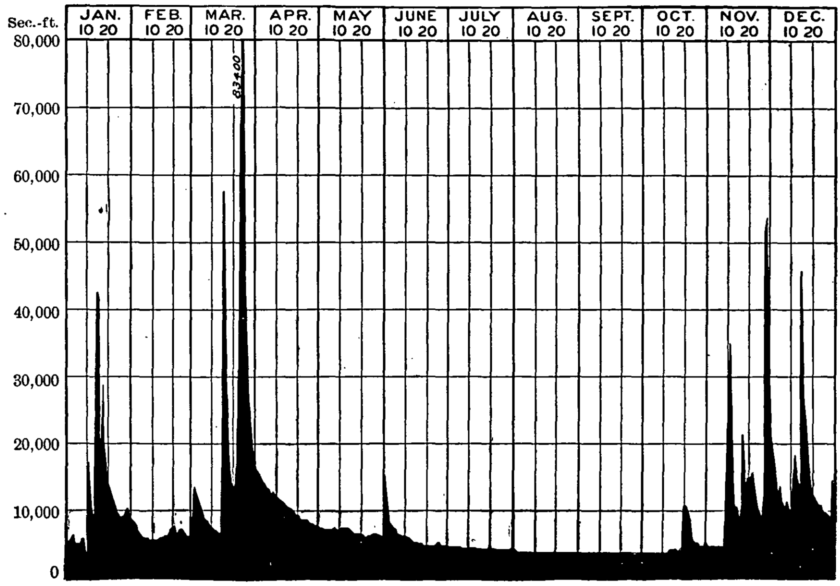


FIG. 254.—Discharge of Sacramento River at Jellys Ferry, California, 1899.

STANISLAUS RIVER.

Stanislaus River rises on the crest of the Sierra Nevada in Tuolumne and Calaveras counties, on the coast side of the range. It possesses numerous storage possibilities, three dams having been already constructed for this purpose on the South Fork of the river. The original purpose of this conservation was to furnish water for the hydraulic and river mining of gold. Two power plants have been built, one at Knights Ferry and the other near Sonora. Stanislaus River passes through one of the richest mining districts of the State of California, the Mother Lode, which is a remarkable quartz deposit, passing diagonally across Tuolumne, Calaveras, and Mariposa counties. The mines near Sonora, which is the center of mining development, suspend operations almost every summer, owing to the small amount of water in the stream from which their power is derived. A large portion of the water is diverted soon after it leaves the mountain by the Stanislaus Water Company's canal. Other diversions occur lower down, so that practically its entire summer flow is used for irrigation purposes between Stockton and Oakdale. The gaging station, which was established May 3, 1895, is a half mile north of Oakdale, California. Measurements are made under the direction of J. B. Lippincott.

Estimated monthly discharge of Stanislaus River at Oakdale, California.

[Drainage area, 1,051 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,240	70	457	28,100	0.44	0.51
February	690	130	355	19,716	0.34	0.35
March	13,940	220	2,425	149,108	2.31	2.66
April	5,270	1,450	3,525	209,752	3.35	3.74
May	5,780	1,450	2,559	157,348	2.43	2.80
June	4,632	1,045	2,663	158,459	2.53	2.82
July	1,120	175	502	30,867	0.48	0.55
August	265	90	150	9,223	0.14	0.16
September	130	50	85	5,058	0.08	0.09
October	1,200	90	309	19,000	0.29	0.33
November	2,340	90	1,092	64,978	1.04	1.16
December	5,015	550	1,461	89,834	1.39	1.60
The year	13,940	50	1,299	941,443	1.24	16.77

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 392; discharge measurements, page 391; rating table in Paper No. 39, page 455.

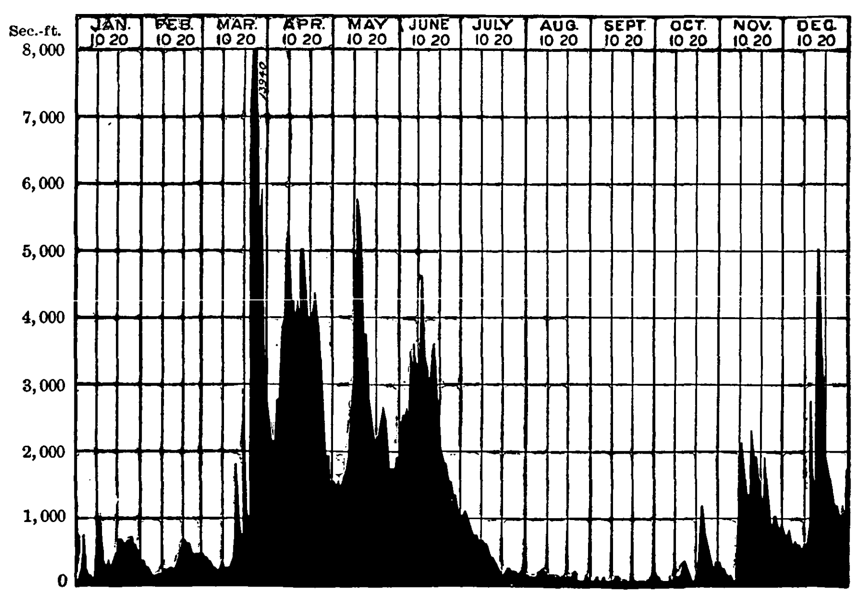


FIG. 255.—Discharge of Stanislaus River at Oakdale, California, 1899.

TUOLUMNE RIVER.

This river rises on the western slope of the Sierra Nevada in California and drains the country between Stanislaus River on the north and Merced River on the south. The northern half of Yosemite National Park includes a portion of the drainage basin of this stream. The river is fed largely from small mountain lakes occurring high in the drainage basin, where the snow remains on the mountain slopes throughout the year, thus insuring a large run-off. The stream has a heavy fall, and the opportunities for power development are numerous. There are also a number of reservoir sites in the basin where water could be stored during the irrigation season. The Tuolumne is an important tributary of the San Joaquin. The station, which was established August 29, 1895, is at Lagrange, California. Measurements were made under the direction of J. B. Lippincott.

Estimated monthly discharge of Tuolumne River at Lagrange, California.

[Drainage area, 1,501 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,940	110	487	29,945	0.32	0.37
February	1,440	410	740	41,098	0.49	0.51
March	21,800	570	3,616	222,341	2.41	2.78
April	8,040	2,285	5,193	309,004	3.46	3.86
May	8,680	2,080	4,513	277,495	3.01	3.47
June	9,960	2,285	6,060	360,594	4.04	4.51
July	2,490	330	1,010	62,103	0.67	0.77
August	570	45	145	8,916	0.10	0.11
September	45	15	33	1,964	0.02	0.02
October	2,285	5	505	31,051	0.34	0.39
November	6,400	660	2,428	144,476	1.62	1.81
December	8,040	850	3,047	187,354	2.03	2.04
The year	21,800	5	2,315	1,676,341	1.54	20.64

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 395; discharge measurements, page 394; rating table in Paper No. 39, page 455.

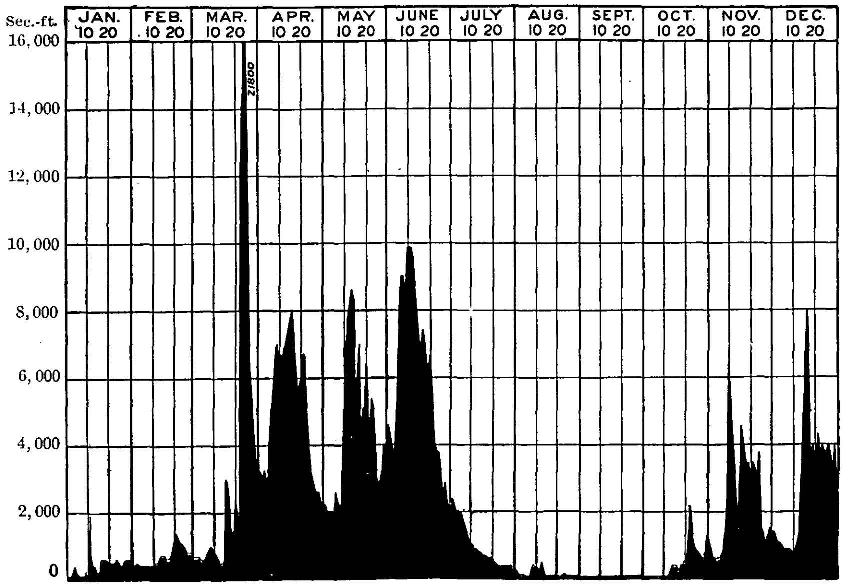


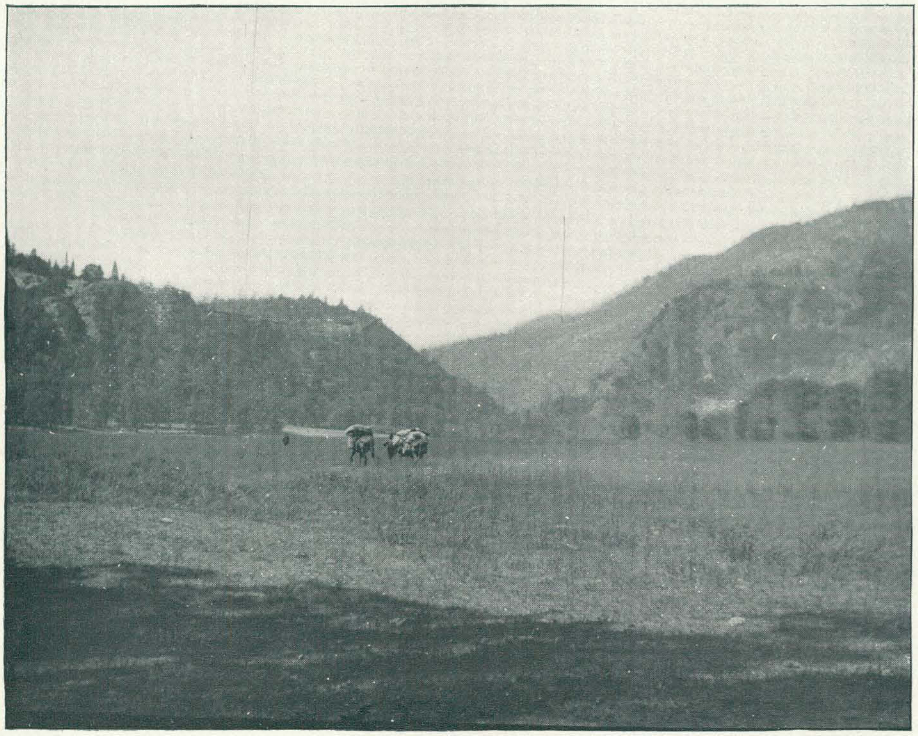
FIG. 256.—Discharge of Tuolumne River at Lagrange, California, 1899.

HETCH HETCHY RESERVOIR.[1]

Hetch Hetchy Valley is a mountain meadow at an elevation of 3,700 feet above the sea. It is situated at the lower end of the Grand Canyon of Tuolumne River, on the western flank of the Sierra Nevada in Tuolumne County, California. It might, indeed, be said to be an enlargement of the Grand Canyon of the Tuolumne. It is a veritable Yosemite Valley on a small scale. The Hetch Hetchy Falls, near the lower end of the valley, are fully equal in beauty and grandeur to many of the falls in Yosemite Valley, but the streams supplying them do not flow all the year, being fed principally by melting snow in the spring and early summer. The valley proper is about 3½ miles long, and its width varies from one-quarter to three-quarters of a mile. The rugged granite walls, crowned with domes, towers, spires, and battlements, seem to rise almost perpendicularly upon all sides to a height of 2,500 feet above this beautiful emerald meadow, which, seen from the trail approaching it from the east, is a sight never to be forgotten. It was visited in May, when the snows on the glacier meadows at the higher altitudes were rapidly melting, and the river was bank full and overflowing the lower part of the valley. The water is here dammed up, owing to the narrow outlet between high mountains of granite. At one place in this gorge, below the valley, the granite walls on either side approach so as to confine the river at low water to a width of about 20 feet, and this has been selected as a dam site. (See Pl. L, A.)

[1] From report of John H. Quinton.

A. HETCH HETCHY DAM SITE, CALIFORNIA.



B. HETCH HETCHY RESERVOIR SITE, CALIFORNIA.

Although no soundings have yet been made here, the nature of the surrounding material—all granite—and its slopes and conformation lead to the conclusion that bed rock is very near the surface. A depth of 25 feet to bed rock has been assumed in the calculations of cost, and this, under the circumstances, would seem a very liberal

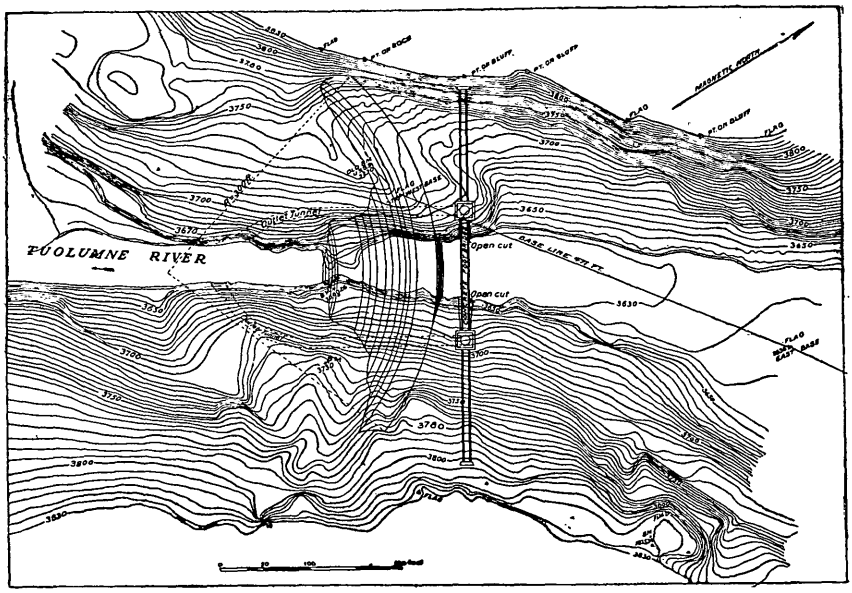


FIG. 257.—Map of Hetch Hetchy dam site.

allowance. In determining the height of dam which would be most economical for this reservoir the following table was used. This table was compiled by J. B. Lippincott from the plane-table survey of the reservoir made last year by Henry Ramel, shown in fig. 257.

Table of heights of dam and corresponding acre-feet impounded.

Height of dam above low water.	Acre-feet.
10 feet	148
30 feet	2,247
50 feet	14,350
70 feet	28,649
90 feet	45,780
110 feet	64,726
130 feet	85,173
150 feet	107,426
170 feet	132,847
190 feet	161,373
210 feet	176,547

For reasons stated hereafter, a height of dam of 150 feet has been selected as the most suitable for all practical purposes. This, if an overflow dam, or a weir, would impound 107,000 acre-feet. As there

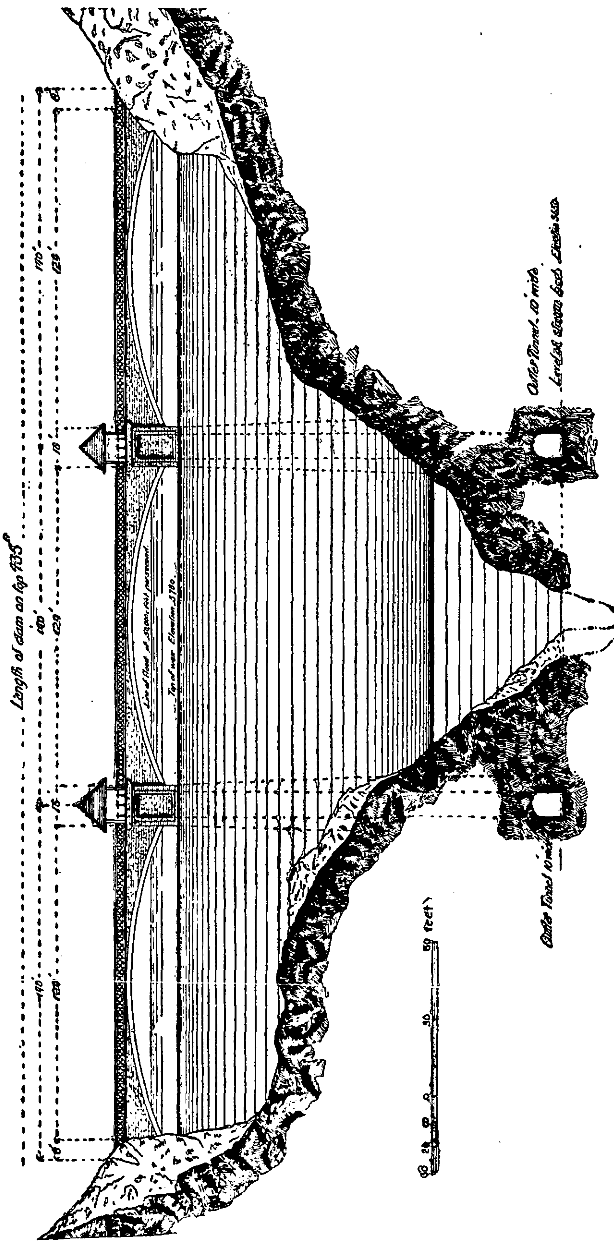


FIG. 258.—Profile of Hetch Hetchy dam site.

are no complete measurements of water flowing at the dam site for one year, the valley at present being quite inaccessible and uninhabited, it will be necessary to use the data which we have on this stream lower down in considering the probabilities of filling the reservoir every year with 100,000 acre-feet of water.

For a proper understanding of the water problem on the streams flowing into San Joaquin Valley from the western slopes of the Sierra Nevada, it must be borne in mind that the rainy season in California usually begins in November and ends in April. During these months there is generally plenty of water in the streams from the rainfall in the foothills and lower part of the mountains, where most of the precipitation is in the form of rain rather than snow. In the higher part of the drainage basins the snow lies unmelted on the ground and trees during the winter, usually remaining until April or May, when the warmer weather causes it to melt and reenforce the streams, which begin to fall as soon as the rains are over. This melting of snow continues to increase until the middle of June, when it begins to diminish, and toward the end of July the river has practically reached its low stage. It is, however, still furnished with a little melting snow every day, also with the drainage from the forests and marshes, but the months of August and September may be said to be the low-water months of the year. The irrigation season generally commences in April and ends in October, so that of these six months two have no water for irrigation purposes.

The entire drainage area of Tuolumne River above Lagrange is about 1,500 square miles, some 400

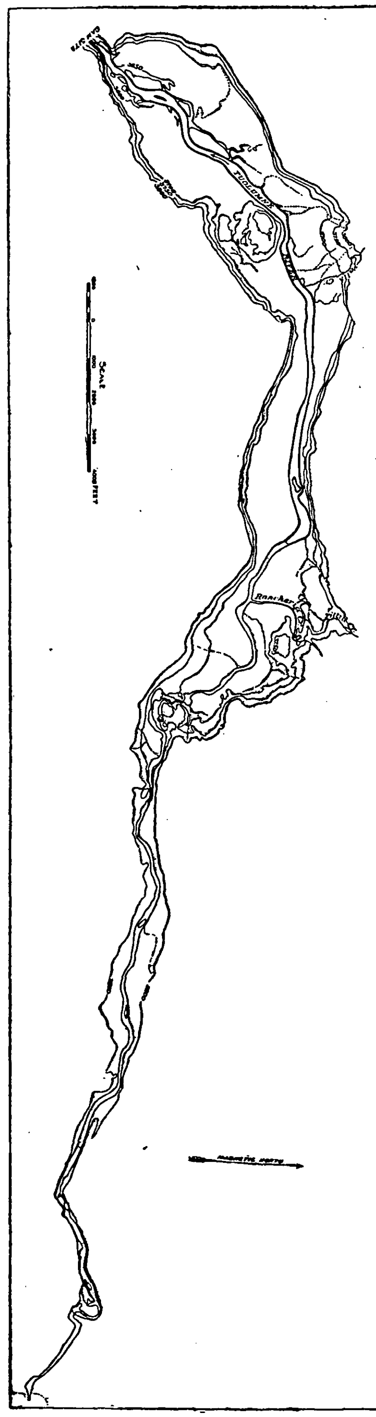


Fig. 259.—Map of Hetch Hetchy reservoir site.

square miles of the higher altitudes of which are situated above Hetch Hetchy Valley. This territory is largely made up of high granite mountains covered in places with forests of pine, cedar, and fir, dotted with many small lakes and with streams running to the foot of the glaciers which flank the western slopes of Mount Dana, Mount Gibbs, and Mount Lyell. In the months of April, May, and June this region supplies a large part of the water which flows into the river, and it is safe to say that during those months this is not less than one-fourth of the water which passes the Lagrange dam. In those months the flow of the river at Lagrange has been—

	Acre-feet.
In 1896	939,000
In 1897	1,530,950
In 1898	656,629
In 1899	477,490

These figures, which are taken from the measurements made at Lagrange, show that even in the three driest years of which we have any record there would still be sufficient water to fill the Hetch Hetchy reservoir every spring. These figures give the record for extraordinarily dry years; in ordinary years many times this amount would go to waste over the weir. Assuming, then, that we have a full and overflowing reservoir every spring, what can be done to better the conditions for irrigation in the valley and foothill lands below? An inspection of the following table, which gives the discharge of the river in acre-feet, will show that the supply is always short in the months of August and September—the hottest season of the year in California:

Discharge, in acre-feet, of Tuolumne River at Lagrange, California.

Month.	1896.	1897.	1898.	1899.
January	142,159	75,692	27,916	15,100
February	66,954	287,238	49,983	20,720
March	167,578	247,920	75,261	112,100
April	209,574	460,263	238,849	155,780
May	272,371	733,121	284,075	139,895
June	457,705	337,566	133,705	181,815
July	184,677	134,105	17,032	312,975
August	29,828	14,573	5,226	4,485
September	25,742	5,117	1,190	990
October	7,366	13,650	3,197	15,645
November	67,543	45,699	2,321	72,833
December	66,603	67,883	15,741	94,455
Total	1,698,100	2,422,827	854,496	1,126,793

By proper regulation this reservoir could be made to tide over this season of low supply, and an average of 800 second-feet for sixty days—during the months of August and September—could be delivered to the Lagrange dam. Taking the months of August, September, and October for the years 1896 to 1899, inclusive, it is found that in order to pass 800 cubic feet per second (48,000 acre-feet per month) into the canals at Lagrange, the following quantities would have to be supplied from this regulating reservoir:

Storage capacity of Hetch Hetchy reservoir.

Month.	Flowing in the river.	To be supplied by reservoir.
1896.	*Acre-feet.*	*Acre-feet.*
August	29,828	18,172
September	25,742	22,258
October	7,366	40,634
Total	62,936	81,064
1897.		
August	14,573	33,427
September	5,117	42,883
October	13,650	34,350
Total	33,340	110,660
1898.		
August	5,266	42,734
September	1,190	46,810
October	3,197	44,803
Total	9,653	134,347
1899.		
August	4,485	43,515
September	990	47,010
October	15,645	32,355
Total	21,120	122,880

This tabulation shows that in very dry years the supply for the month of October would be short, but it could be safely counted upon for the months of August and September. Again, it will be seen that in the month of July, 1898, the amount of water passing in the river at Lagrange amounted to only 17,032 acre-feet. In all the other years there was a large excess. The season of 1897–98 was certainly the driest year on record in that part of California, the snowfall in the mountains being unusually light and all of it apparently melted by the first of June. It would hardly be fair to take this into consideration in the calculation of the duty of this reservoir, as such a combination of unfavorable circumstances might not occur again in fifty years. It has, therefore, been assumed that the amount of water to be counted upon from the reservoir would be 800 cubic feet per second for sixty days—sometime during the months of July, August, September, and October—of each year. This would require about 100,000 acre-feet of water in the reservoir at the commencement of each dry season. A dam 150 feet high would be needed to impound this quantity of water.

To arrive at the loss by evaporation and seepage, except by actual measurement, in carrying 800 cubic feet of water per second through the channel of a mountain stream for a distance of over 50 miles, is a difficult problem. Some allowance, however, must be made for this loss, and the following method of reasoning may be adopted:

Assuming the average velocity of the water from the time it is turned into the river until it arrives at the point of distribution to be 3 feet per second, and the average depth of the water 2⅔ feet, the average width of the stream would be 100 feet.

By referring to the table in the Twelfth Annual Report of the United States Geological Survey, page 308, it will be seen that the evaporation in Arizona—a much hotter climate than that of Tuolumne County, California—in the months of August and September amounted to 23 inches in sixty-one days. Taking the mean area of the reservoir between the heights of 10 feet and 150 feet at 800 acres, and the area of the stream as 100 feet wide and 53 miles long, or 642 acres, the total surface exposed to evaporation would be approximately 1,500 acres. Allowing 2 feet of evaporation on this surface, in two months there would be 3,000 acre-feet of water lost from this cause. Double this for seepage and it would still leave 101,000 acre-feet for distribution. This is a large amount of water, if carefully used in irrigation. In the Redlands and Highlands districts of southern California—a very hot climate for that State—the best water right and the one which so far has proved ample, is an allowance of 1 California miners' inch to 4 acres. This is one-fiftieth of a second-foot to 4 acres, or one two-hundredths of a second-foot to 1 acre. This water is all delivered in two hundred days of the year, which constitutes an irrigating season, so that in one day there would be delivered to the land 1 second-foot of water per acre, which is equivalent to 2 acre-feet of water for each acre of land during the season. The average quantity for two months would be one-third of this, or two-thirds of an acre-foot, to each acre of land. Thus 100,000 acre-feet of water would be sufficient for 150,000 acres of citrus fruits, or 100,000 acres of alfalfa, for the two driest months of the year, and would really mean success, rather than failure, in farming in the districts covered by this water.

The advantages of irrigation in a climate like that of San Joaquin Valley in California are too well known to need recapitulation here. For the benefit of those who are not familiar with the crops raised in that climate, a single instance may be cited to show the difference in the value of land with water and without it. Take, for example, a crop of alfalfa. Six crops a year of this clover, with a yield of 2 tons to the acre, is not unusual where water is delivered to the land. The alfalfa raised in this valley is much superior to that raised on the lands nearer the coast, the fogs on the coast tending to produce mold in curing, whereas, owing to the extreme dryness of the atmosphere in San Joaquin Valley, the hay is cured quickly, without mold, and retains all of its nutritious qualities. Taking one year with another, alfalfa hay will yield a profit over and above all expenses of $2 a ton, and probably more if fed to stock. This makes the land easily worth $100 an acre, which for wheat raising would not bring more than $30, a high estimate. If it be true that "he is a public benefactor who makes two blades of grass grow where one grew before," what shall be said of him who makes six crops of alfalfa grow where only one crop of wheat grew before? Other crops might be mentioned which would make even a better showing, but enough has already been written on this subject to fill many volumes. The fact is that 10 acres of land with water is better than 100 acres without water, and this means that with water the lands in question will support in plenty ten times as many people as can now earn a scanty livelihood on them by raising cereal crops.

There are about 250,000 acres in the Turlock and Modesto districts depending on Tuolumne River for a supply of irrigating water. Up to the present time very little use has been made of the water in this stream for the irrigation of valuable crops. The Modesto district has been tied up in litigation, in connection with the construction of the Lagrange dam, but the Turlock district has almost completed its diversion works. The first settlers in San Joaquin Valley, where these irrigable lands are situated, naturally turned their attention to wheat raising, and, taking one year with another, used to make this business fairly remunerative; but the gradual impoverishment of the land by sowing it to one crop for many years in succession, the low price of wheat for some years, and the last three years of unexampled drought in California, have shown that in order to make farming a success on these lands other crops than wheat must be raised. The lands of these districts vary in elevation from a few feet above the sea to a height, in the warm belt of the foothills, of 500 feet. Experience in other parts of the valley has shown that grapes, deciduous fruits, alfalfa, and root crops, with occasional citrus fruit crops in the more favored corners of the foothills, can all be made to pay where there is an unfailing supply of water during the months when irrigation is necessary.

Hitherto, as an inspection of the discharge table on page 454 will show, water has not been available at the most critical period—late summer and fall—when two months without water, in the heat of the valley, means death to most fruit trees and plants. This can now be remedied by a proper regulation of the waters of Tuolumne River, by means of the proposed dam and reservoir.

The immense amount of water running down this mountain stream during the year naturally suggests the possibility of developing power at a low cost. To be economical, however, a power plant should be arranged so that it can be run all the time and with little variation in the quantity of water. An examination of the figures in the tables of discharge (page 454) will show that with the assistance of the proposed reservoir 800 cubic feet of water per second might be safely counted upon for eight months of the year; but for the other four months of a dry year provision would have to be made either for a reservoir to carry enough water to tide over the period of low discharge or for an auxiliary steam plant to take the place of the water plant until the suppiy of water was sufficient to run the latter. Such a reservoir would at times need to carry as much as, or more than, the Hetch Hetchy reservoir, which gives practically about 800 second-feet for two months, and as such a reservoir is not known to exist on the river below Hetch Hetchy Valley, this would seem to render impracticable the project of a reservoir for irrigation and power at the same time.

Whether a water power on this river, with an auxiliary steam plant, would be a success financially is a question which can not be discussed here; but it is very evident that the Hetch Hetchy weir could not be counted on in this connection to influence in any great degree the location of a power plant on this river, unless designed for power instead of for irrigation.

The value of such a reservoir for irrigation purposes only would be very great. One dollar an acre per annum on the land covered with this water represents the interest at 6 per cent on $2,500,000. In a district where the main canal and most of the distributing system are already provided, this would be a small charge on the land, and after deducting expenses of delivery, repairs, etc., would leave a large margin of profit on the original investment for the dam and reservoir.

The value of the proposed dam and reservoir for power purposes only is not so great as might appear at first sight. It is evident that the only use of the reservoir in this connection would be to regulate the flow of water in the river so that a certain amount could be counted on every day in the year. By examination of the table on page 454, it will be seen that in very dry years the water in the reservoir would have to be divided in such a way, for several months, as to insure this minimum amount of water for the power plant. In the season of 1898–99, a very dry year, this amount at Lagrange would have been, in the months of July to February, inclusive, about 390 cubic feet per second, of which the reservoir would have had to supply six-tenths.

The fall of the river below Hetch Hetchy Valley is approximately as follows:

Fall of Tuolumne River below Hetch Hetchy Valley.

Fall.	Distance.	Elevation.
Feet.	*Miles.*	*Feet.*
700	8	3,000
500	4	2,500
500	6½	2,000
500	9	1,500
500	12	1,000
500	13½	500

For example, taking the most favorable of these falls, say 500 feet in 4 miles, the theoretical horsepower that could be developed with this amount of water would be $390\times500\times0.11=21{,}450$. With the most modern machinery not over 80 per cent of this amount would be available for generating electricity. The loss in transforming, transmission, and distribution would probably consume 40 per cent of the remainder, so that this would really represent about 10,000 horsepower to be sold. Taking into account the difficulty and cost of constructing a plant in one of the roughest and most inaccessible mountain canyons in California, and the cost of transmission to widely separated points in the mountains—for the miners of the foothills would probably be the only customers for a long time—this would not seem so enticing a commercial proposition as the irrigation project. In the case of the latter the people are willing and anxious to buy the water, provided a certain amount can be assured them during the dry months of the year; but in the former case the customers are not only limited in number but are scattered over a large area, making the revenue from the investment much more uncertain. Still it is a use for this reservoir which is not to be lightly considered.

Another purpose which this dam and reservoir might be made to serve would be to furnish the city of San Francisco with an unfailing supply of pure water. Without entering into details, it will suffice to say that the dam and reservoir as proposed would insure a supply in the driest years of 250 gallons per diem per capita for 1,000,000 people.

A weir or overfall dam has been selected for the following reasons: Owing to the conformation of the ground it would be impracticable to secure a wasteway sufficiently large to carry the water which might pass over this dam during a heavy storm. Experience has shown that the greatest flood in a mountain stream is likely to occur when a warm rain follows a heavy snowstorm. A large part of the drainage area above this dam site is composed of bare granite hills, from which the run-off in such a case would be very great. The freshet flow of the entire drainage basin has been estimated by Mr. Grunsky (see Water-Supply and Irrigation Paper No. 19, page 41) at 120,000 second-feet. It is not unreasonable to suppose that one-fourth of this might pass over the weir. A depth of 10 feet of water on the crest would, by Clark's formula, show 48,935 cubic feet per second passing over the weir, and this depth of water has been used in the calculations for lines of pressure. Such a quantity of water passing over wasteways at the sides of a dam in a narrow gorge would strike the foot of the dam unless very expensive training walls were built to prevent it.

By making the dam an overfall the sheet of water is spread over its whole length, and is consequently much thinner than if confined in a narrow wasteway. The material at the dam site is a hard siliceous granite, weighing about 170 pounds to the cubic foot, and offers ideal conditions for an overfall dam. The location of the dam, with an inexhaustible supply of granite on each side, is such that wire cables can be used most effectively in placing the stone.

Below the weir the gorge is very narrow for about 200 feet, being not more than 100 feet wide at a height of 50 feet above the bottom of the stream. As the dam is more than 400 feet long on top, it is evident that for 10 feet of water flowing over the crest there would be about 40 feet of water acting as a cushion for the falling water in the narrow gorge below. This would not only serve to protect the lower toe, but would to some extent relieve the resultant pressure on the base of the dam. There is considerable drift to be taken care of in Tuolumne River above Hetch Hetchy Valley, and if at any time the wasteways should become choked, the water would go over the dam, which would have to be strong enough to provide for this contingency.

Taking all of these facts into consideration the conclusion has been reached that an overfall dam is the most suitable for this location. In view of the number of failures of dams of late years, there has been taken into account the possibility of a flotation effect, due to the water passing under the dam itself or through any section of it, and the cross section adopted (fig. 260) is so designed that if the dam were actually immersed, and should lose in weight an amount equal to the weight of its own volume of water, the resultant pressure, with 10 feet of water flowing over the top, would still pass through the middle third of any horizontal section. If the dam is properly built, so that no water can pass underneath it or through any section of it, the resultant pressure would then fall very near the center line of the cross section at all points, and the dam would be an unusually safe one. While this cross section appears very heavy, it must be remembered that there is always a possibility of vibration from the long-continued fall of a large body of water affecting the foundations of the dam in such a way as to allow water to pass underneath it. There is also danger of imperfect work in joining the masonry to the bed rock, and an earthquake is not an unusual occurrence in these mountains. In addition to the precautions taken against these dangers, the dam has been given a curved form upstream, so as to accommodate itself more easily to the expansion and contraction which must necessarily occur in a monolith of this size.

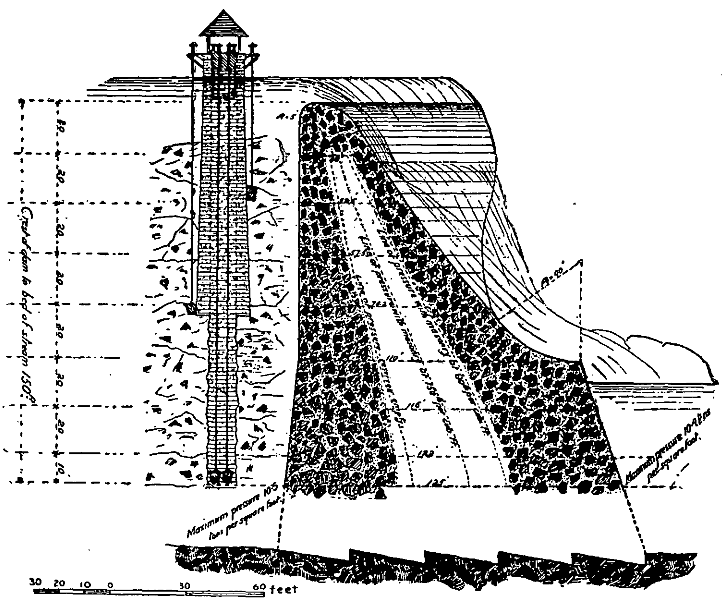


FIG. 260.—Cross section of proposed weir on Tuolumne River.

It is proposed to build the dam of Cyclopean rubble, or large irregular blocks of granite embedded in concrete. These blocks should be very large, for two reasons: First, because the larger they are the less concrete will be required; and, second, because they offer a greater resistance to shearing strains than smaller blocks, which require so many joints. A little consideration will show that for this class of work a large rock is more economical of cement than a small one. It is evident that if a rock is to be entirely surrounded by concrete mortar—which it should be, and in this case, to allow of tamping and proper material in the concrete, the thickness of the concrete mortar should be not less than 12 inches—there is a point at which the surrounding concrete will be equal to the volume of the inclosed cube. In this case the cube, whose side is 3.8 feet, gives a mass in which the concrete will form, roughly, one-half the dam and the granite one-half. Such a block of granite would weigh (55×170) 9,350 pounds; so that we may specify stones weighing 5 tons or more. The smaller blocks and quarry refuse could be crushed and used for concrete. If rocks smaller than this are used, there will be a greater proportion of concrete than rock in the dam, and vice versa, provided the blocks are roughly cubical in shape. This is also true of spherical blocks, and in a lesser degree of pyramidal blocks.

In laying these blocks in the wall care should be taken to place them in such a way as to bind the different days' work together, as in heavy concrete work these joints are always weak spots. Experience has shown that water will follow such joints very easily, and resistance to sliding at such points is not nearly so great as is generally supposed. The reason for this appears to be that concrete mortar contracts in setting. Take an iron tube 2 feet long and fill it with concrete. When it is set, the concrete can be shaken out of it without much difficulty. Plug the bottom of this same tube and place it with 1 foot of its length in a mass of fresh concrete, and it will be found, when the concrete has set, that it has adhered so tightly to the tube that it will be almost impossible to pull the latter out of the concrete. The mortar in concrete will stick to the smoothest gravel. A good concrete can be made with waterworn shingle from the sea beach, simply because the mortar contracts around it. If it be true, then, that concrete contracts in setting, of what use is a thin layer of mortar between two stones in a masonry wall, or between two layers of concrete, to keep the stones from sliding on each other? Such a layer of mortar simply draws away from the stones, or from one of them, and leaves a space, imperceptible, indeed, to the eye, but easily detected when water under pressure is forced against the joint. Large stones should be laid so as to interlock at all joints in the concrete, and thus offer as much resistance as possible to the sliding action. The weeping or leakage through joints generally disappears after a few months, owing to the joints being filled with the salts of soda and potash, which so often disfigure the outside of walls exposed to water on the back.

During the construction of the proposed dam the water of the river would of course have to be taken care of. For this purpose, as well as to permit a large quantity of water being turned out of the reservoir during the dry months, two outlet tunnels, as shown in fig. 261, page 463, are proposed. An open cut can first be made on each side above the dam and the tunnel be connected with it, as shown. During low water, by diverting the water through one of these tunnels, the entrance to the other can be walled up and the inlet valves set. When this is done, the water can be turned through the inlet valves of that tunnel and the entrance to the other be completed. When both are finished, they can be used to carry all the water during the dry months, and when high water comes it will run over the top of the dam till the water is low enough to allow work to be resumed the following season.

The towers which cover the inlets to the tunnels can serve the double purpose of valve chambers and piers for a small concrete footbridge crossing the gorge in which the dam is situated. This bridge will be necessary in order to obtain access to the valves and gates, and will also be useful in getting rid of any drift which may collect around the towers or on top of the dam. The narrow entrance to the gorge above

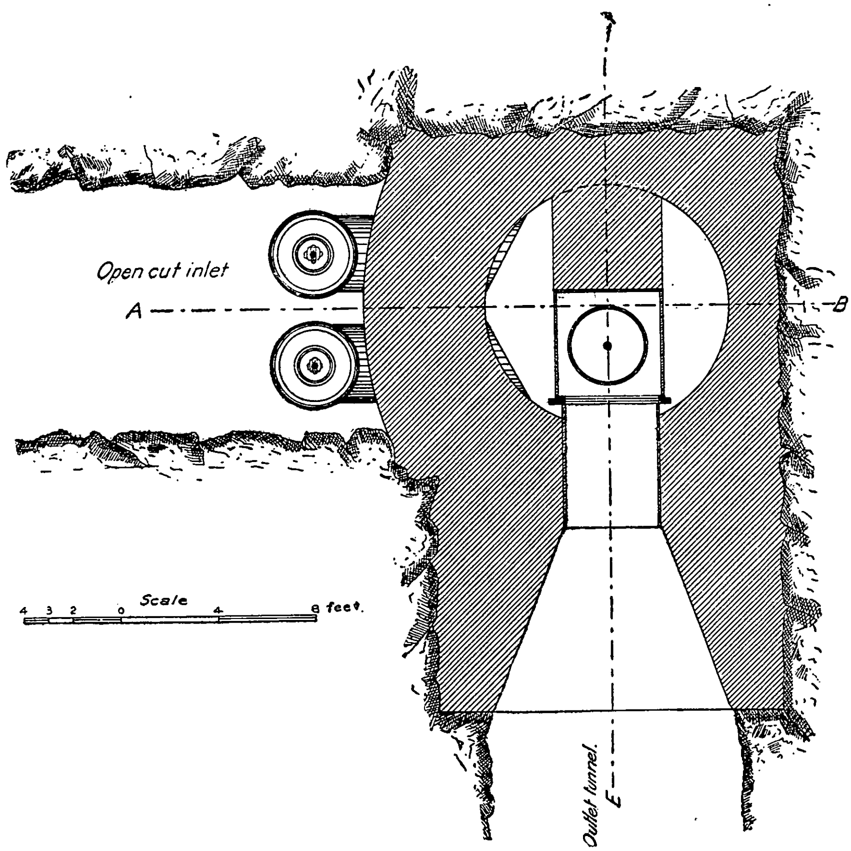


FIG. 261.—Horizontal section showing details of inlet and outlet in valve towers of Hetch Hetchy reservoir.

the dam offers a fine location for a boom of logs, which would arrest all large drift in times of high water and prevent its accumulation above the bridge or dam.

The most expensive item in the cost of this dam is the cement. This is due to the inaccessibility of the dam site. There is a good wagon road from Chinese Camp, which is a railroad station, to Crockers, a distance of about 35 miles, an unused but fairly good road from Crockers to Hog Ranch, a distance of 8 miles, but from that point to

Hetch Hetchy Valley a wagon road would have to be built, the cost of which would be about $20,000. The sum of $5,000 would have to be

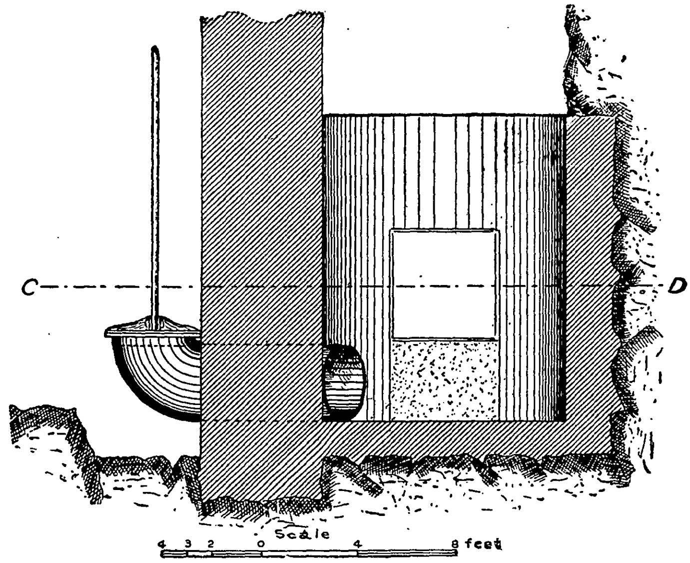


FIG. 262.—Vertical section on line A-B of fig. 261.

allowed for a new bridge across one of the forks of the river and for repairs to the old road. The cost of hauling a barrel of cement from

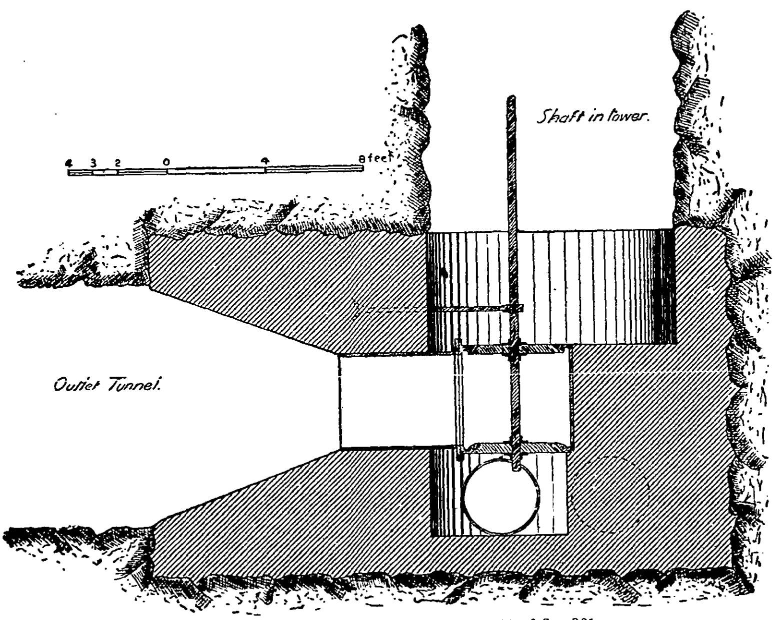


FIG. 263.—Vertical section on line E-F of fig. 261.

Chinese Camp to Hetch Hetchy Valley is estimated to be $7; the cement could probably be delivered at Chinese Camp for $3, making a total of $10 delivered at the dam site. By making a sand-cement, as described in Water-Supply and Irrigation Paper No. 33, a saving in the cost of concrete could be made, thus—

One-half barrel Portland cement	$5.00
One-half barrel crushed sand	.18
Grinding same	.20
Royalty	.05
Total cost of sand cement per barrel (375 pounds)	$5.43

This is 1.45 cents a pound. With 270 pounds of cement at 2.66 cents a pound, one cubic yard of concrete would cost, for cement alone, $7.18. With 340 pounds of sand cement at 1.45 cents a pound, one cubic yard of concrete would cost, for cement alone, $4.93. This would effect a saving of $2.25 for each cubic yard of concrete used in the dam. The cost of a cubic yard of concrete at the dam site may therefore be estimated as follows—

Cement	$4.93
Sand	.50
Crushed rock and gravel	2.50
Labor	1.00
Total	$8.93

The dam as designed will contain 65,000 cubic yards of masonry. Assuming one-half of this to be concrete and one-half large rock, the estimated cost of the masonry would be—

Concrete, 32,500 cubic yards, at $8.93	$290,225
Rock, 32,500 cubic yards, at $3.50, in place	113,750
Total	$403,975

or $6.21 per cubic yard.

Estimated cost of Hetch Hetchy Valley dam and accessories.

Masonry	$403,975
Wagon roads (building new and repairing old)	25,000
Cement-grinding plant, crusher, etc	15,000
Two concrete towers and piers, 85,000 cubic feet, at 50 cents	42,500
Twelve inlet valves for towers, $500 each	6,000
Two balance valves, $1,000 each	2,000
420 linear feet of footbridge, at $20	8,400
600 feet of tunnel, at $15	9,000
Excavation, cleaning, and stepping foundation	16,000
Total	527,875
Contingencies, 10 per cent	52,788
Engineering, 5 per cent	26,394
Total	$607,057

The total number of acre-feet of water stored would be 107,000, making the cost per acre-foot $5.67.

SAN JOAQUIN RIVER.

San Joaquin River is divided into two distinct parts. The valley portion forms the central drainage line of San Joaquin Valley, and during the spring is navigable for a hundred or more miles. The Stanislaus, Tuolumne, and Kings are the largest affluents of this portion of the stream. Its valley is fertile and almost destitute of timber. It discharges into Sacramento River near Suisan Bay. The mountainous portion of the stream drains the western slopes of the Sierra Nevada between Yosemite National Park and Mount Goddard, the crest of its divide reaching an elevation on the north, in Mount Lyle, of 13,000 feet, and an elevation of 14,000 feet in Mount Goddard. The resulting steep grades of this river offer exceptional opportunities for water-power developments, and the high elevations of the basin insure a well-sustained summer flow from perpetual snow banks. The gaging station is located at Herndon, California, about 20 miles below the point where the river issues from its mountain canyon and above its junction with other tributaries. Measurements are made under the direction of J. B. Lippincott.

Estimated monthly discharge of San Joaquin River at Herndon, California.

[Drainage area, 1,637 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,170	170	463	28,469	0.28	0.32
February	1,060	350	645	35,821	0.39	0.41
March	16,206	692	2,689	165,341	1.64	1.89
April	7,354	2,030	4,233	251,880	2.59	2.88
May	7,090	1,830	3,730	229,350	2.28	2.63
June	9,070	2,620	5,700	339,173	3.48	3.88
July	3,105	955	1,664	104,284	1.02	1.18
August	745	250	428	26,317	0.26	0.30
September	220	70	152	9,045	0.09	0.10
October	776	69	214	13,158	0.13	0.15
November	1,175	130	565	33,620	0.34	0.39
December	4,775	220	1,018	62,595	0.62	0.71
The year	16,206	69	1,792	1,299,053	1.09	14.84

NOTE.—Gage heights and discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 38, page 396; rating table in Paper No. 39, page 455.

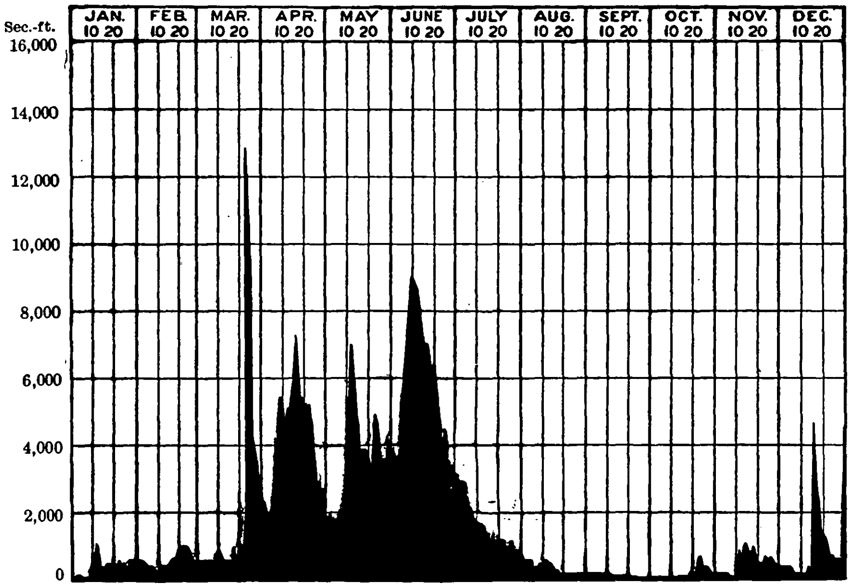


FIG. 264.—Discharge of San Joaquin River at Herndon, California, 1899.

KINGS RIVER.

Kings River rises on the western slope of the Sierra Nevada in Fresno County, California. The waters coming from the high catchment basin are probably of greater value for irrigation purposes than those of any other stream in central California, being used for raising grapes and deciduous fruits in the neighborhood of Fresno, Selma, and Hanford. The summer flow of the river is now entirely diverted, and during the dry season of the last few years the scarcity of water has caused many hardships. In the spring there is a large surplus, due to the melting of snows, which if stored in suitable reservoirs would bring larger areas under cultivation. The mountainous basin of the river has never been systematically explored for reservoir sites. Two stations have been maintained on the river, one at Red Mountain, established September 3, 1895, and the other at Kingsburg, the latter having been maintained by the Southern Pacific Railway Company since 1879. Measurements at the Red Mountain station are made under the direction of J. B. Lippincott.

Estimated monthly discharge of Kings River at Red Mountain, California.

[Drainage area, 1,775 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	1,310	250	513	31,543	0.29	0.33
February	1,036	440	660	36,655	0.37	0.39
March	20,200	624	2,165	133,122	1.22	1.41
April	7,300	1,834	4,512	268,482	2.54	2.83
May	4,870	1,450	3,568	219,389	2.01	2.32
June	10,320	2,584	6,077	356,845	3.42	3.82
July	2,852	676	1,411	86,760	0.79	0.92
August	624	250	411	25,272	0.23	0.26
September	285	180	215	12,793	0.12	0.13
October	1,205	180	378	23,242	0.21	0.24
November	1,240	345	638	37,964	0.36	0.40
December	5,096	400	991	60,935	0.56	0.64
The year	20,200	180	1,795	1,293,002	1.01	13.69

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 39, page 404; discharge measurements, page 403; rating table, page 455.

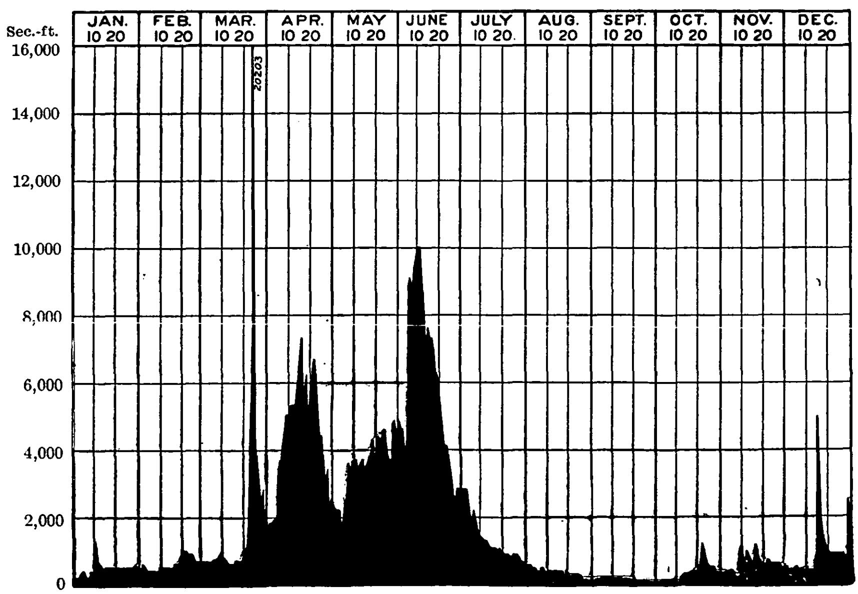


FIG. 265.—Discharge of Kings River at Red Mountain, California, 1899.

SOUTHERN CALIFORNIA DRAINAGE.

KERN RIVER.

Kern River rises at the southern end of the Sierra Nevada and flows first southerly and then westerly into what is sometimes called Kern Valley, but which is really the southern end of San Joaquin Valley. During recent years the entire summer flow of the river has been utilized for irrigation, while the surplus winter waters have practically all been stored in Buena Vista Lake, situated in the central portion of Kern Valley, and during the following summer have been used for irrigation purposes by the Miller & Lux Estate. A water-power electric plant (described in the Nineteenth Annual Report, Part IV, page 524) is located at the mouth of the canyon. During the last two years Mr. Lewis Hicks has been conducting some interesting and valuable investigations for the Kern County Land Company, pumping water for irrigation with centrifugal pumps operated electrically, power being obtained from the power plant referred to. The company has found that it can sell water so obtained for 75 cents an acre-foot. The lift is approximately 30 to 40 feet, and the water supply, which is constantly replenished by the heavy spring irrigations, is considered inexhaustible. During the summer of 1899 more water was obtained from these pumping plants than was flowing in the natural channel of Kern River. These investigations suggest in a striking manner the possibility of augmenting, by similar developments, the midsummer supply in other portions of San Joaquin Valley.

Estimated monthly discharge of Kern River at first point of measurement.

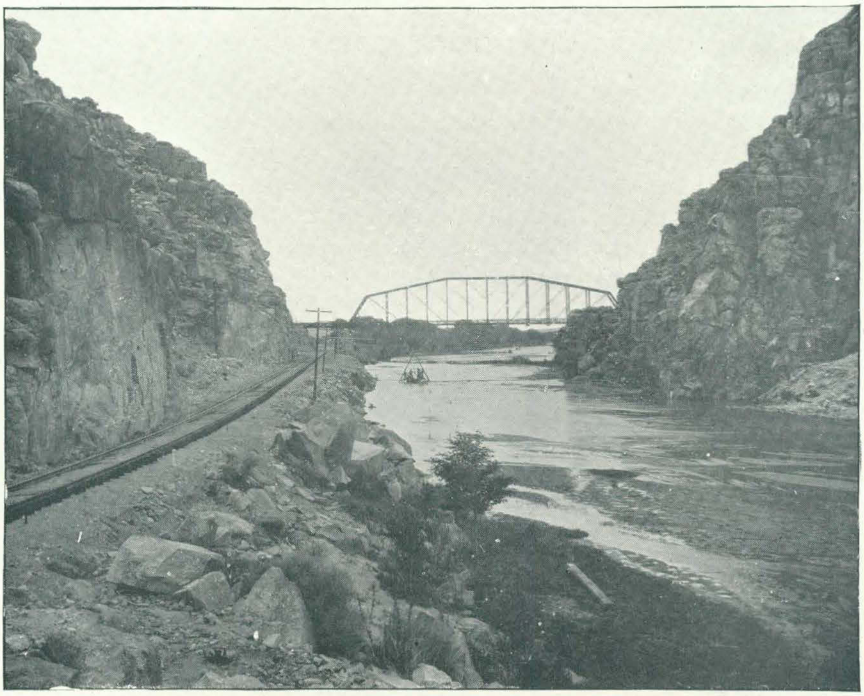
[Drainage area, 2,345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	361	182	263	16,171	0.11	0.13
February	365	258	302	16,772	0.13	0.14
March	4,932	247	590	36,278	0.25	0.29
April	1,167	593	893	53,138	0.38	0.43
May	1,302	576	835	51,342	0.36	0.41
June	2,230	809	1,331	79,200	0.57	0.63
July	894	229	489	30,067	0.21	0.24
August	240	99	156	9,592	0.07	0.08
September	117	89	105	6,248	0.04	0.04
October	228	86	160	9,838	0.07	0.08
November	384	183	221	13,588	0.09	0.10
December	780	182	278	17,032	0.12	0.14
The year	4,932	86	467	339,266	0.20	2.71

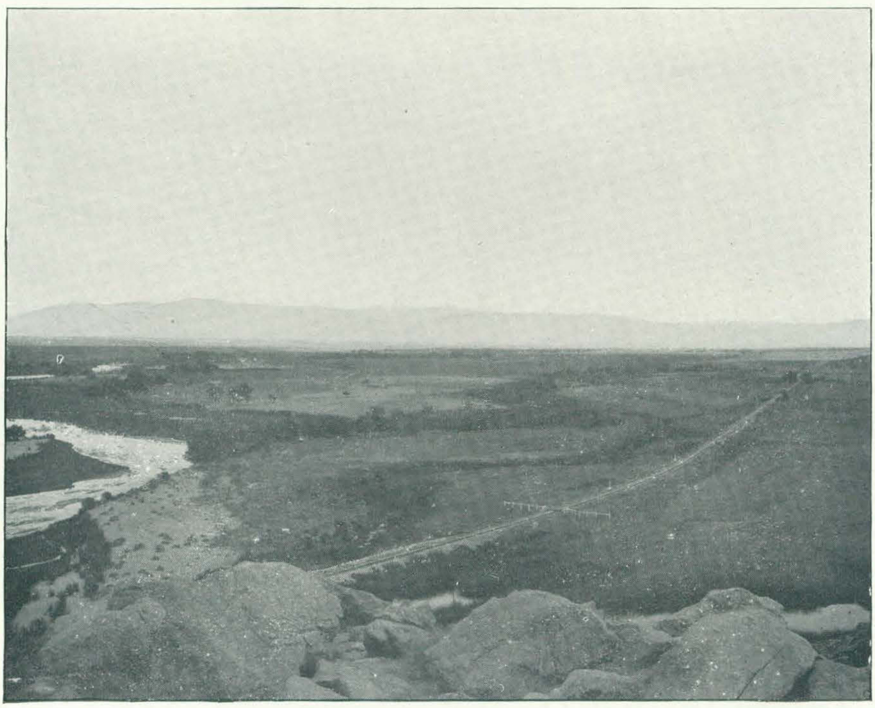
LITTLEROCK CREEK.

This creek rises on the north side of the Sierra Madre in Los Angeles County. The discharge of the basin is interesting not only in itself, but in comparison with the discharge of San Gabriel River, which flows from the south side of the same range at a point immediately opposite. It will be seen that the run-off to the square mile is substantially less from Littlerock Creek than from San Gabriel River. No storage-reservoir sites of importance exist upon the drainage line proper, but an old lake bed, situated about 3 miles south of Palmdale, has been connected with the channel of Littlerock Creek by a conduit 8 miles in length, with a capacity of 100 cubic feet per second, the purpose being to carry the storm waters of the creek to the lake bed, the storage capacity of which has been greatly increased by the construction of a dam at its lowest divide. This reservoir site is at an elevation which commands the lands of the South Antelope Valley Irrigation Company near Palmdale, and also the lands of the Littlerock Creek Irrigation District. During the last three years the discharge from Littlerock Creek has been abnormally low.

All the watei of the stream is turned into the headworks flume of the South Antelope Valley Irrigation Company's canal near the mouth of the canyon of the creek. The gage heights in the canal are kept, and an additional rod is located in the bed of the stream below the point of diversion, at the flume crossing in the river. No water, however, passed these headworks during the year 1899. The observations were made at the headworks by the irrigation company's watchman, and are believed to be accurate. Mr. Burt Cole, engineer-in-charge of this work, reports final results. They may be accepted as correct. The station was rated for the Geological Survey by J. B. Lippincott and Mr. Cole.



A. VICTOR DAM SITE, CALIFORNIA.



B. VICTOR RESERVOIR SITE, LOOKING UPSTREAM FROM DAM SITE.

Estimated monthly discharge of Littlerock Creek at headworks of South Antelope Valley Irrigation Company's canal, near Palmdale, California.

[Drainage area, 78 square miles.]

Month.	Discharge in second-feet.			Total for month in acre-feet.	Run-off.		Rainfall in inches.
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.	
1899.							
January	7.00	0.0	4.90	318	0.0765	0.062	1.00
February	5.00	3.0	4.41	245	0.0588	0.056	0.31
March	16.50	4.0	7.66	472	0.1135	0.098	0.97
April	6.00	2.0	4.50	268	0.0644	0.058	0.00
May	2.00	1.0	1.50	166	0.0399	0.019	0.00
June	3.00	0.2	2.00	119	0.0286	0.026	0.00
July	0.20	0.2	0.20	12	0.0029	0.003	0.00
August	0.20	0.2	0.20	12	0.0029	0.003	0.00
September	0.20	0.2	0.20	11	0.0028	0.003	0.00
October	0.00	0.0	0.00	0	0.0000	0.000	1.28
November	0.00	0.0	0.00	0	0.0000	0.000	0.27
December	4.00	0.0	1.00	61	0.0128	0.013	0.32
The year	16.50	0.0	2.21	1,684	0.4022	0.027	4.15

MOHAVE RIVER.

This river, as described in the Nineteenth Annual Report, Part IV, page 614, rises on the northern slope of the Sierra Madre in San Bernardino County, California, at elevations of from 5,000 to 8,000 feet. The stream flows in a general northerly direction and disappears in the Mohave Desert, to the north of the mountains. Near the town of Victor, on the Southern California Railroad, the river passes through a narrow gorge known as Victor Narrows. This is bounded on the side by almost vertical granite cliffs. Above this point the valley expands in a broad basin, forming an excellent site for a reservoir. This has been described by Mr. James D. Schuyler, in his paper upon Reservoirs for Irrigation, in the Eighteenth Annual Report, Part IV, pages 708 to 710. During 1899 borings were made at the Victor Narrows, at the location shown by the accompanying diagram, fig. 266, where it is most probable that a dam for impounding the water of Mohave River will be constructed. The table on the next page gives the elevation above sea level of the top and bottom of these borings.

Elevation of surface and bed rock at Victor Narrows, California.

Boring.	Surface (elevation above sea level).	Bed rock (elevation above sea level).
	Feet.	*Feet.*
No. 1	2,708.99	2,694.58
No. 2	2,709.03	2,660.03
No. 3	2,709.10	2,655.00
No. 4	2,708.76	2,670.11
No. 5	2,708.75	2,668.09
No. 6	2,708.77	2,664.87
No. 7	2,709.20	2,664.75
No. 8	2,709.27	2,663.05
No. 9	2,709.27	2,671.55
No. 10	2,709.00	2,674.75

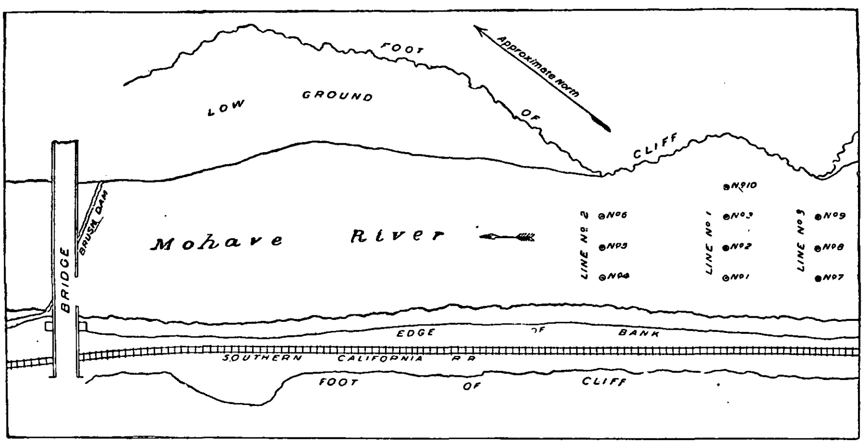
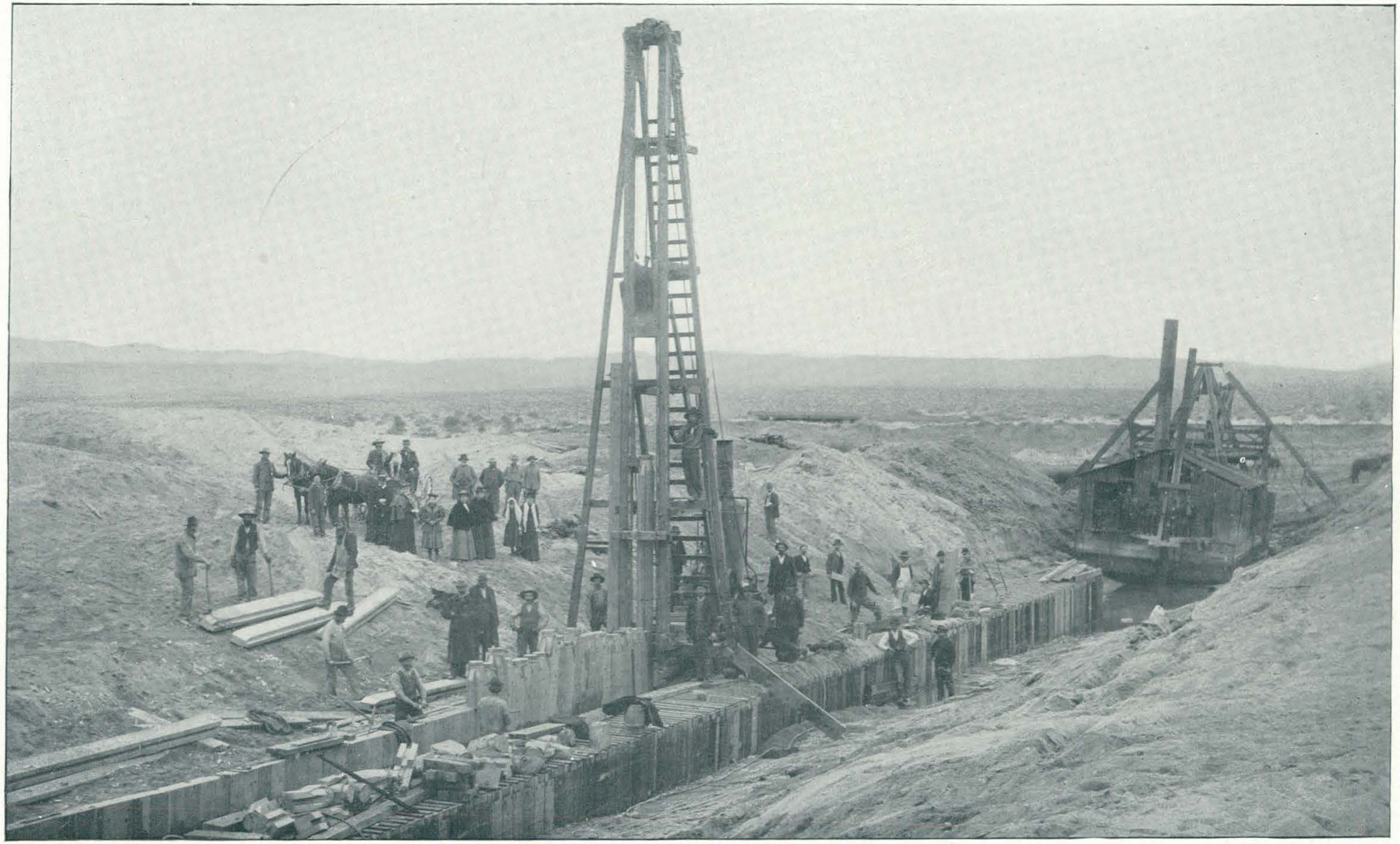


FIG. 266.—Map showing location of borings at Victor Narrows, on Mohave River.

A map showing the outline of the basin and the location of the dam site is given as Pl. XCI of the Eighteenth Annual Report, Part IV. A general view of the dam site is shown on Pl. LI, *A*. A view of the reservoir site, looking upstream from the dam site, is shown on Pl. LI, *B*. About 50 miles farther down the river, near Daggett, attempts have been made to recover the so-called underflow by means of development works. Extensive dredgings have been made in the bed of the stream and a flume buried in the gravel in which to collect water percolating through the gravels. The results, however, have not apparently justified the outlay. The work is illustrated by Pl. LII.



UNDERFLOW DEVELOPMENTS ON MOHAVE RIVER AT DAGGETT, CALIFORNIA.

Estimated monthly discharge of Mohave River at Victor, California.

[Drainage area, 400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March	60	28	37	2, 275	0. 09	0. 10
April	60	28	37	2, 202	0. 09	0. 10
May	44	28	33	2, 029	0. 08	0. 09
June	44	28	29	1, 726	0. 07	0. 08
July	28	22	27	1, 660	0. 07	0. 08
August	28	17	24	1, 476	0. 06	0. 07
September	22	22	22	1, 309	0. 05	0. 06
October	28	17	23	1, 414	0. 06	0. 07
November	44	22	27	1, 607	0. 07	0. 08
December 1 to 13	28	28	28	1, 722	0. 07	0. 08

NOTE.—Gage heights for 1899 are given in Water-Supply and Irrigation Paper No. 39, page 409; discharge measurements and rating table, page 408.

SANTA CLARA RIVER.

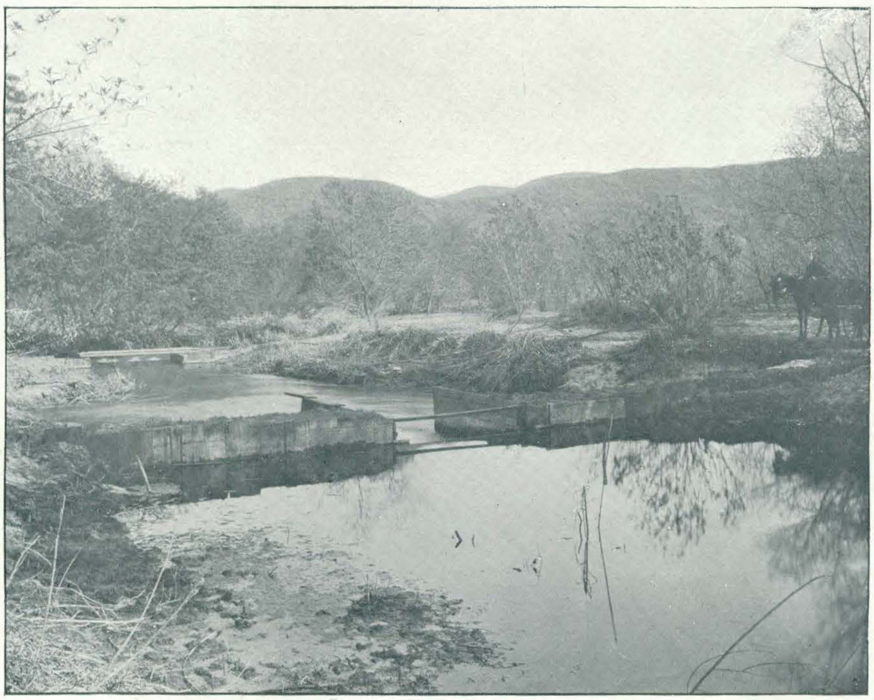
This river rises in the northwest end of the Sierra Madre in Los Angeles County, California, and flows in a westerly direction through what are known locally as the Piru, Sespe, and Santa Clara valleys. The stream is augmented by five tributaries, which enter it from the north. They are the San Francisquito, the Castac, the Piru, the Sespe, and the Ojai. The river passes through Ventura County and empties into the Pacific Ocean about 6 miles south of Ventura. A remarkable feature is the small run-off from this large drainage basin. The flood stages of the stream are almost wholly in the winter months, and at most points on the drainage line it is dry during the summer. The valley through which the river flows is of a high order agriculturally, growing all of the citrus fruits common to California. The area irrigated is limited, however, probably aggregating not more than 5,000 or 6,000 acres. There are storage reservoir sites on Piru Creek, which if utilized will afford opportunity for power development, as the canyon of the creek is very steep below the sites. While the first gold that was discovered in California was on San Francisquito Creek mining has never been extensively developed in that basin. Numerous small irrigation works have been built in the valley, consisting mainly of pipe lines, cement ditches, and wooden flumes. Measurements at the lower stages of the streams during the summer of 1898 are of special value, as they show the minimum flow on record. These are given in Water-Supply and Irrigation Paper No. 39, in the table of miscellaneous low-water measurements, pages 432 to 436.

LOS ANGELES RIVER.

This is a stream of the peculiar type found in southern California between the San Bernardino Mountains and the ocean. The supply is mainly from the southeastern extremity of the Sierra Madre—an area of 179 square miles in Los Angeles County—and from the low line of hills surrounding San Fernando Valley, known as the Santa Monica (Cahuenga) Mountains and the Santa Susana Range, and covering an area of 127 square miles. This mountainous basin discharges into San Fernando Valley. The valley has an area of 182 square miles. Its eastern portion is filled with granite, sand, and débris, onto which the water is projected and which absorbs it like a sponge, the storm channels being normally dry. The plane of saturation of the valley slopes in a southerly direction until the Santa Monica Mountains, which inclose the southern end of the valley, are reached. Here the underground waters, encountering this intercepting bank, are brought to the surface and Los Angeles River is formed, increasing in size as it proceeds toward its outlet. It attains its maximum flow when it reaches The Narrows, at a point known as Crystal Springs, where it flows through a valley 3½ miles in width, the total area drained being 488 square miles. Los Angeles River is the source of the domestic water supply of the city of Lcs Angeles. The water from the Sierra Madre is from granite hills, and quite pure in quality, while the drainage from the Santa Monica Mountains, which are of shale, is alkaline. The city of Los Angeles is considering the construction of a system of filtering or gathering galleries, to be built in the sand and gravel beds of San Fernando Valley, to collect the underground waters before they reach the surface or become contaminated. This will give the city a supply filtered through miles of sand beds and which practically never sees the light until it is drawn from the faucet at the house. The ownership of this underground water has been a source of litigation. The city maintains that it is a portion of Los Angeles River, whether under or above ground, while the owners of the land maintain their right to develop the water and dispose of it as they may elect. The city's claims have been sustained in the decisions of the California supreme courts.

On Pl. LIII, *A*, is shown a view of measuring weir E on Los Angeles River. Pl. LIII, *B*, shows measuring weir I and meter-measuring flume below. Numerous measurements of discharge of this stream are given on page 410 of Water-Supply and Irrigation Paper No. 39.

A. MEASURING WEIR E ON LOS ANGELES RIVER, CALIFORNIA.



B. MEASURING WEIR I, AND METER-MEASURING FLUME BELOW, ON LOS ANGELES RIVER.

SAN GABRIEL RIVER.

The drainage basin of this river lies on the southern slope of the Sierra Madre, the watershed being included in Los Angeles County, California. The various tributaries join the river before it enters its lowest canyon, whence it appears finally on the plain in the vicinity of Azusa. The seepage waters of this valley appear lower down in the river, and finally enter the Pacific Ocean not far from the mouth of Los Angeles River. Most of the winter waters of this stream are now used for irrigation purposes. The station is located above Azusa, at the mouth of the canyon.

The San Gabriel Electric Company has constructed a conduit for the diversion of water from the main San Gabriel River at a point approximately 1½ miles south of the main forks to the mouth of the canyon. The elevation of this conduit above the creek increases until the mouth of the canyon is reached, when a drop of 450 feet occurs. The water is discharged through nozzles against impulse water wheels of the Tuttle type. These water wheels are connected directly to four large dynamos of 300 kilowatt capacity each, which generate a current at 500 volts. This current is stepped up to about a 16,500-volt pressure, and transferred on copper wires to Los Angeles, where it is again stepped down to about 500 volts, and used for power and light. The line is 23 miles in length, and about 66 per cent of the theoretical horsepower of the falling water at the power house is delivered in Los Angeles.[1]

The irrigators in the neighborhood of Azusa, Duarte, and Covina, all in Los Angeles County, take this water as it leaves the power house and use it for the irrigation of extensive and valuable citrus orchards in those districts. The summer's water supply is always entirely consumed, and during the drought of the last seven years the demand has been during the summer months far in excess of the supply; consequently these irrigators watch with the keenest interest any interference by the power company with the natural conditions of the stream which might tend to diminish the volume of water available for irrigation purposes.

San Gabriel River flows from a granitic drainage basin, San Antonio Peak, on the east, and the San Gabriel Range, on the west, being the highest points tributary to the stream. The drainage basin is entirely within the San Gabriel Forest Reserve. The canyons of the various branches of the river are, as a rule, narrow and precipitous, with granite walls frequently rising abruptly from the sides of the streams. In other places the canyons widen and the streams spread out over the bowlders which everywhere cover the bed rock of the canyon. The various branches enter from the north, east, and west. The San

[1] For description of plant, see Engineering News, Vol. XLI, p. 164.

Gabriel Electric Company claims that during the summer months the river loses in volume from these main forks as it proceeds down the canyon, and that there is an actual salvage of water, due to the prevention of loss from seepage and evaporation, because of the diversion into their conduits, which are either pipes or tunnels. The diversion is made at the headworks in question, about 25 feet below the surface of the stream, by means of a tunnel, and it is the intention to put in a concrete dam to bed rock at that point. The irrigators admitted a saving of 10 per cent in their water supply during the summer months owing to that diversion, but claimed that the electric company should be allowed this salvage only when the volume of water in the river was greater than 500 miners' inches (10 second-feet). An agreement has been reached practically upon this basis, but it is not believed that the fact is conclusively established that there is a saving of 10 per

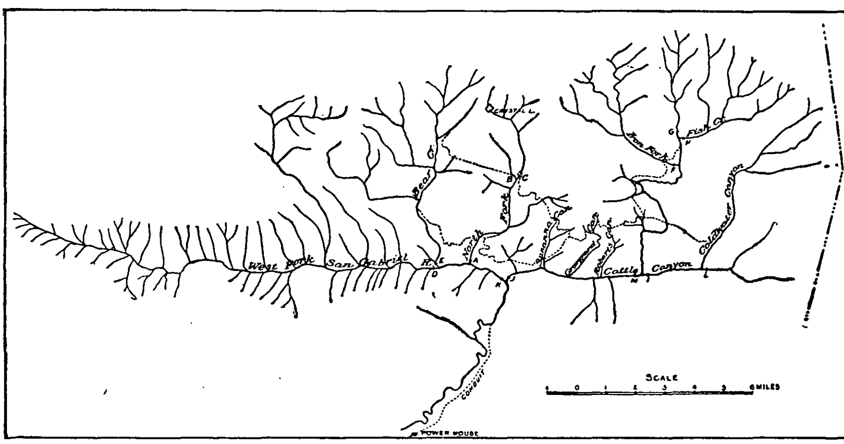


FIG. 267.—Drainage basin of San Gabriel River, California. Letters A to M, inclusive, indicate points where measurements were made.

cent between the points mentioned. It is now proposed by another electric company, which has recently been incorporated, to make extensive diversions of the water of the various tributaries of the San Gabriel above the main forks, as indicated on the accompanying map (fig. 267), and to assemble the water, particularly from the North Fork and the main forks, above the point known as Doe Valley, from which place it would be dropped into the canyon of San Gabriel River with a head of approximately 2,000 feet. This new company claims that during the summer months the point of maximum flow on the San Gabriel recedes to higher elevations, particularly during times of drought, and that another large saving of water would result from the construction of these upper diversion lines.

The irrigators, who are admitted to be prior proprietors of this water, are, of course, deeply interested in these projects, and express doubt as to there being a greater quantity of water at the higher elevations, where it is proposed to make diversions. Investigations have been made to determine this question, and the table of measurements on page 478 was compiled for the irrigators for the purpose of making comparison. The table has been prepared covering the period from November, 1896, to September, 1897, inclusive, from data furnished by the power company in its application to the United States Land Office for right of way over the public domain. The measurements which were made in April, 1900, by the Board of Engineers were made for the irrigators. The summations shown have been prepared from these compilations by that board.

Referring to the table, under "Flow of all tributaries near possible upper diversion" are included all of the branches of the stream, a portion of which it is admitted will not be diverted. The "Total flow of main river at mouth of canyon" gives the volume of water determined at the gaging station of the United States Geological Survey during the period in question. The last line of the table shows either the gain or the loss between the three diversions now proposed and the mouth of the canyon. The measurements in 1896 and 1897 at the upper points were usually weir measurements, and no extended effort was made to gage floods at upper diversion points. These floods were all gaged at the gaging station of the United States Geological Survey, and consequently were included in the determination of means for the months of January to June, 1897, for that lower gaging station. These floods could not be measured on the weirs at the higher points, and consequently the table indicates a greater difference during the winter months between the points in question than really existed. It is claimed by the power company that midsummer measurements in dry years show a relatively greater amount of water at the higher points than is indicated by the table.

Comparative statement of volumes of water at or near certain proposed upper diversion points and at mouth of San Gabriel Canyon, based on measurements by F. C. Finkle, except as indicated.

[Mean discharge in cubic feet per second.]

	1896. November.	1896. December.	1897. January.	1897. February.	1897. March.	1897. April.	1897. May.	1897. June.	1897. July.	1897. August.	1897. September.	April, 1900 (Board of Engineers). *a*
Main river above Iron Fork	7.7	7.4	28.4	42.0	52.1	27.9	24.7	25.4	17.8	16.4	16.5	5.76
Iron Fork at mouth..........	5.6	3.0	10.1	18.3	18.9	10.2	8.9	7.7	8.6	3.9	4.1	1.69
North Fork at Sycamore flat..	3.7	3.6	10.8	17.0	19.4	13.8	11.2	7.1	5.9	4.1	3.9	1.43
Total	17.0	14.0	49.3	77.3	90.4	51.9	44.8	40.2	32.3	24.4	24.5	8.88
Coldwater Canyon............	4.1	4.2	11.3	19.1	17.8	11.3	9.8	8.3	6.5	5.1	5.0	1.46
West Fork above Bear Creek	....	....	....	....	....	....	....	....	....	....	....	1.80
Bear Creek	3.3	3.4	9.1	24.7	23.9	17.3	14.1	6.3	6.2	4.4	4.5	2.42
Cattle Canyon above Coldwater Canyon .	....	....	....	....	....	....	....	....	....	....	....	.32
Total	7.4	7.6	20.4	43.8	41.7	28.6	23.9	14.1	12.7	9.5	9.5	6.00
Flow of all tributaries near possible upper diversion	24.4	21.6	69.7	121.1	132.1	80.5	68.7	54.8	45.0	33.9	34.0	14.88
Total flow of main river at mouth of canyon *b*	19.2	21.90	57.9	344.8	465.6	294.4	145.0	67.8	38.1	26.4	20.7	*c*16.15
Gain or loss between three diversions now proposed and mouth of canyon............	+2.2	+7.9	....	....	....	....	....	....	+5.8	+2.0	*d*-3.8	+7.27

a All measurements in April, 1900, are by Board of Engineers.
b Measurements at mouth of canyon in 1896-97 are by United States Geological Survey.
c Mean. *d* Loss.

In explanation of the table it may be said that during the last seven years the rainfall in southern California has been below the normal. During the season 1896-97 there was approximately a year of average rainfall, but since then the precipitation has been but about 33 per cent of the mean annual. It is therefore probable that the lower elevations of the drainage basin, upon which lighter rainfall occurred than on the higher elevations, exhausted their water supply first and ceased to supply the stream in its course toward its outlet. Evaporation, in the meanwhile, going vigorously on along the entire course of the stream, may result in a diminished river at the mouth of the canyon. It will, however, be noted that in case of the diversion of a portion only of the tributaries, those remaining undiverted would be called upon to supply the water consumed in evaporation, and the salvage which might occur from a complete diversion would not necessarily occur from an incomplete diversion of the tributaries.

Estimated monthly discharge of San Gabriel River and canal at Azusa, California.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	33	15	23	1,414	0.104	0.120
February	28	20	22	1,244	0.102	0.106
March	40	18	26	1,623	0.119	0.137
April	28	16	21	1,262	0.096	0.107
May	17	12	14	842	0.062	0.071
June	22	5	10	565	0.043	0.048
July	4	3	4	221	0.016	0.018
August	6	4	5	295	0.022	0.025
September	6	3	4	220	0.019	0.021
October	26	4	11	683	0.050	0.058
November	24	10	14	847	0.064	0.071
December	39	16	20	1,247	0.091	0.105
The year	40	3	19	10,463	0.065	0.887

NOTE.—Discharge measurements for 1899 are given in Water-Supply and Irrigation Paper No. 39, pages 411 and 413; rating table, page 411.

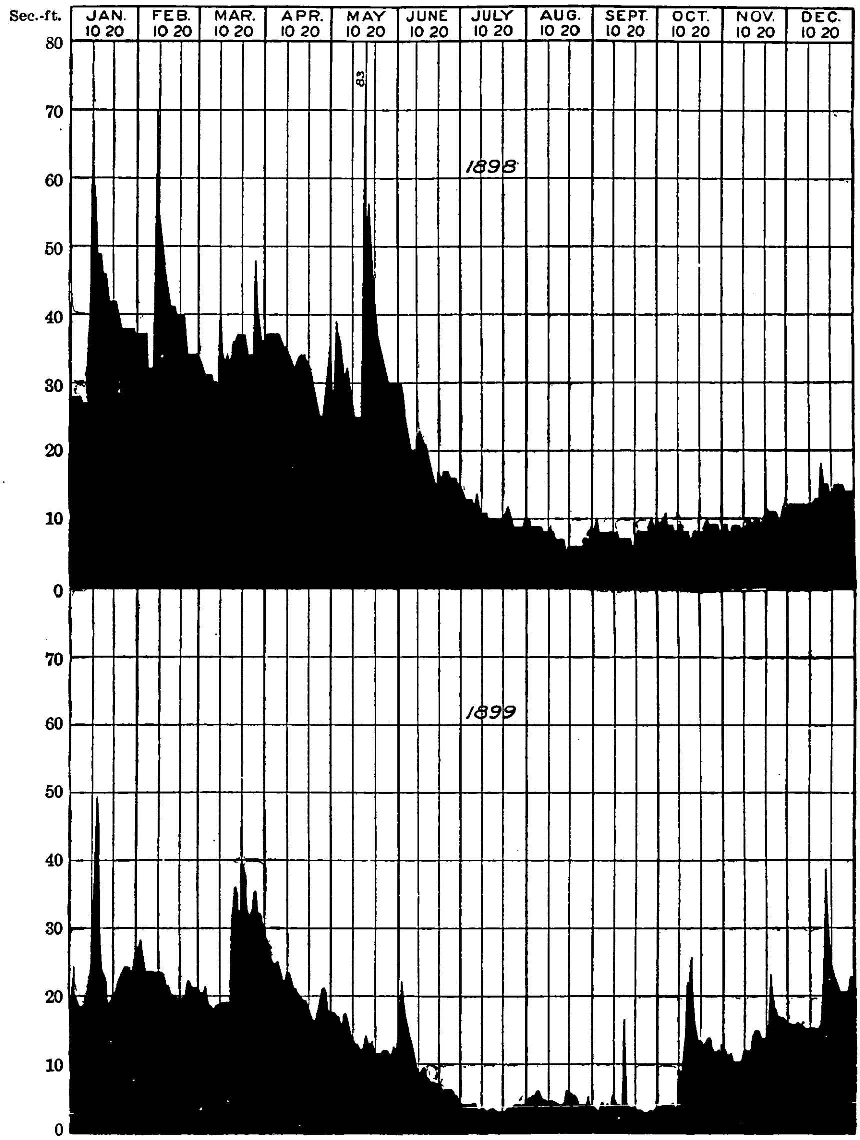


FIG. 268.—Discharge of San Gabriel River and canal at Azusa, California, 1898 and 1899.

SAN ANTONIO AND CUCAMONGA CREEKS.

San Antonio Creek drains 29 square miles of the southern face of the Sierra Madre, Cucamonga Creek having a much smaller drainage area. These streams are both important irrigation feeders for the valley land between Pomona and San Bernardino. On San Antonio Creek is an electric power development which is described in the Nineteenth Annual Report, Part IV, page 549. This creek furnishes the principal water supply for Pomona and Ontario. The course of the underground water from San Antonio Basin is not well defined, there being two outlets toward the sea, one directly tributary to the Santa Ana, passing by Chino, and the other passing west from Pomona down the San Jose Wash. Artesian water is found in the latter locality between Pomona and Spadra, also on the lower lands near Chino. The water of Cucamonga Creek is used at Ontario and Cucamonga. Low-water measurements of these streams for 1898 are given on page 196 of Water-Supply and Irrigation Paper No. 28, and those for 1899 in Water-Supply Paper No. 39, page 434.

LYTLE CREEK.

This creek rises on the northern and eastern slopes of San Antonio Peak, draining the eastern end of the Sierra Madre in San Bernardino County. As on other streams of the Sierra Madre, the grades are very steep, and consequently the possibilities of water storage are limited. The grade of Lytle Creek averages nearly 200 feet to the mile through its main canyon. The Anglo-American Canaigre Company has planned the construction of expensive dams on this stream, for storing storm waters, but they have not yet been built. The area of this drainage basin above sec. 8, T. 1 N., R. 5 W., is 54 square miles, as determined by the State engineers. The water from this stream, to the extent of 2 cubic feet per second, is used for the water supply of the city of San Bernardino, the remaining portion of the stream being diverted, during at least nine months of the year, for irrigation near Rialto and Colton. The water from Lytle Creek is exceedingly valuable, as the lands irrigated produce citrus fruits of a high order. A number of power development plants are contemplated for this stream, but none have yet been constructed. Placer mining is carried on in a desultory way, auriferous gravel being found in the higher portion of the drainage basin on top of many of the ridges and peaks. Numerous irrigation works, elaborate in detail but not large in capacity, are used to distribute the water.

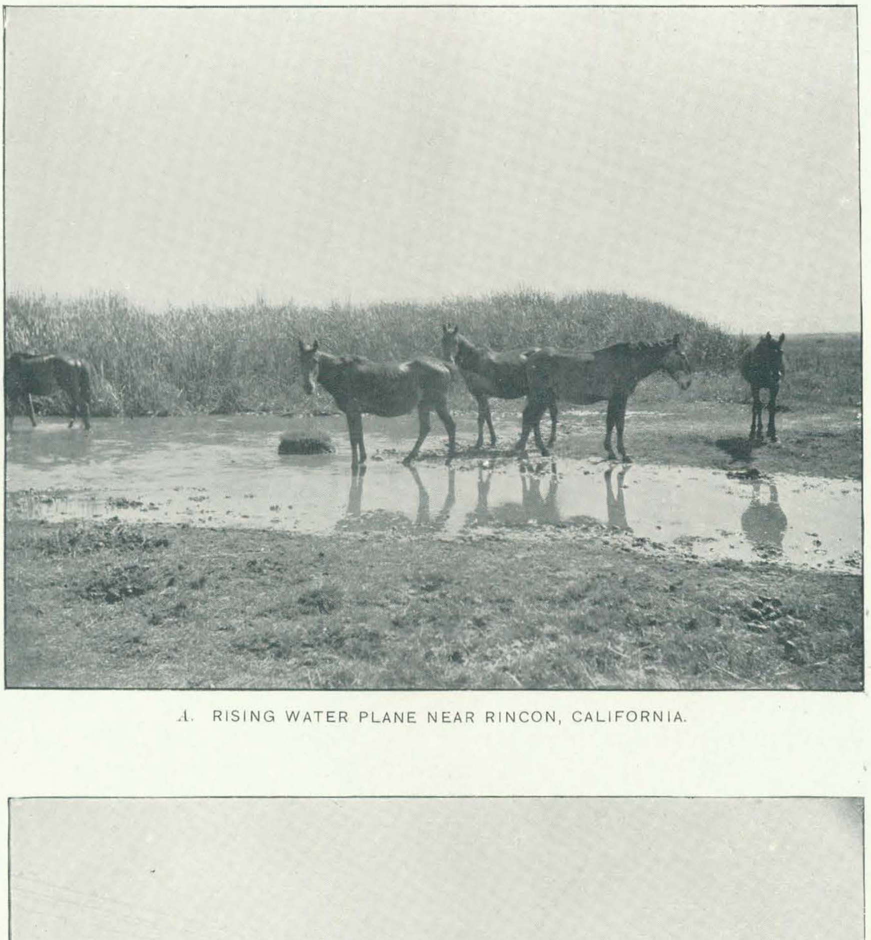
In the case of Lytle Creek, as with other streams entering the San Bernardino and San Gabriel valleys, a large delta of sand and gravel is built up at the mouth of the canyon, which is charged by the winter floods and which absorbs readily the water which is applied thereon for irrigation. Part of this underground water returns above Colton and part of it below that place, producing artesian water in the district immediately west of the city of San Bernardino and in the neighborhood of Colton. It mingles its underflow with the drainage from the eastern portion of San Bernardino Valley. There is a clay dike on the western bank of the wash, extending from a point 2½ miles west of San Bernardino, passing in a southeasterly direction through a hill known as Bunker Hill. At a point approximately 2 miles east of

Colton this dike is cut by the main drainage line of Santa Ana River, and it is near this point that the water for Riverside is obtained. A number of measurements of this underflow of Lytle Creek and of Santa Ana River are given in the list of sundry miscellaneous discharge measurements of streams in San Bernardino Valley, published in Water-Supply and Irrigation Paper No. 39, pages 423 to 425. The aggregate amount of underground water obtained from the gravel beds and washes of Lytle Creek on June 10, 1898, was 19 cubic feet per second, while on September 21 it was 14 cubic feet per second.

An interesting feature in connection with the discharge of these drainage basins is the wide range in run-off per square mile of San Gabriel River, Lytle Creek, and Cajon Pass Creek. The discharge of the San Gabriel during the summer of 1898, from 222 square miles of drainage basin, was as low as 3 cubic feet per second, while in the case of Lytle Creek it never fell below 5.41 cubic feet per second from a drainage basin of 54 square miles. The discharge of Cajon Pass Creek, adjoining the basin of Lytle Creek on the east, fell as low as 1 cubic foot per second from 78 square miles of drainage. This is explained by the fact that the storms approaching from the southwest give their heaviest precipitation just beyond the crest of the range—within 2 or 3 miles of it—and that after passing beyond this point the rainfall rapidly decreases as the lower elevations to the north are passed over. The San Gabriel is exposed to approaching storms, while Lytle Creek drains the region of heaviest rainfall, and Cajon Pass Creek is in the zone of decreased precipitation. There is little timber or brush in the basin of the latter creek, while the basins of the other creeks are timbered. Cajon Pass Creek is subject to violent floods.

Numerous measurements of Lytle Creek between the years 1892 and 1899 are given on pages 413 to 417 of Water-Supply Paper No. 39.

The record of discharge measurements of Lytle Creek canals on the next page has been furnished by the Anglo-American Canaigre Company, J. H. Carruthers, manager.



A. RISING WATER PLANE NEAR RINCON, CALIFORNIA.

B. SANTA ANA RIVER BELOW RINCON, CALIFORNIA.

Estimated monthly discharge of Lytle Creek canals at intake.

[Drainage area, 54 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	16.07	11.07	11.90	732	0.220	0.25
February	12.60	11.29	11.74	650	0.216	0.23
March	15.29	10.37	12.23	750	0.226	0.26
April	12.55	8.47	10.83	643	0.200	0.22
May	11.78	8.98	9.81	603	0.181	0.21
June	12.20	6.39	8.14	482	0.150	0.17
July	10.02	5.41	7.06	437	0.131	0.15
August	12.60	8.68	11.76	726	0.218	0.25
September	16.68	10.29	14.30	851	0.265	0.30
October	72.14	9.85	13.30	818	0.246	0.29
November	12.69	9.90	11.20	666	0.207	0.23
December	12.93	10.94	11.30	695	0.209	0.24
The year	72.14	5.41	11.10	8,053	0.205	2.80

SANTA ANA RIVER.

This river has its source on the southern slope of the San Bernardino Mountains and flows southerly, appearing from its canyon 4 miles east of Redlands. Its waters are completely used in San Bernardino Valley. At the lower part of the valley the water appears again in the vicinity of Rincon, where the river passes through a comparatively narrow gorge. The direction is then southwesterly. It empties into the Pacific Ocean. The station, established in June, 1896, is at Warmsprings, about 5 miles northeast of Mentone, California. Measurements are made under the direction of J. B. Lippincott. Pl. LIV, *A*, shows the rising water plane near Rincon, California. Pl. LIV, *B*, is a view of Santa Ana River below Rincon.

Low-water measurements in the summer of 1899, on lower portion of Santa Ana River, are given on pages 424, 427 to 428, and 436 of Water-Supply Paper No. 39.

Measurements of numerous canals deriving their water supply from rising water near San Bernardino and Colton are given on pages 423 and 425 of Water-Supply Paper No. 39.

Estimated monthly discharge of Santa Ana River at Warmsprings, California.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
January	34	22	26	1,593	0.138	0.159
February	34	27	27	1,516	0.145	0.151
March	48	24	32	1,949	0.168	0.194
April	34	22	25	1,458	0.130	0.145
May	27	19	22	1,365	0.118	0.136
June	34	19	22	1,315	0.118	0.132
July	29	19	22	1,371	0.119	0.137
August	19	11	13	782	0.068	0.078
September	12	10	12	690	0.062	0.069
October	19	12	17	1,015	0.088	0.101
November	49	17	21	1,268	0.113	0.126
December	36	18	23	1,427	0.123	0.142
The year	49	10	22	15,749	0.116	1.570

NOTE.—Gage heights, discharge measurements, and rating table are given in Water-Supply and Irrigation Paper No. 39, page 419.

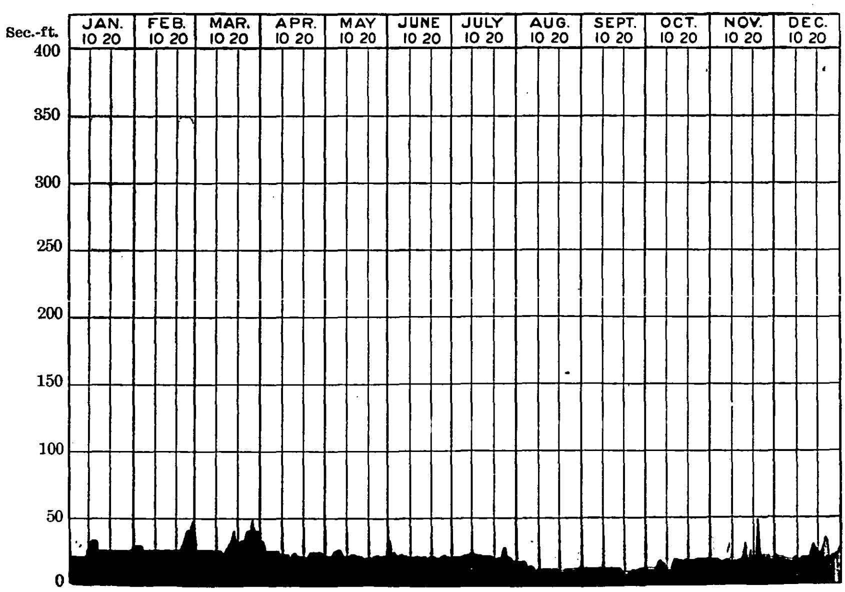


FIG. 269.—Discharge of Santa Ana River at Warmsprings, California, 1899.

MILL CREEK.

Mill Creek rises on the western slope of San Gorgonio Peak, which is the culmination of the San Bernardino Range and approximately 11,000 feet in elevation, and flows in a westerly direction into the extreme eastern end of San Bernardino Valley. The water from this stream passes through two conduits, and is used for the generation of electric power; a third conduit is under construction. Near the mouth of the canyon the water is diverted by the Crafton Water Company and used chiefly for irrigation in the high bench lands south of Redlands. The water, therefore, is used three times for the generation of power, and is finally applied for irrigation purposes on the most valuable citrus fruit lands in California. During the year 1899 the diversion has been practically completed. The water is measured by the Crafton Water Company over a weir near the intake of its canal system, and the records are obtained through Mr. Herbert Garstein, manager.

Estimated monthly discharge of Mill Creek canals at Crafton headworks.

[Drainage area, 47 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
February	13.0	11.0	11.6	644	0.25	0.26
March	16.0	10.0	12.2	750	0.26	0.30
April	13.0	11.0	11.8	702	0.25	0.28
May	12.0	10.0	11.2	689	0.23	0.26
June	17.0	4.0	8.7	518	0.19	0.21
July	7.2	4.8	5.8	357	0.12	0.14
August	7.2	2.9	5.8	357	0.12	0.14
September	5.7	2.0	4.1	244	0.09	0.10
October	8.5	4.3	6.5	400	0.14	0.16
November	11.2	6.1	8.6	512	0.18	0.20
December	14.6	5.3	9.5	584	0.20	0.23

SWEETWATER RIVER.

Sweetwater River rises on the western slope of the Coast Range, in San Diego County, California, and flows in a southwesterly direction into San Diego Bay. It is described in Bulletin 140 of the United States Geological Survey, pages 322 to 330. The record during the last three years is of special value, as it shows the extreme low run-off during the last cycle of dry years. The record is furnished by Mr. H. N. Savage, engineer of the San Diego Land and Town Company.

Estimated discharge of Sweetwater River at Sweetwater dam.

[Drainage area, 186 square miles.]

Season.	Rainfall in inches.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
				Second-feet per square mile.	Depth in inches.
1896-97	10.97	9.35	6,777.0	0.050	0.665
1897-98	7.05	0.006	4.3	0.000032	0.0005
1898-99	5.05	0.339	245.5	0.0018	0.025

SAN DIEGO RIVER.

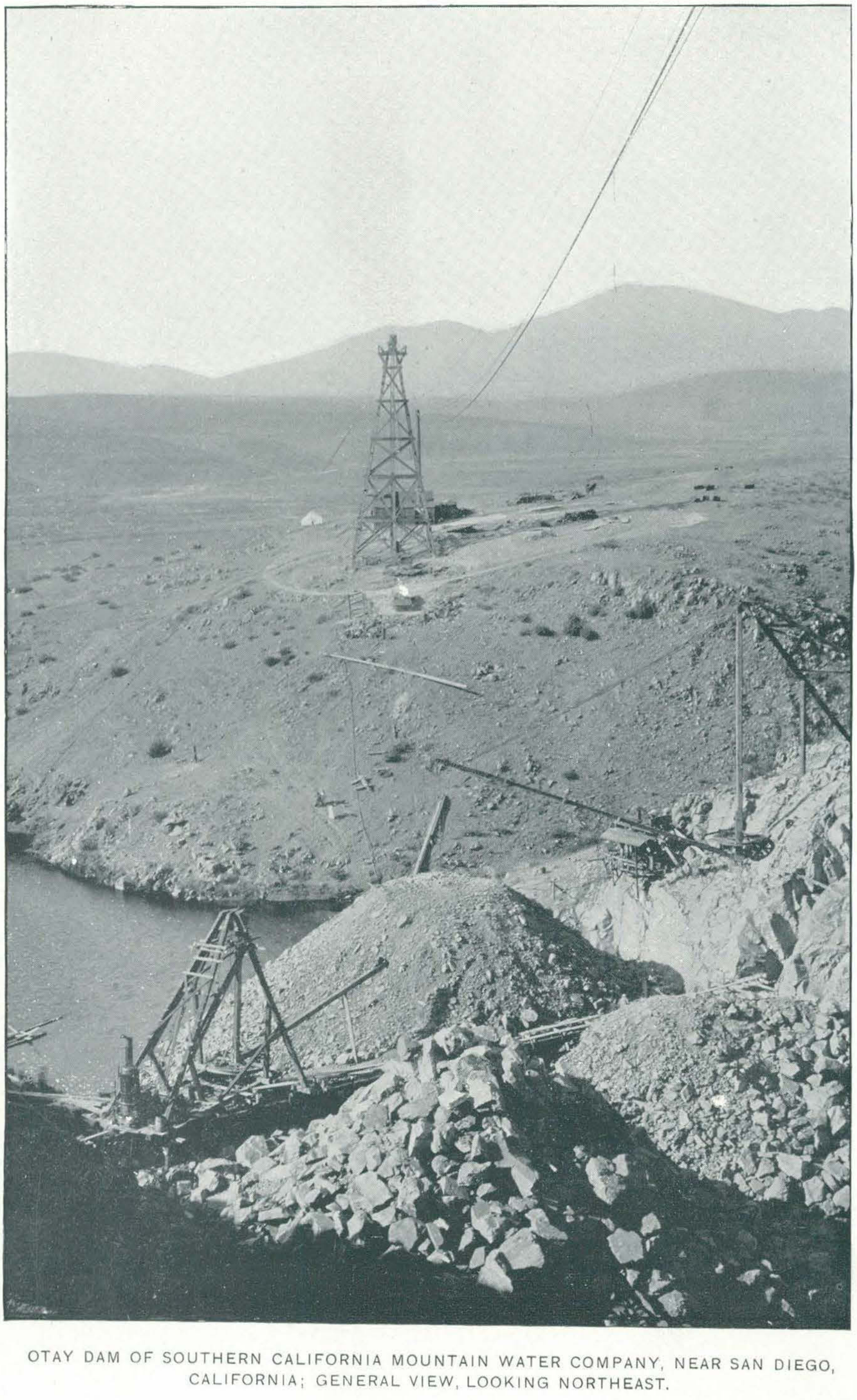
During the drought of 1899 the San Diego Water Company sunk a number of wells in the dry bed of San Diego River and pumped about 590,000,000 gallons of water. Mr. N. B. Livermore, the company's engineer, states that the capacity of the level land in the valley, on the basis of 40 per cent voids and 85 per cent of these available, is about 222,000,000 gallons per foot in depth. Bed rock approaches the surface in the gorge above the valley, which is very narrow, so that there is no opportunity for unlimited underground storage. There is very little underflow in the gorge, or it would be shown at the old Mission dam, which is practically on bed rock. The available water, therefore, is that stored in the sands of the valley, and possibly in the region underlying the mesas on each side.

The only test wells for observing changes in ground-water level were those situated at the various pumping plants. The height of water in these at the beginning of the season is not a matter of record. The level at two of the plants was certainly not reduced more than 1.5 feet, and it is safe to assume that the average ground-water level was not reduced more than 2 feet. A basis of 222,000,000 gallons per foot of depth would account for only 444,000,000 gallons, instead of 590,000,000 gallons, the amount actually pumped. From this it is assumed that the areas under the mesas along the valley are probably furnishing water which helps to maintain the supply in the river valley.

There was only one notable rain during 1899. It caused a flood which covered the sands of the river bed with about 0.3 inch of fine and impervious silt. The water in the test wells was raised about 1 foot, but soon subsided, as the water table became more nearly level.

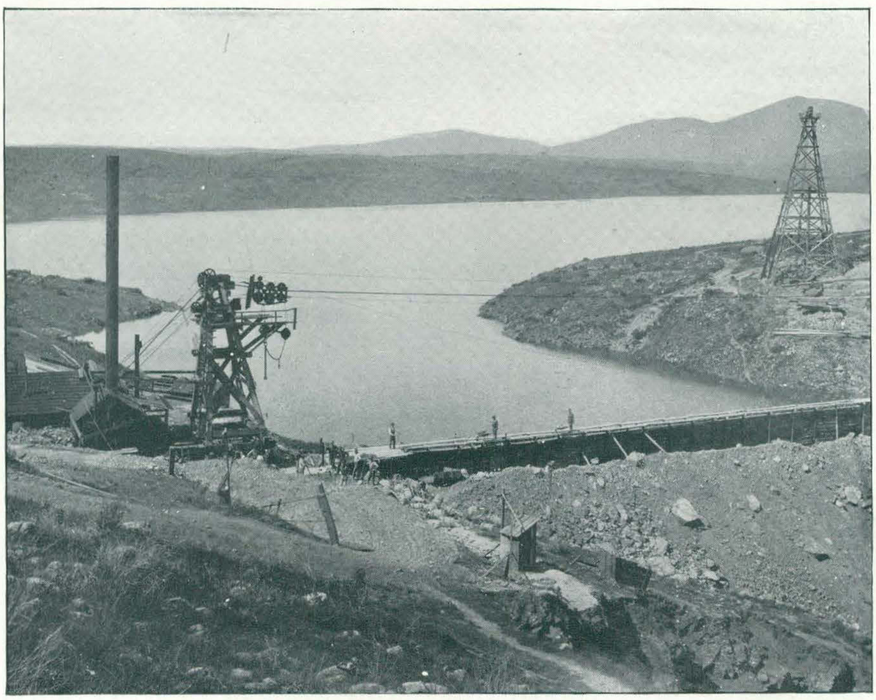
A. MORENA RESERVOIR SITE, NEAR SAN DIEGO, CALIFORNIA.

B. EXPLOSION AT MORENA DAM SITE; 200,000 TONS OF ROCK DISPLACED.



OTAY DAM OF SOUTHERN CALIFORNIA MOUNTAIN WATER COMPANY, NEAR SAN DIEGO, CALIFORNIA; GENERAL VIEW, LOOKING NORTHEAST.

A. OTAY DAM, SHOWING METHOD OF PROTECTING STEEL PLATE.



B. OTAY LAKE, SHOWING SOUTHEAST END OF OTAY DAM.

Two interesting dams in southern California, the construction of which has been delayed by legal complications, are the Otay rock-fill, steel-core dam, located about 20 miles southeast of San Diego, California, about 10 miles back from the coast on Otay Creek, and the Morena rock-fill dam on Cottonwood Creek, tributary of Tia Juana River, about 50 miles from San Diego. These dams, built by the Southern California Mountain Water Company, are designed to store water for irrigation and domestic supply for the city of San Diego and for Coronado Beach and the region south and east of the head of the Bay of San Diego. The Morena dam is at an elevation of 3,100 feet above sea level, on the brink of a precipitous fall or cataract, the stream descending 1,500 feet within a mile, and having eroded a very narrow, deep gorge in the rock back of the brink. Pl. LV, *A*, is a view of the Morena reservoir site. Pl. LVI is a general view of the Otay dam, looking northeast. Another view of this dam, showing the method of protecting steel plate, is shown in Pl. LVII, *A*. Pl. LVII, *B*, is a view of Otay Lake, the southeast end of the dam being shown in the foreground. Material for the construction of the Morena dam is obtained from quarries on each side and above the top of the embank-

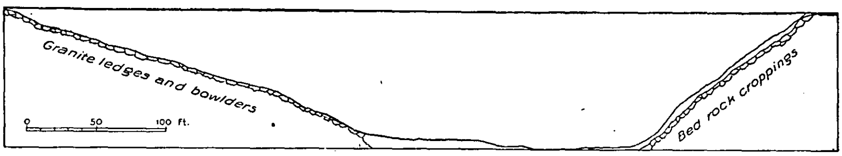


FIG. 270.—Section at site of proposed dam at Warners Valley, California.

ment, and is therefore handled with greater facility, much of it being thrown into place by the use of explosives. The first blast of 100,000 pounds of powder exploded December 26, 1896, and was reported to have moved 150,000 tons of rock. A later explosion displaced 200,000 tons of rock. Pl. LV, *B*, is of a picture taken at the time of the latter explosion.

A description of the Morena dam, by Mr. James D. Schuyler, was published in the Eighteenth Annual Report of this Survey, Part IV, page 640, also a view of the site before work was begun. It is proposed to allow the stored water to flow over the dam and down the natural channel of Cottonwood Creek for a distance of 8 miles, to what is known as the Barrett dam site, where it will be diverted from the Cottonwood Creek drainage through Dulzura Pass, by a conduit 12 miles in length, and dropped into the drainage lines leading to Otay Creek. It will then be caught in the lower Otay reservoir.

A description (also prepared by Mr. Schuyler) of the method of constructing the lower Otay dam was also published in the report mentioned. The inclusion of a central core of steel plates is, so far as known, the first attempt of the kind on a large scale. The height of the lower dam above the stream bed is 130 feet, and its total length 565 feet. Views illustrating the method of construction accompany Mr. Schuyler's report, and other views are published herein, notably Pl. LVII.

Throughout southern California reservoirs are one of the chief sources of water supply, and a careful search has been made for every location suitable for flood storage. One of the most notable of the projects now under consideration is that at what is known as Warners Valley. This is on the head waters of San Luis Rey River, a small stream flowing westerly into the Pacific Ocean. A few measurements of the flow of this river have been made, as noted in the Nineteenth Annual Report of this Survey, Part IV, page 432, and also in Water-

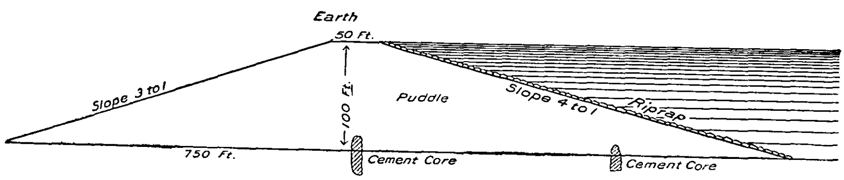


FIG. 271.—Section of proposed dam at Warners Valley, California.

Supply Paper No. 39, page 428. A survey of the dam site at the lower end of Warners Valley has been made by interested parties, and estimates have been prepared of the amount of water which can be stored. Fig. 270 (page 487) is a section of the site, and fig. 271 is a cross section of the proposed dam, which is to be of earth, 100 feet in height above the stream bed, 750 feet thick at the base, 50 feet thick on top, and to contain 377,000 cubic yards of earth. The water side is to be faced with rock and cement or asphalt, and a spillway is to be provided on the natural surface away from the dam. The cost has been estimated at $75,000. The elevation of the dam is given as 2,603 feet above tide. At a point 14 miles below the dam the water can be used for power purposes under a considerable head, the elevation of the irrigable lands being less than 900 feet.

PRELIMINARY DESCRIPTION

OF THE

GEOLOGY AND WATER RESOURCES OF THE SOUTHERN HALF OF THE BLACK HILLS AND ADJOINING REGIONS IN SOUTH DAKOTA AND WYOMING

BY

NELSON HORATIO DARTON

CONTENTS.

ILLUSTRATIONS.

PRELIMINARY DESCRIPTION OF THE GEOLOGY AND WATER RESOURCES OF THE SOUTHERN HALF OF THE BLACK HILLS AND ADJOINING REGIONS IN SOUTH DAKOTA AND WYOMING.

By Nelson Horatio Darton.

INTRODUCTORY.

This report is the result of studies made in the field mainly in the seasons of 1898 and 1899. It relates to an area of about 5,500 square miles situated in the southwestern corner of South Dakota and the adjoining portion of Wyoming. Its location and general surroundings are shown in Pl. LVIII. It covers the southern half of the Black Hills uplift and portions of the adjacent plains. The report describes the geology of the sedimentary rocks, their structure, history, and mineral resources, including underground water, coal, gypsum, grindstone, etc. It also contains information respecting surface waters available for irrigation and stock raising, timber, climate, and the history of the topographic development of the region. The crystalline rocks of the central portion of the Black Hills area are shown on some of the maps accompanying this report, but without differentation, as it was not practicable to study their geology; neither will their mineral resources be considered here.

I was assisted in the field work by Mr. C. A. Fisher in the season of 1898 and by Mr. George B. Richardson in the season of 1899, and these gentlemen obtained a portion of the data on which this report is based.

All those who study Black Hills geology must feel impressed by the remarkably clear general conception of relations afforded by the survey made by Mr. Henry Newton nearly a quarter of a century ago.[1] In one short season, with many unfavorable conditions for travel, he determined most of the broader features and recorded many of the essential details. His partly posthumous report, edited by Mr. G. K. Gilbert, will always remain a standard work on Black Hills geology. Later studies will add greatly to our knowledge of the details of the stratigraphy and structure, and of the distribution of rocks and minerals, will throw much light on age of beds, and afford means for a more complete

[1] Geology and Resources of the Black Hills of South Dakota, by Henry Newton and W. P. Jenney: U. S. Geog. and Geol. Survey of Rocky Mountain Region, J. W. Powell, Director.

elucidation of the geologic history, particularly of the physiographic development of the Black Hills.

TOPOGRAPHY.

Extending from the Mississippi River to the Rocky Mountains is the province known as the Great Plains. It presents broad areas of treeless, plane surfaces sloping upward to the west and traversed by wide, shallow valleys of rivers flowing to the east and south. The Black Hills rise out of these plains as a small group of forest-clad mountains several thousand feet high. With their vigorous vegetation, greater rainfall, and running water these hills are an oasis in the sur-

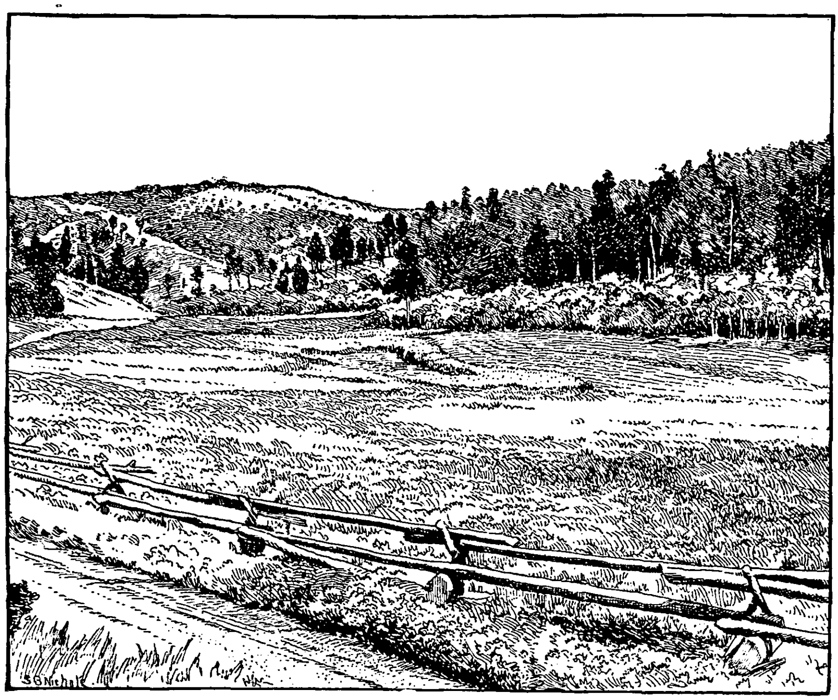
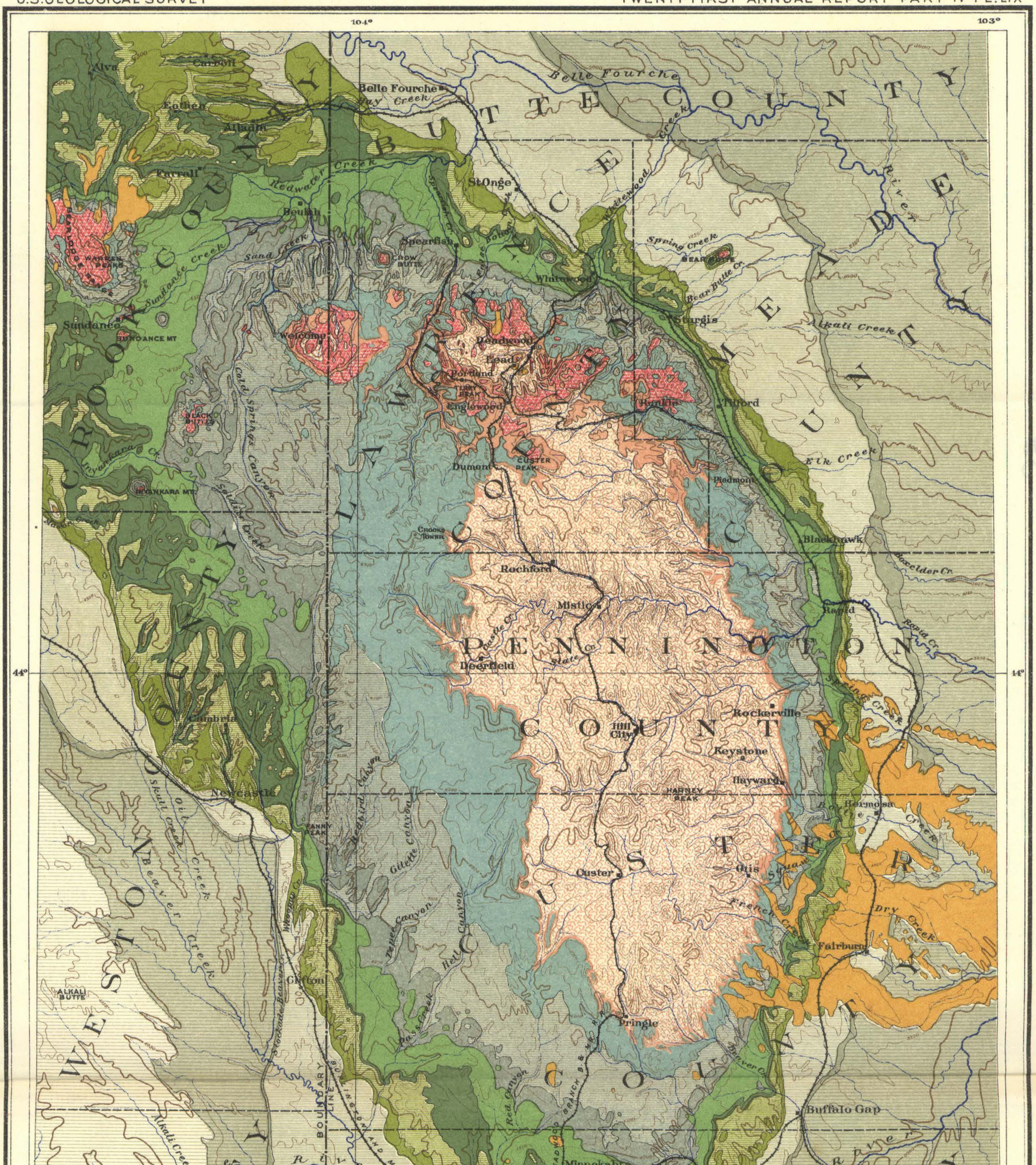


FIG. 272.—An open park north of Custer, South Dakota.

rounding semiarid plains. The length of the more elevated area is about 100 miles, and its greatest width is 50 miles. The hills rise abruptly from the plains, although the flanking ridges are of moderate elevation. The configuration of the greater part of the region is represented in Pl. LIX, and that of the southern half is shown on a larger scale in Pl. LXV. The salient features are the hogback ridges of the outer rim and the Red Valley beyond, both of which extend completely around the uplift; the limestone plateau, with its infacing escarpment; and the central area of high ridges culminating in the rough mountain crags of Harney Peak at an altitude of 7,216



PRELIMINARY GEOLOGIC MAP OF THE BLACK HILLS
WITH ADJOINING PORTIONS OF SOUTH DAKOTA, WYOMING AND NEBRASKA

BY
N. H. DARTON
1899

DATA FOR 450 SQUARE MILES ABOUT DEADWOOD BY T. A. JAGGAR JR.
DATA ABOUT RAPID BY C. C. O'HARRA.

BASE COMPILED FROM MAPS OF U.S. GEOLOGICAL SURVEY
U.S. LAND OFFICE, AND ORIGINAL SURVEYS

SCALE
5 0 5 10 15 20 MILES

CONTOUR INTERVAL 250 FEET

EXPLANATION

TERTIARY
- Arikaree formation
- White River group (Chadron, Brule and Gering formations)

CRETACEOUS
- Laramie and Fox Hills formations
- Pierre shale
- Niobrara formation
- Benton group
- Dakota sandstone (and Fuson formation)
- Lakota sandstone (and Minnewasta limestone)

JURATRIAS
- JURASSIC: Sundance formation Beulah shale and Unkpapa Sandstone
- TRIASSIC: Spearfish formation

CARBONIFEROUS
- PERMIAN: Minnekahta limestone (and Opeche formation)
- Minnelusa formation
- Pahasapa limestone (and Englewood limestone)

CAMBRIAN
- Deadwood formation

ALGONKIAN
- Schists, Granite etc.

EOCENE
- Igneous

feet. All of the southern portions of the region are drained by the South Fork of Cheyenne River.

The central area.—The central area of the Black Hills comprises an elevated basin with scattered rocky ridges and groups of mountains interspersed with wide valleys or parks. These wide valleys are in the divides at the heads of canyons of greater or less size, which become deeper and steeper sided as the waters which they carry increase in volume. The region is one of crystalline schists and granite. Some typical and picturesque features of the area are shown in Pls. LX–LXII. The group of mountains culminating in Harney Peak is completely isolated by valleys, of which the highest is in the divide in a low saddle north of Custer, at an altitude of 5,800 feet. About Custer

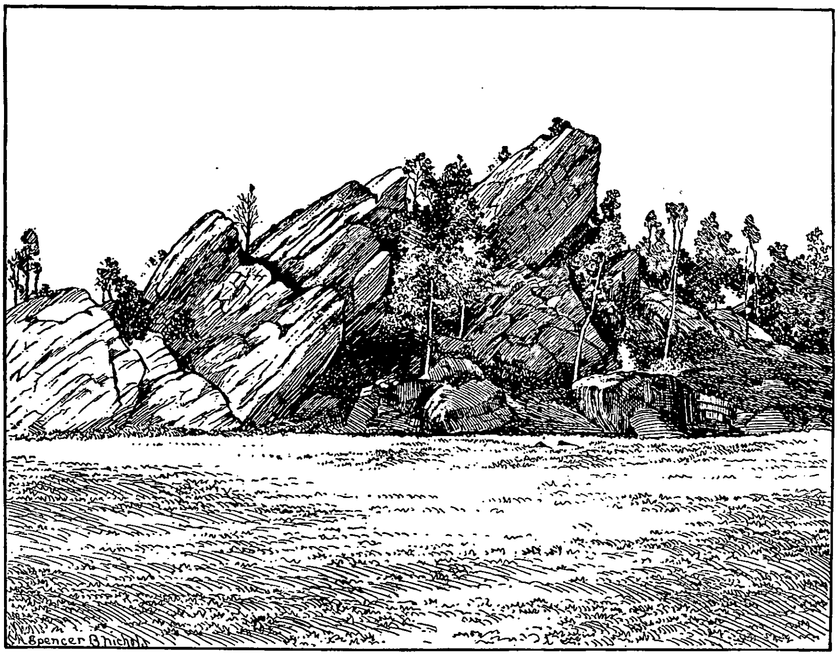


FIG. 273.—Ridge of schist rising out of a park near Custer, South Dakota.

there is a wide area of rolling park land, out of which rise steep, rocky ridges of various sizes and heights. Characteristic views of these features are given in figs. 272 and 273. Many streams head in the central basin and flow out of the hills to the northeast, east, and south. French Creek is here the dominant stream of the system.

The limestone plateau.—The limestone plateau, with its infacing escarpment, occupies a wide area of the central hills, rising high above the greater part of the nucleal area of crystalline rocks. To the west it has a very broad, flat surface, level near its inner margin, but toward its outer side sloping gently downward. On the western side of the crystalline-rock area its escarpment is a line of high cliffs presented to the east and trending nearly due north and south for many miles. It is occasionally notched more or less deeply by upper branches of streams which head on the plateau and cross the central basin. A typical view of this escarpment is shown in fig. 274. The cliffs and steep slopes which they surmount often rise 800 feet above the central basin, and the summits of the plateau attain an altitude of over 7,000 feet in Pennington County, several points being almost as high as the summit of Harney Peak. This limestone plateau is the main divide for the drainage of the Black Hills. On its western slope are head branches of affluents of Beaver Creek to the southwest and of the Belle Fourche to the northwest. Toward their heads the valleys on the plateau are

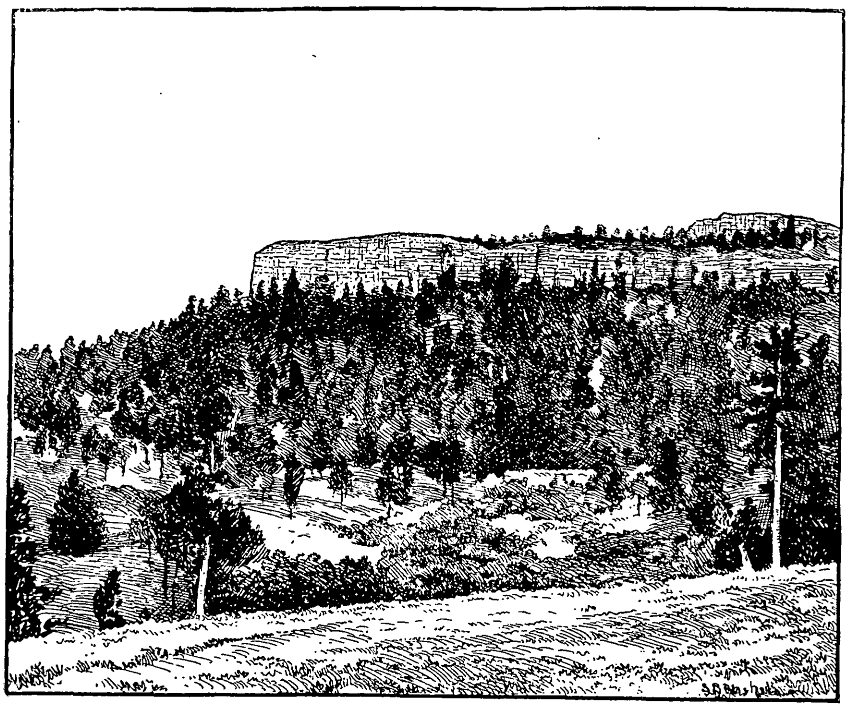
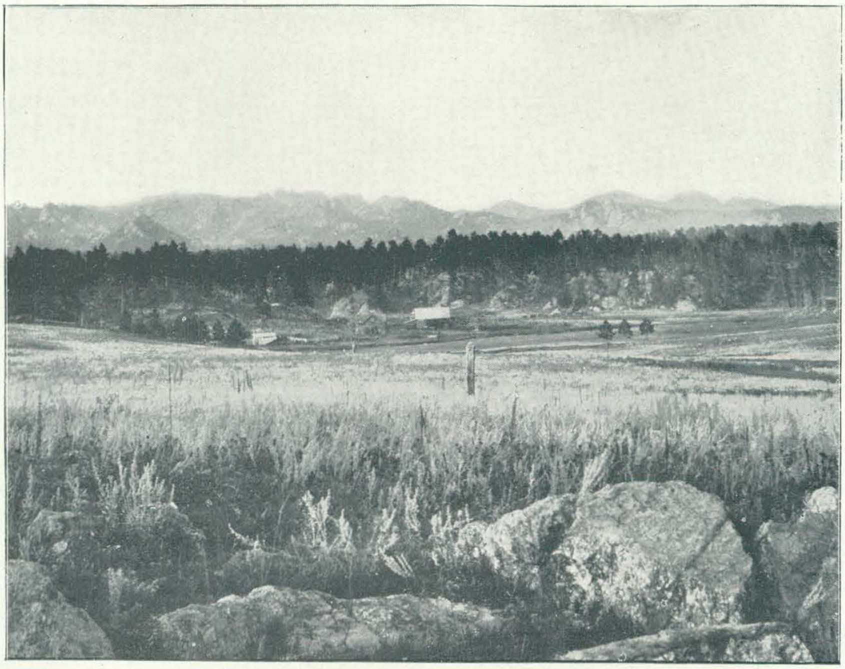


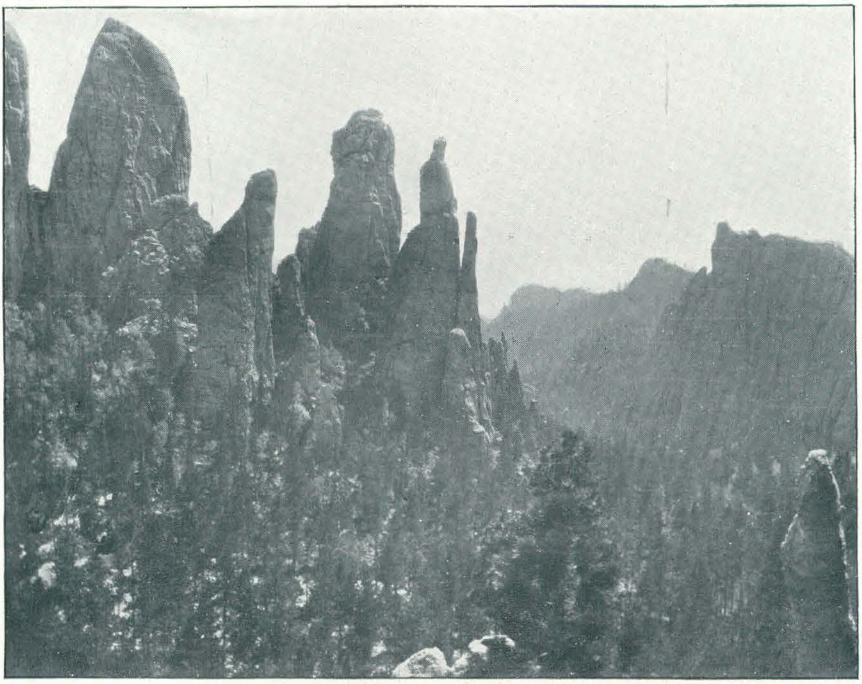
FIG. 274.—Limestone cliffs at the eastern edge of the high plateau northwest of Custer, South Dakota.

open parks, but farther down they merge into deep canyons having precipitous walls of limestone. Hell Canyon is the most notable of these, its walls being 400 feet high in places. To the south the limestone plateau and its escarpment swing around to the east side of the hills, where, owing to the steeper dip of the limestone, the plateau narrows into a sloping ridge with a west-facing escarpment which is broken by numerous cross valleys, beginning with the head branches of Red Canyon Creek. All of the larger streams in the southeastern and eastern portion of this region rise in the high limestone plateau west of the central basin, cross the region of crystalline rocks, and flow through canyons in the flanking regions of the east side of the Black Hills to reach Cheyenne River in the Plains beyond. The principal members



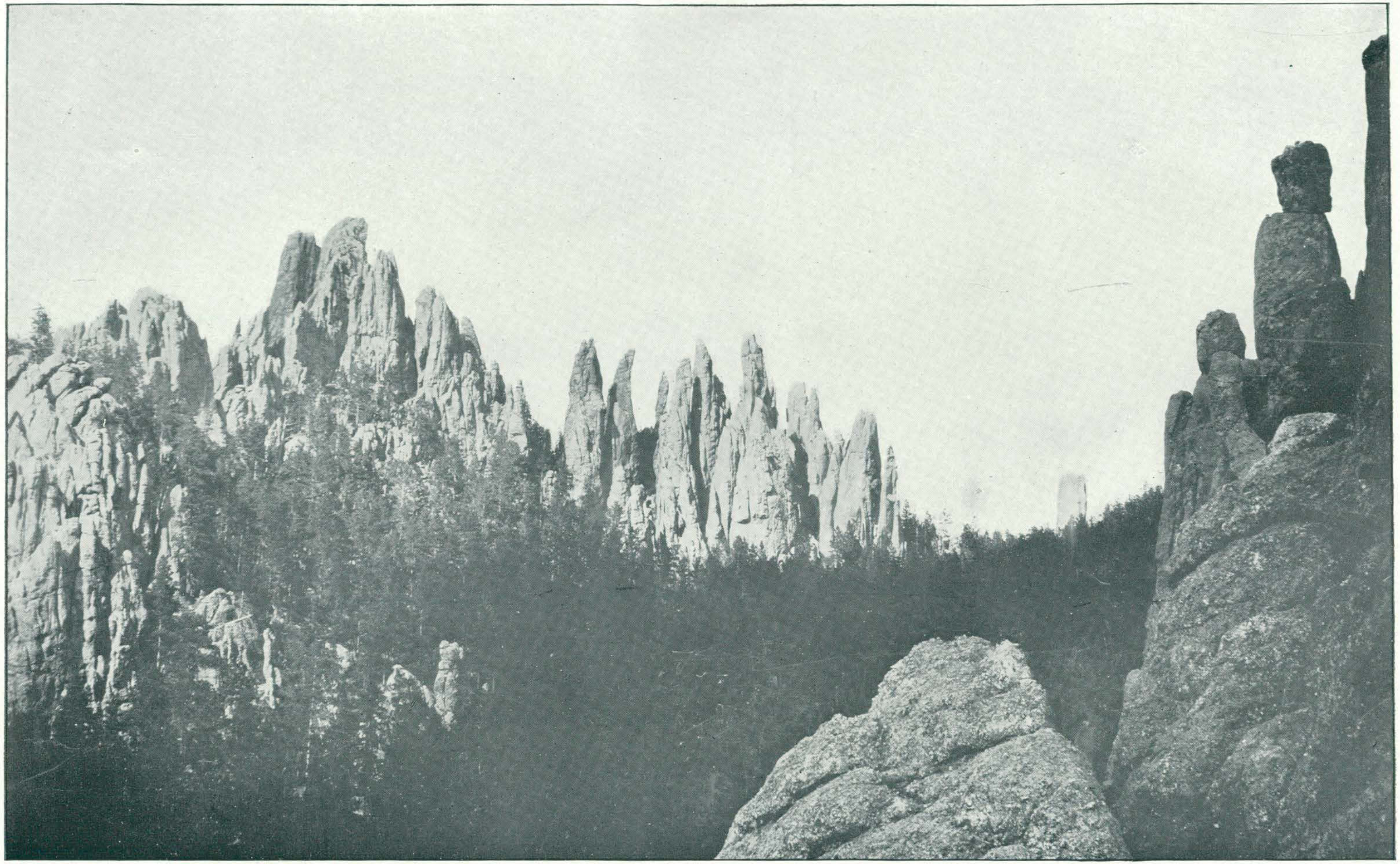
A. HARNEY PEAK RANGE FROM THE SOUTH; TYPICAL "PARK" IN MIDDLE GROUND.

B. SYLVAN LAKE FROM THE SOUTH, SHOWING GRANITE TOPOGRAPHY NEAR HARNEY PEAK.



A. GRANITE NEEDLES SOUTH OF HARNEY PEAK.

B. HARNEY PEAK FROM THE SOUTH, SHOWING TYPICAL GRANITE TOPOGRAPHY.



GRANITE NEEDLES NEAR HARNEY PEAK.

of this drainage system are Red Canyon, Beaver, French, and Spring creeks. Battle Creek and its branches rise on the eastern slope of the Harney Peak Range. A typical canyon through the eastern limestone range is shown in Pl. LXIII.

The limestone plateau has its descending slope outward all around the hills, but this declivity always bears a low but sharp infacing escarpment of Minnekahta limestone from 40 to 50 feet high, surmounted by a bare rocky slope descending several hundred feet into the Red Valley. This minor escarpment and slope is usually sharply notched by the canyons which cross it, giving rise in each stream to a constriction, or "gate," beyond which the canyon opens widely into the Red Valley.

The Red Valley.—The Red Valley is a wide depression that extends more or less continuously around the hills, with long, high limestone slopes on the inner side and the steep hogback ridge on the outer side. It is one of the most conspicuous features of the region, owing in no small degree to the red color of its soil and the absence of trees, the main forest of the Black Hills ending at the outer margin of the Minnekahta limestone. The Red Valley often has a width of 2 miles, but in the vicinity of Cascade and in a portion of the valley of Stockade Beaver Creek it is very much less. In the region west of Fairburn and Hermosa it is extensively choked with overlapping Tertiary deposits. The larger streams coming out of the hills generally cross the Red Valley without material deflection, but the divides are usually so low as to give the valley the appearance of being continuous.

The hogback range.—The hogback range constitutes the outer rim of the hills throughout. Ordinarily it is a single-crested ridge of hard sandstone, having the form shown in Pl. LXIV, but its prominence and slope vary greatly. Along the southern margin of the Black Hills north of Edgemont and in places north of Newcastle it is spread out into a long, sloping plateau. It nearly always presents a steep face toward the Red Valley, above which its crest line rises several hundred feet. On the outer side the slopes descend to the Plains, which extend far out from the hills in every direction. The hogback range is crossed by numerous valleys or canyons cutting it into short, level-topped ridges. At the southern point of the hills Cheyenne River has cut a tortuous valley through the outer ridge for several miles.

The Plains.—In the Plains, which stretch away from the hills on all sides, the topography usually presents a vast, monotonous expanse of gently undulating prairie, with long slopes leading into wide, shallow valleys. It is a region mainly underlain by shale, rarely containing any beds of harder materials. One very persistent feature adjoining the Black Hills, which is particularly prominent in the region from near the mouth of Stockade Beaver Creek to Fairburn, is a low but characteristic escarpment due to a limestone layer in the shale series. It rises about 4 or 5 miles from the slope of the hogback range about

Edgemont, and about a mile from it near Buffalo Gap. Toward the hills it presents a steep slope or cliff 50 feet high. North of Fairburn and Hermosa it is generally buried under Tertiary deposits.

West of the Black Hills there is an east-facing escarpment of the Fox Hills sandstone which passes through central Weston and Converse counties, Wyoming. It usually presents steep slopes and cliffs rising from 100 to 250 feet above the valley to the east. From Newcastle to Argentine it lies from 12 to 15 miles from the hogback ridge of the hills, but to the south it bears off to the westward. Its surface presents features shown in fig. 278. In the region east of Fairburn and Oelrichs, and on Sage and Old Woman creeks in Converse County, Wyoming, the overlapping White River formation gives rise to bad lands of moderate extent having forms like those shown in Pl. LXXXIV, but on a much smaller scale.

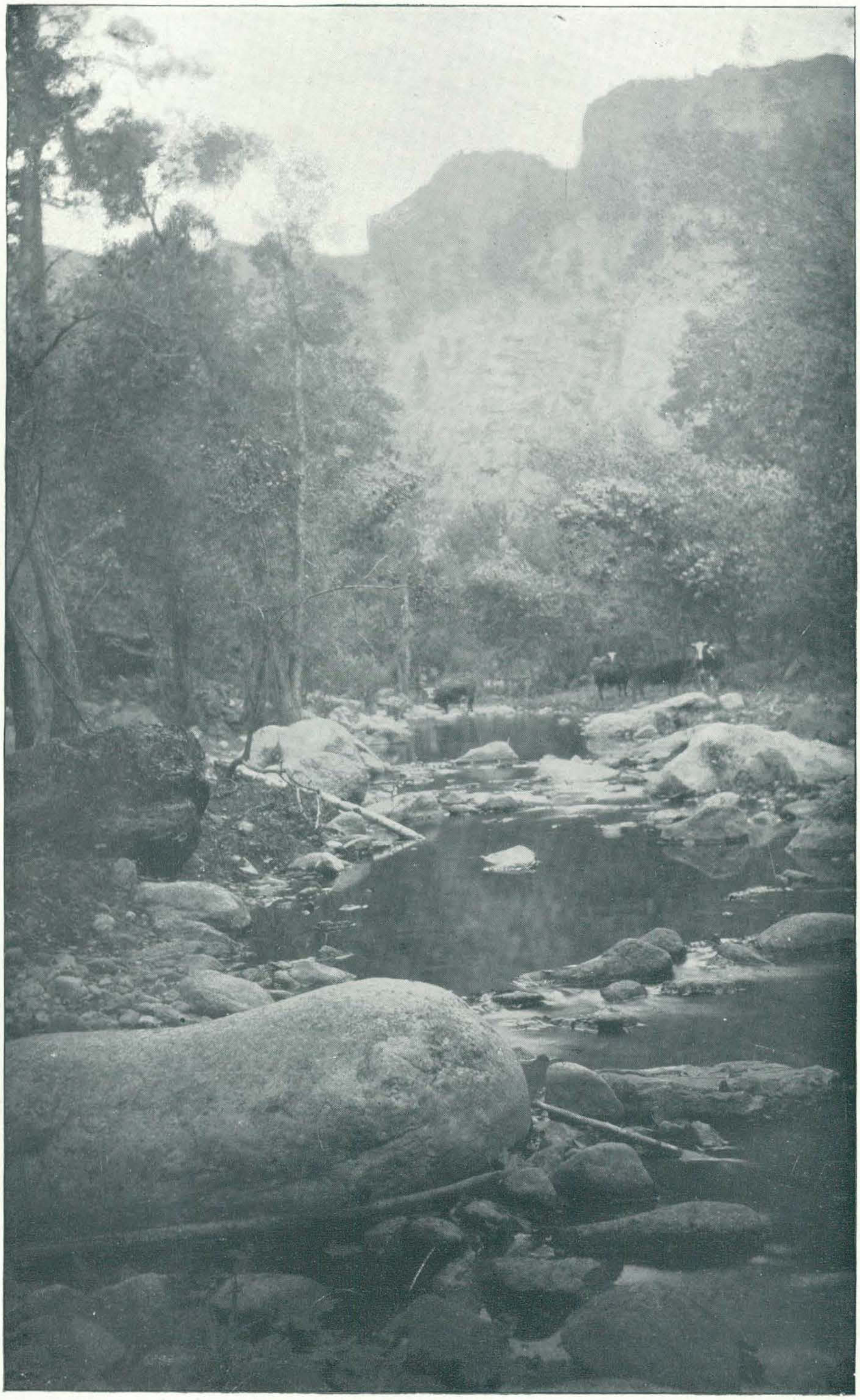
Pine Ridge.—In Pl. LIX is shown the relation of Pine Ridge to the Black Hills. It is a great escarpment marking the northern limit of the later Tertiary deposits which underlie the high plains extending far to the south through western Nebraska and Kansas. Properly speaking it is not a ridge but the eroded margin of a high plateau. It usually presents north-facing cliffs and slopes from 500 to 600 feet high.

GEOLOGY.

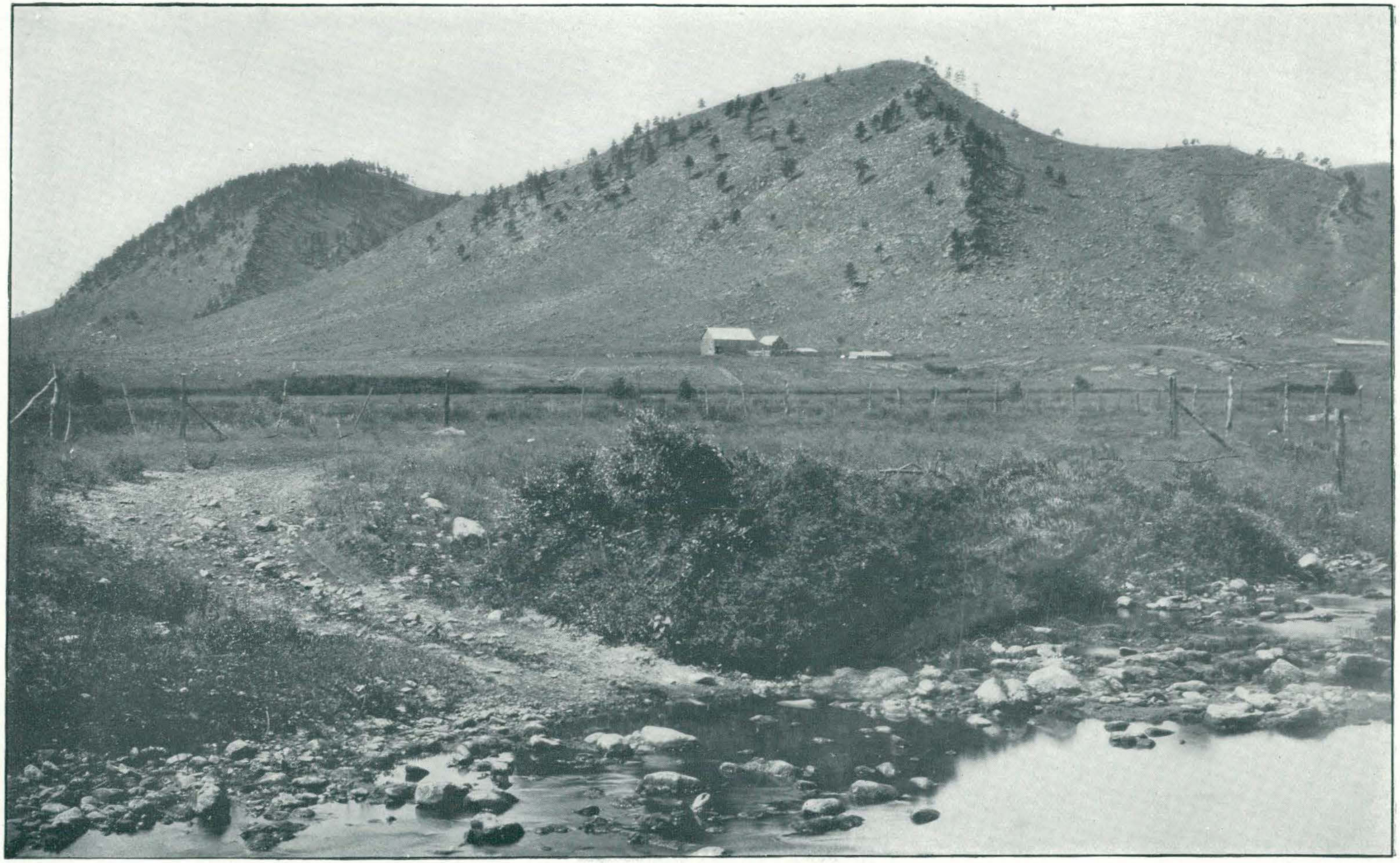
STRATIGRAPHY.

GENERAL RELATIONS.

The Black Hills uplift is an irregular dome-shaped anticline, embracing in its more obvious features an oval area 125 miles in length and 60 miles in breadth, with its larger dimension lying nearly northwest and southeast. It is situated in a wide area of almost horizontal beds underlying the great east-sloping plain that extends from the Rocky Mountains to the Mississippi River. It has brought above the general surface level an area of pre-Cambrian crystalline rocks about which there is upturned a nearly complete sequence of the Paleozoic and Mesozoic rocks from Cambrian to Laramie, all dipping away from the central nucleus. There are also extensive overlaps of the Tertiary deposits, which underlie much of the adjoining plains area. The region is one of exceptionally fine exposures, which afford rare opportunity for a study of stratigraphic relations and variations. Many of the rocks are hard, and the streams flowing out of the central mountain area have cut canyons and gorges, in the walls of which the formations are often extensively exhibited. The structure presented locally is that of a monocline dipping toward the plains. The oldest sedimentary rocks constitute the escarpment facing the crystalline rock area, and each higher stratum passes beneath a newer one in regular succession outward toward the margin of the uplift. In Pl. LXXXVIII



LIMESTONE WALLS OF FRENCH CREEK CANYON WEST OF FAIRBURN, SOUTH DAKOTA.



TYPICAL HOGBACKS OF DAKOTA SANDSTONE AT BUFFALO GAP, LOOKING SOUTHWEST.

there are given cross sections showing the general relations of the formations. In this illustration it will be seen that the sedimentary formations consist of a series of thick sheets of sandstones, limestones, and shales, all essentially conformable in structure. The overlapping areas of the Tertiary deposits extend across the edges of the older formations. The stratigraphy presents many features of similarity to the succession of rocks in the Rocky Mountains of Colorado and Wyoming, but it possesses numerous distinctive local features.

The following is a list of the formations which are exhibited in the uplift, with a generalized statement as to the thickness, characteristics, and age:

Generalized section in the Black Hills region.

Formation.	Character.	Average thickness.	Age.
		Feet.	
Laramie	Massive sandstone and shale.	2,500	Cretaceous.
Fox Hills	Sandstone and shale	250–500	Do.
Pierre shale	Dark-gray shale	1,200	Do.
Niobrara	Chalk and calcareous shale.	225	Do.
Benton group:			
Carlile formation	Gray shales with thin sandstones, limestones, and concretionary layers.	500–750	Do.
Greenhorn limestone	Impure slabby limestone	50	Do.
Graneros shale	Dark shale with lenses of massive sandstone in its lower part at some places.	900	Do.
Dakota sandstone	Massive buff sandstone.	35–150	Do.
Fuson	Very fine-grained sandstone and massive shales. White to purple color.	30–100	Do.
Minnewaste limestone.	Gray limestone	0–30	Do.
Lakota	Massive buff sandstone, with some intercalated shale.	200–350	Do.
Beulah shale	Pale grayish-green shale.	0–150	Jurassic.
Unkpapa sandstone	Massive sandstone; white, purple, red, buff.	0–250	Do.
Sundance	Dark-drab shales and buff sandstones; massive red sandstone at base.	60–400	Do.
Spearfish	Red sandy shales with gypsum bed.	350–500	Triassic.
Minnekahta limestone.	Thin-bedded gray limestone.	30–50	Permian.

Generalized section in the Black Hills region—Continued.

Formation.	Character.	Average thickness.	Age.
		Feet.	
Opeche	Red slabby sandstone and sandy shale.	90–130	Permian?
Minnelusa	Sandstones, mainly buff and red; in greater part calcareous. Some thin limestone included.	400–450	Carboniferous.
Pahasapa limestone	Massive, gray limestone.	250–500	Do.
Englewood limestone	Pink slabby limestone	25	Do.
Deadwood	Red-brown quartzite and sandstone, locally conglomeratic, partly massive.	4–150	Cambrian.

The principal features of stratigraphic variation in the region are shown in Pl. LXVI and fig. 275, where it will be seen that certain

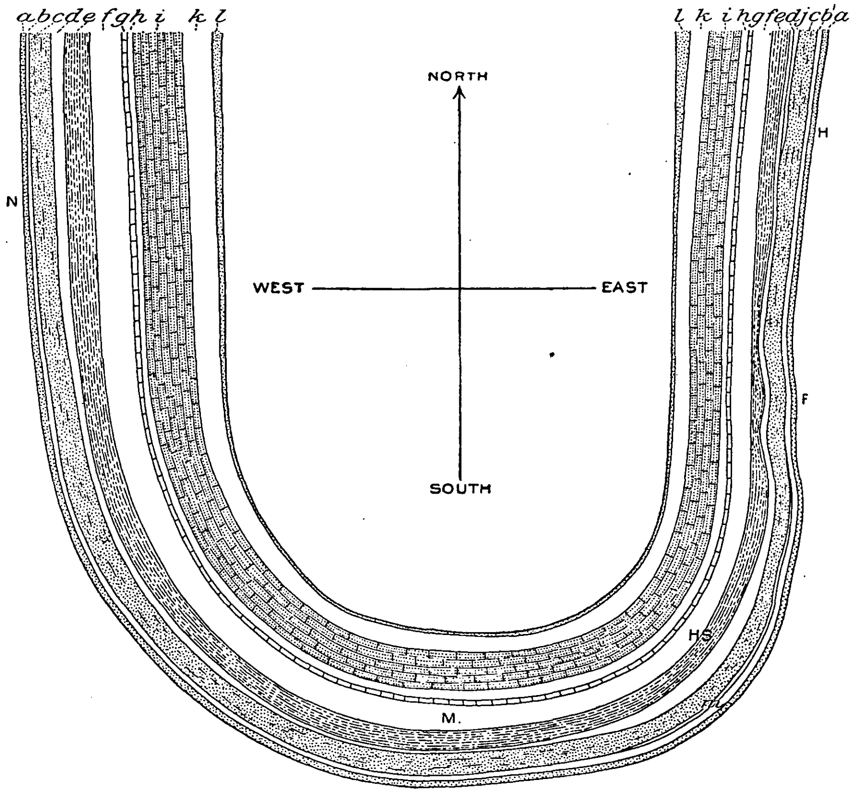
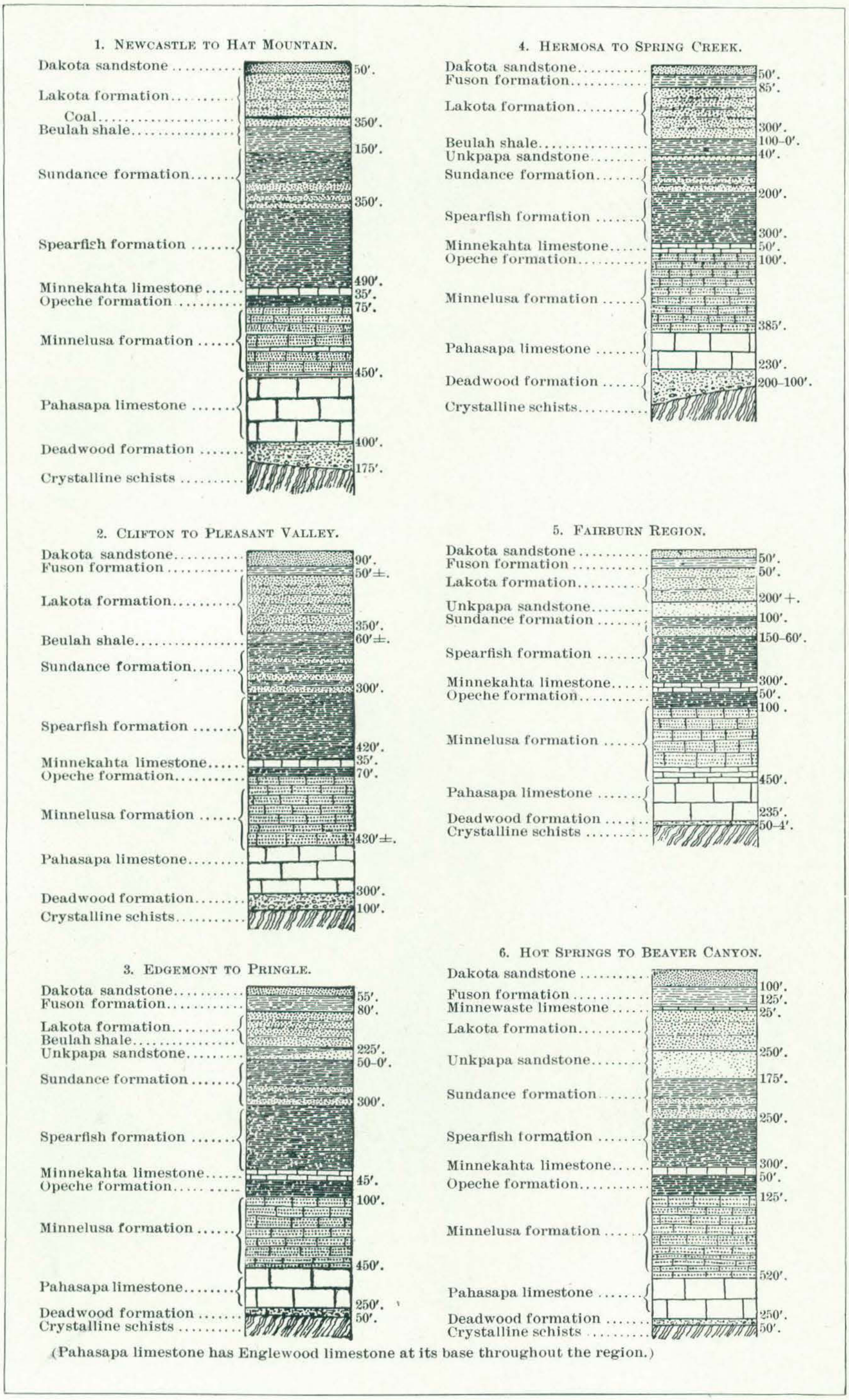


FIG. 275.—Diagram showing regional stratigraphic variations in the southern Black Hills, as exhibited along the outcrop zones. H, Hermosa; F, Fairburn; H S, Hot Springs; E, Edgemont; M, Minnekahta; N, Newcastle. *a*, Dakota sandstone; *b*, Fuson formation; *c*, Lakota formation; *d*, Beulah shale; *e*, Sundance formation; *f*, Spearfish red beds; *g*, Minnekahta limestone; *h*, Opeche red beds; *i*, Minnelusa formation; *k*, Pahasapa limestone; *l*, Deadwood sandstone; *m*, Minnewaste limestone.



COLUMNAR SECTIONS OF STRATIGRAPHIC FEATURES OF SOUTHERN BLACK HILLS.

By N. H Darton, 1899.

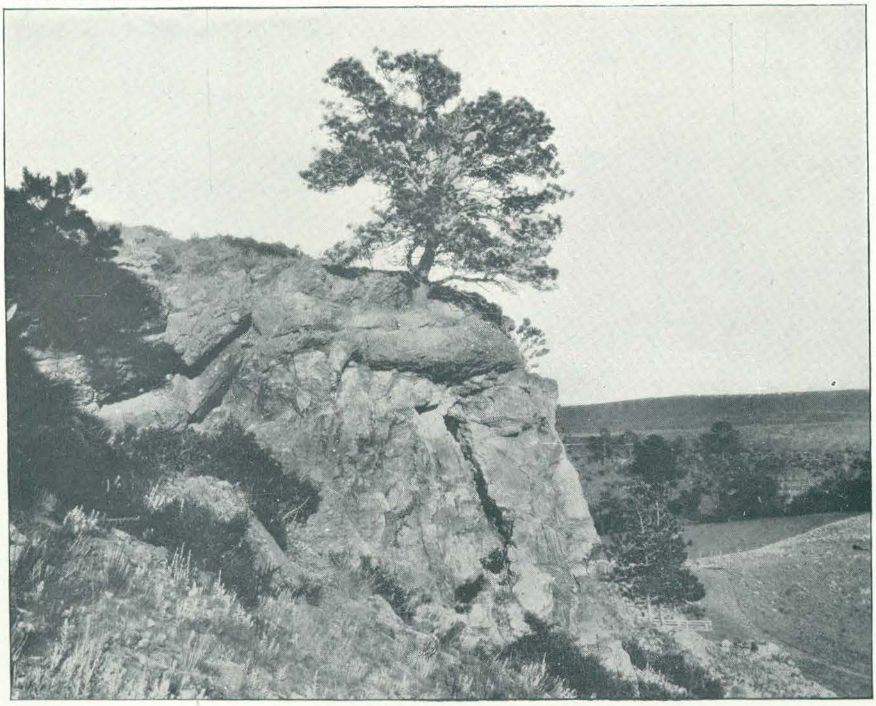
features are uniform over wide areas, with many local variations. These will be pointed out in the detailed descriptions of the individual formations. In the latter portion of this report there will also be discussed the sequence of events attending the deposition of these formations.

CAMBRIAN.

DEADWOOD FORMATION.

This representative of the Cambrian appears to entirely encircle the Black Hills, but it has been removed completely from the central area. We do not yet know whether in this region it originally covered the entire area of crystalline rocks, but it appears likely that a portion of these old rocks formed the surface during the greater part of the time, and probably furnished the material for the Cambrian sediments. The beds lie unconformably across the upturned edges of the schists and granites on a relatively smooth plain with local shallow channels. The formation is thick in the northern hills, attaining a thickness of over 300 feet in the Deadwood region, but it thins gradually to the south and especially to the southeast. In the region west of Fairburn exposures were found in which the formation is represented by only 4 feet of coarse sandstone lying on the pre-Cambrian schists. The materials of the formation are always prominently sandy, and the colors dark reddish brown or dirty buff. The basal member ordinarily is a hard, massive, reddish-brown quartzite. As the formation thickens this member is seen to be overlain by thinner bedded, softer sandstones, in some cases interbedded with more or less shale. The dark color of the rock is in striking contrast to the overlying limestones, and its nearly horizontal attitude and distinct bedding render it easily distinguishable from the underlying schists or granite. Portions of the basal beds of the Deadwood formation are conglomeratic, ranging from a sprinkling of quartz pebbles in the sandstone to a very coarse, heavy conglomerate of large, rounded masses of crystalline rocks and vein quartz in a red-brown matrix. An exposure of this sort of material on a northerly branch of Lame Johnny Creek is shown in part in Pl. LXVII, *B*. Here the crystalline schists are overlain by 8 feet of coarse conglomerate, with pebbles up to 8 inches in diameter, merging upward into coarse red sandstone, in all a thickness of about 20 feet. A few rods downstream there are exposures in which the formation is seen to consist of only 4 feet of coarse red-brown sandstone lying on the schists and overlain by Carboniferous limestones. There may be points in this vicinity where the formation thins out entirely, but it is present in all of the exposures scattered at intervals along the transverse valleys and intervening slopes.

Outcrops of the Deadwood formation vary greatly in prominence, but their extent in general is small. For many miles they lie in the slope below the high escarpments of the Pahasapa limestone, where the ledges are often deeply buried under talus from the cliff above. This is particularly the case on the western side of the uplift. On the eastern side, where the dip is steeper, the hard quartzitic basal member gives rise to several knobs or long, bare rocky slopes of considerable prominence. The many canyons cutting back into the western escarpment and those crossing the ridges on the eastern side of the uplift often afford excellent exposures of the formation. In the vicinity of Hat Mountain, northwest of Hill City, the formation has a thickness of 180 feet, possibly slightly less, and comprises an upper member of brown sandstone about 60 feet thick and coarse sandstone, conglomeratic in part, brownish buff above and reddish brown below, lying on the crystalline schists. Fossils occur at intervals in the beds, but mainly in the lower member. They are largely *Lingulepis* and *Obolella;* but fucoids also are found in small quantity. Hat Mountain is a small, conical outlier of the Deadwood beds, overlain by a few feet of Englewood pink limestone. Much of the sandstone in this vicinity is soft and weathers into slopes from which but few ledges protrude. The sands are composed in greater part of small, round quartz grains with occasional scales of mica. Some beds contain grains of glauconite in small proportion, a component which is abundant in the formation in the northern hills. The conglomerate which gives rise to some prominent ledges on Castle Creek, a few miles farther north, is a variable bed and becomes fine grained to the south. Its materials are mainly quartzitic crystalline rocks, similar to some of those of pre-Cambrian age in various parts of the Black Hills. The pebbles are rounded, and were doubtless the product of either a river or a shore of early Cambrian time. From Hat Mountain east is the widest portion of the Black Hills uplift, although possibly not quite the highest. The area of bared pre-Cambrian rocks is here 25 miles wide. In the escarpment west of Custer there are many scattered exposures of red sandstone in the slopes below the high cliffs of Pahasapa limestone. In this direction the formation gradually decreases somewhat in thickness, the conglomerate disappears, and sandstones are seen lying directly on the schists. In the canyons at the head of Pleasant Valley there are excellent exposures, and here, near the Eightmile ranch, *Obolella*, *Lingulepis*, and trilobite fragments are particularly abundant and well preserved. It was in this vicinity that Newton collected much of his Cambrian material. About Pringle the Deadwood sandstone is often exposed in the slopes of the escarpment and its outlying knobs, capped by the Englewood and Pahasapa limestones. It is a moderately hard, red-brown sandstone, containing numerous fossils and here dipping south on the axis of the uplift. The thickness was not ascertained precisely, owing to the lack of continuous exposures, but it is about



A. DEADWOOD CONGLOMERATE LYING ON CHANNELED SURFACE OF GRANITE AND SCHIST, ON BEAVER CREEK, 2 MILES NORTHWEST OF WIND CAVE, SOUTH DAKOTA, LOOKING EAST.

B. DEADWOOD CONGLOMERATE ON ALGONKIAN SCHIST, LAME JOHNNY CREEK, WEST-SOUTHWEST OF FAIRBURN, SOUTH DAKOTA, LOOKING NORTH. ALSO SHOWS ENGLEWOOD PINK LIMESTONE.

50 feet. On Beaver Creek, 2 miles north of Wind Cave, there are several instructive exposures. One exhibits a basal conglomerate lying on an irregular surface of crystalline rocks, shown in Pl. LXVII, *A*. The indications here suggest stream deposition, but there may have been simply a shore with low cliffs of crystalline rocks, against which the bowlder deposit was laid down. Farther down the canyon there is a cliff exposing the Deadwood formation lying between the Englewood limestone and the crystalline schists. The rock is a hard, dark-brown sandstone, massive above and conglomeratic below. Its thickness is 20 feet. Fossils occur in some of the layers. This formation is overlain by 6 feet of alternating beds of light-colored, thin sandstones, shales, and limestones which present no evidence as to their age. They are sharply separated from the underlying sandstones by abrupt change in color, texture, etc., and are overlain by the typical pink, slabby limestones of the Englewood formation.

In the gorge of Lame Johnny Creek the Deadwood formation is a coarse, brown, fossiliferous sandstone with a few intercalated pinkish, calcareous beds, having a thickness of about 40 feet altogether. On a branch of this creek 2 miles north of this place the formation thins to 4 feet, as described on page 505, and may locally thin out entirely, but this is not probable. The basal conglomerate at this place is shown in Pl. LXVII, *B*.

The deep canyon of French Creek affords a fine exposure of the contact of the Deadwood formation with the pre-Cambrian granite. The material is mainly a reddish quartzite, with streaks of quartz pebbles in its lower portion and a transition breccia for several inches. The thickness of the formation here has increased to more than 60 feet. The underlying granite is the typical pegmatite, of which there is so great a development in the Harney Peak region. At other points in the canyon different relations are exhibited, the quartzite grading into sandstones and overlapping onto schists. The upper member of the formation is thin-bedded soft sandstone. The lower quartzite is a prominent member from here northward to Hayward, rising high in knobs and ridges in the divides between the many transverse valleys. Its hardness is great and its massive dark red-brown blocks and surfaces are conspicuous features in this region.

On Squaw Creek below Otis there are extensive exposures of the Deadwood sandstones and quartzite, the latter giving rise to the fine bluff along the north side of the valley, shown in Pl. LXVIII. The series comprises a basal quartzite, which is prominent in the photograph, thin-bedded sandstone and shales, thin-bedded red sandstones, and thin-bedded gray sandstones overlain by the buff, slabby Englewood limestones. The thickness is about 75 feet.

Little Squaw Creek exposes a section showing massive red sandstones below with reddish-brown and gray, thin-bedded sandstones above and a capping of 18 inches of buff conglomerate. The pebbles in the conglomerate are small and the bed is a local one. Along the creek 2 miles below Spokane the Deadwood formation presents the following section:

Section 2 miles from Spokane, South Dakota.

	Feet.
Brown sandstone, overlain by pink, slabby limestone	5
Thin-bedded red sandstone and shale	25
Brown-red massive quartzite lying on crystalline rocks	30

In the vicinity of Battle Creek, about Hayward, the Deadwood formation is conspicuously exposed in frequent cliffs and long, rocky slopes, due mainly to the thick bed of hard quartzite at the base of the formation. This quartzite is dark reddish, moderately fine-grained, and has a thickness of about 30 feet. It is overlain by 30 feet of sandy shales and thin sandstones, varying from reddish brown to grayish brown. The top member is a bed of softer, lighter reddish-brown sandstone, averaging 10 feet in thickness. North from Hayward for several miles the formation gives rise to a narrow shelf in the slope of a west-facing ridge, capped by an escarpment of Pahasapa limestone. On Spring Creek, north of Rockerville, the formation thickens considerably, becomes glauconitic, and partially loses its quartzitic character. Its basal member is a conglomerate, at some points 20 feet thick, and a thick mass of alternating thinner and thicker bedded brown sandstones, with numerous fossils. Some of the layers are covered with impressions of large fucoids.

About Rockerville and Hayward the basal portion of the Deadwood formation has been found to be gold bearing, and many drifts have been run in on the contact.

CARBONIFEROUS.

In the Black Hills region the Carboniferous rocks comprise several formations apparently representing continuous deposition throughout the period. The many formations of Mississippian and Missourian age, which compose the Carboniferous in the central United States, are not differentiable in the Black Hills, not even in their broader features. There appear to be only five formations separable—the thin Englewood limestone at the base, the massive gray Pahasapa limestone next above, the thick mass of Minnelusa sandy beds, and the overlying series of Opeche red beds and Minnekahta limestone, the latter, at least, of Permian age. The Carboniferous lies directly on the Cambrian in the central and southern parts of the Black Hills, but to the north these are separated by a mass of buff limestone of Silurian age and some shales the age of which has not been determined.

ENGLEWOOD LIMESTONE.

In the southern Black Hills the Deadwood formation is overlain by a series of thin-bedded, pale pinkish-buff limestones. On the suggestion of Mr. Jaggar it is proposed to designate this formation the Englewood limestone, from a locality in the northern Black Hills where it is extensively exposed. It appears to extend continuously around the Black Hills, everywhere immediately underlying the Pahasapa limestone. It averages 20 to 30 feet in thickness and presents frequent outcrops in the lower slopes of the limestone escarpment and in numerous canyons. It merges rapidly into the overlying limestone, occasionally with a few feet of impure buff limestone intervening. It is usually sharply separated from the Deadwood formation, but only by a sudden change in the nature of the materials. The Englewood limestone is usually fossiliferous, containing numerous corals and occasional shells. The following forms have been reported: *Fenestella*, *Orthothetes*, *Leptæna*, *Spirifer*, *Chonetes logani*, *Reticularia peculiaris*, *Syringothyris carteri*, and crinoids. It is correlated with the Chouteau or Kinderhook of the Mississippi Valley.

PAHASAPA LIMESTONE.

This prominent member, heretofore known as the the Gray limestone, has an extensive outcrop area in the Black Hills uplift. It constitutes much of the high, wide plateau west of the central region of crystalline rocks, and is most characteristically exhibited in the great lines of cliffs in the infacing escarpment surrounding that region. Mr. Jaggar has suggested that there be applied to it the Dakota Indian name for the Black Hills, Pahasapa. The formation consists of a thick deposit of massive gray limestone, usually outcropping in precipitous cliffs with many picturesque irregularities of form, or with wide, flat surfaces. Caverns are of frequent occurrence, some of them being of large size. One having several miles of galleries is known as Wind Cave, from the strong current of air which usually issues from its mouth. It is situated 8 miles north of the Hot Springs and attracts thousands of visitors. Crystal Cave, in the northern Black Hills, is also a very interesting cavern, with many large deposits of dog-tooth spar on its walls.

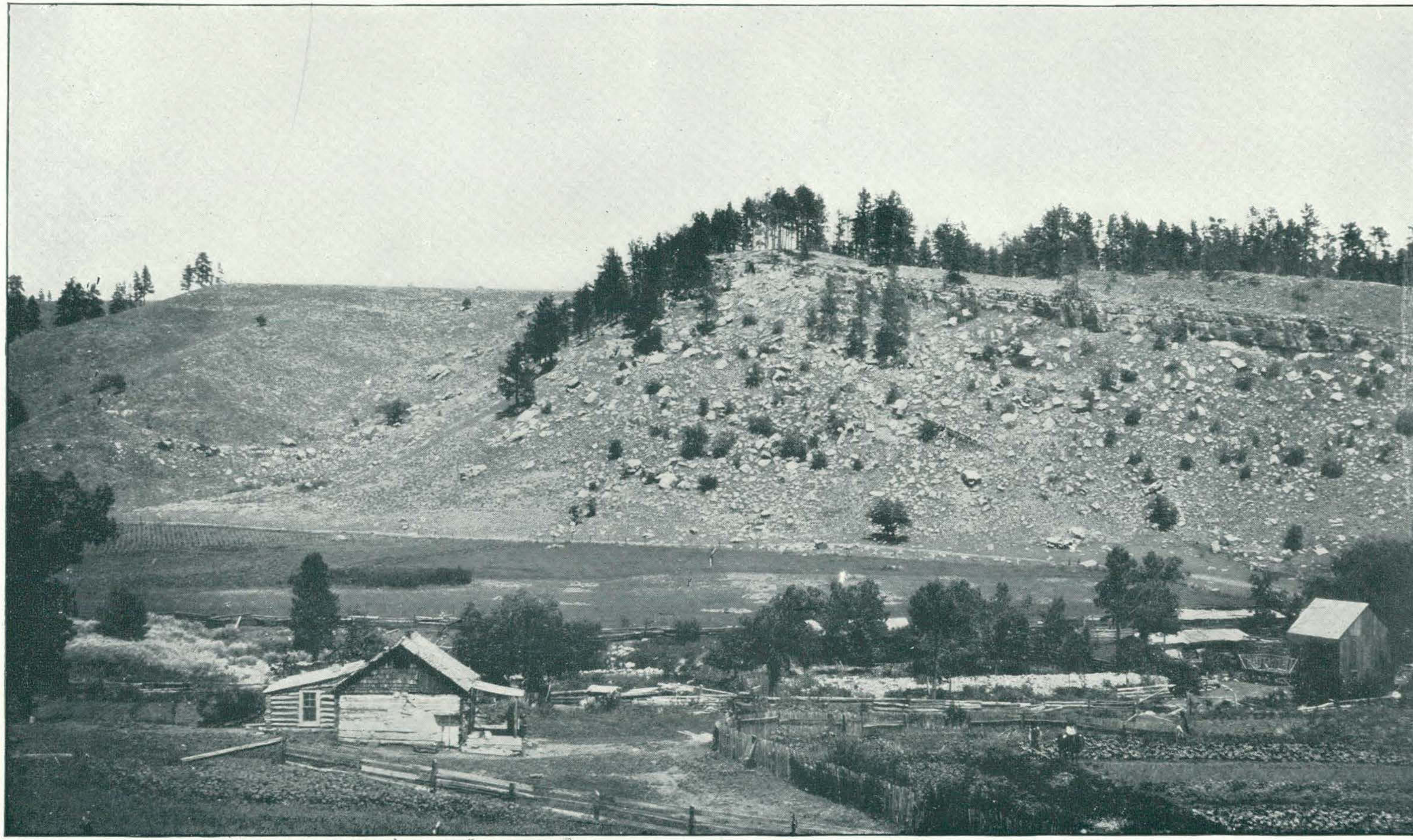
The most extensive exposures of the Pahasapa limestone are in the great plateau west of Custer. Here the formation begins in a line of high cliffs surmounting slopes of crystalline schists and the relatively thin sheets of Englewood limestone and Deadwood sandstone. A view of one of these cliffs is shown in fig. 274. In Pennington County the plateau has a width of 10 miles of continuous limestone outcrop, constituting the most elevated area in the Black Hills excepting the small summit of Harney Peak. To the west the limestone passes beneath the sandstone of the Minnelusa formation, but it is exposed again in the arch of the steep anticline near the Wyoming-South Dakota line. Hell Canyon cuts deeply into the Pahasapa limestone, as does also the wider canyon known as Pleasant Valley. East of the crystalline rock area the limestone stands out on many conspicuous knobs, or lies on the eastern slopes of ridges due to the Deadwood quartzite, but it does not attain the high altitude which it has farther west. With decreased thickness, the more rapid dip to the east soon carries the formation below the surface in that direction, but it constitutes the walls of many of the canyons of the streams from Beaver Creek northward. French Creek has extensive cliffs of the limestone, one of which is shown in Pl. LXIII, and Spring Creek has cut a long, deep canyon through it.

The thickness of the Pahasapa limestone in the central and southern Black Hills varies from about 500 feet at the northwest to 225 feet on the east and southeast. All along the eastern side of the hills it appears to have the latter thickness, with slight local variations. It does not present any noteworthy lithologic subdivisions, but its upper part is often siliceous and flinty and stained red to a greater or less extent from the overlying red beds of the Minnelusa formation. At its top there is usually a red shaly bed of slight thickness, containing oval concretions of hard silica from 6 inches to 2 feet in diameter in greater part. Fossils occur sparingly throughout the formation, including *Spirifer rockymontanus*, *Seminula dawsoni* (*Athyris subtilita*), *Productus*, and *Zaphrentis*, a fauna which indicates Lower Carboniferous age.

MINNELUSA FORMATION.

This term was applied by N. H. Winchell[1] to a portion of the bright-colored sandy members of the Carboniferous lying above the Gray or Pahasapa limestone. Minnelusa is the Dakota Indian name for Rapid Creek, and in this report will be employed to designate all the sandstones and limestones lying between the well-defined limits of the Pahasapa limestone below and the deep-red sandstones and shales of the Opeche formation above. It is next to the Pahasapa limestone in order of prominence among the Black Hills formations, extending in a broad zone all around the uplift, with conspicuous outcrops. It varies in components, but consists mainly of thick masses of buff and reddish sandstones that are striking features in the walls of the many canyons by which the formation is traversed. The sandstones are mostly fine grained, massively bedded, and in their unweathered condition contain a considerable proportion of carbonate of lime. Thin sheets of limestone occur in places, and, less frequently, sandy shales of red or gray color. Some layers are cherty. Although the formation

[1] Report of a reconnaissance of the Black Hills of Dakota made in the summer of 1874 by Capt. William Ludlow, United States Engineers, 4°, Washington, 1875, p. 65.



DEADWOOD RED SANDSTONE LYING IN ALGONKIAN SCHISTS ON SQUAW CREEK BELOW OTIS, SOUTH DAKOTA, LOOKING NORTH.

was deposited at the same time as the Coal Measures which contain extensive beds of coal in the Mississippi Valley, it is barren of coal in the Black Hills, except in the occasional occurrence of very thin beds of impure coal in gray shales. The formation is thickest on the western side, where it is fully 450 feet thick; it thins gradually to the south and east, being about 420 feet thick west of Hot Springs and less than 400 feet thick on Spring Creek. Although the Minnelusa formation has wide areas of exposure it does not give rise to very marked topographic features. It occupies elevated slopes surmounted by low hills and ridges due to its harder layers. Its inner boundary is usually not marked by an escarpment such as is seen at the inner margin of the Pahasapa limestone, and there is never any noticeable topographic break in passing from one formation to the other. On the slopes the soil becomes sandy on the Minnelusa beds. In the many canyons which are cut through the formation the Pahasapa limestone usually passes beneath it without presenting any marked change of features except in color. The fine colors exhibited by the Minnelusa formation give great beauty to some of the canyons. One of the finest exposures of this sort is on Hot Brook, the south branch of the head of Fall River. It is shown in Pl. LXIX. The upper sandstones are brilliant red-brown and orange, and contain layers presenting much bright yellow. Below these are gray sandstones containing a layer of bright purple clay. Above are the brilliant dark reds of the 100 or more feet of Opeche sandstones surmounted by a cap of the purplish-gray Minnekahta limestone. Four hundred feet of beds are exposed, with colors of most unusual brilliancy. Portions of the color on some of the beds is due to staining from the overlying strata, but several of the sandstones are colored throughout. The railroad from Minnekahta to Hot Springs passes at the foot of the cliff. The strata exposed at this place are as follows:

Section on Hot Brook, South Dakota.

	Feet.
Opeche red sandstone.	
Gray limestone	10
Soft red sandstone	20
Limestone breccia, red to buff matrix	15
Yellow arenaceous limestone	15
Red limestone	5
Yellow arenaceous limestone	5
Red arenaceous limestone	5
Gray limestone breccia, red matrix	15
Red sandstone	25
Greenish-gray limestone	5
Red sandstone, soft	50
Gray limestone	10
Red sandstone	10
Gray sandstone	10
Red sandstone	6

	Feet.
Red shale	30
Pale-red sandstone with thin coaly shale partings	20
Light-buff and gray sandstones	15
Breccia	3
Reddish-gray sandstone	25
Green shale	1
Gray to buff sandstone	12
Black shale	2
Light-buff, soft sandstone	15
Dark shale	2
Soft white sandstone	15
Gray calcareous sandstone with coaly shale partings	30

The section comprises about two-thirds of the formation brought up

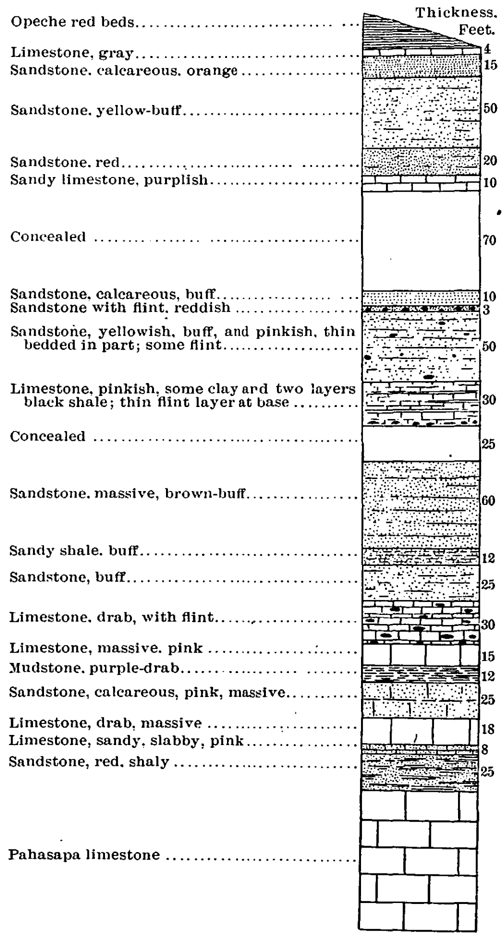
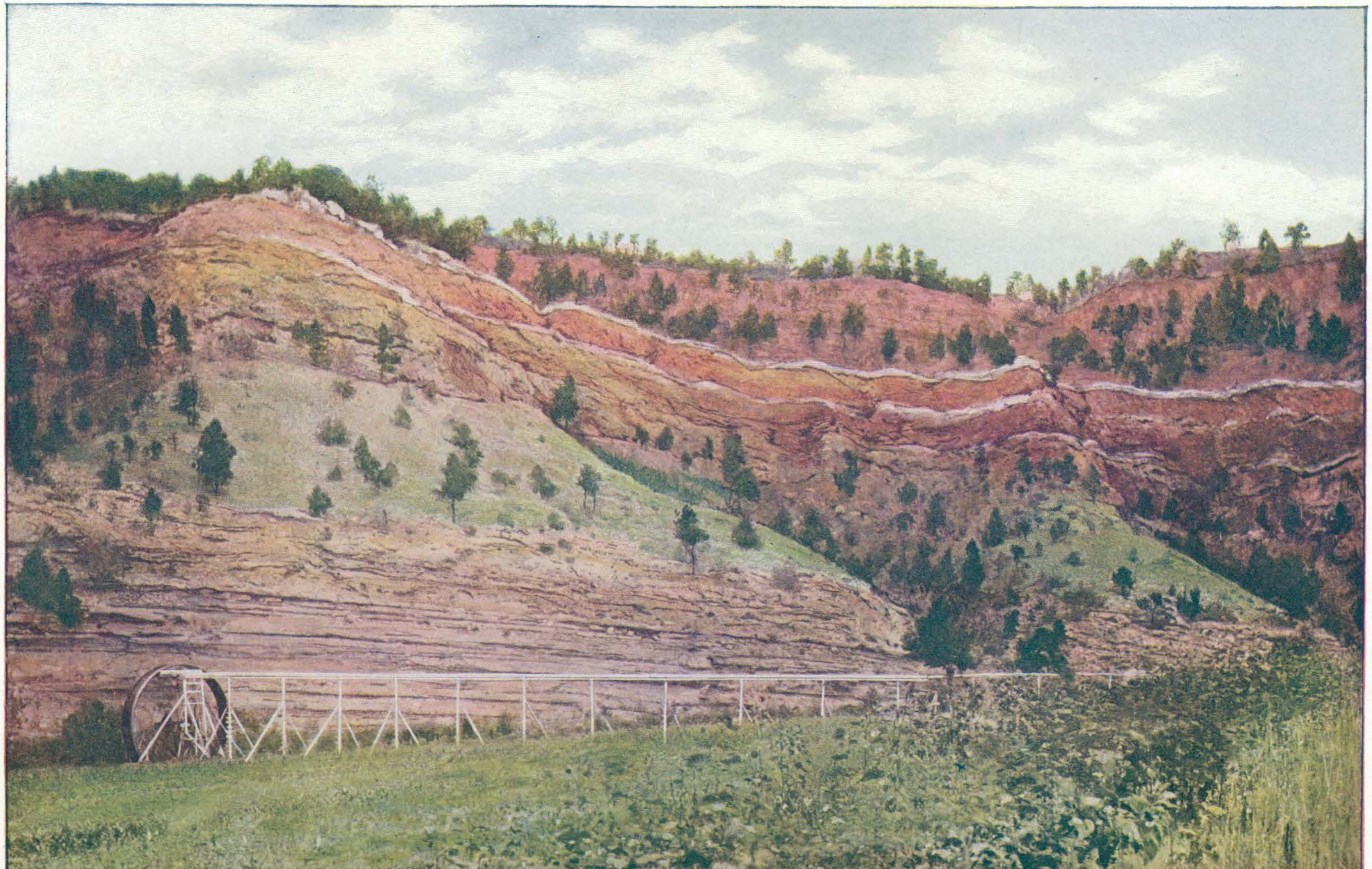


FIG. 276.—Columnar section of Minnelusa formation in Beaver Canyon, north of Hot Springs, South Dakota.

by a local anticline of considerable height. The uppermost layer is a nearly pure limestone, in which, in an adjoining canyon, were discov-



3-COLOR PROCESS FROM PHOTOGRAPH BY N. H. DARTON

UPPER PORTION OF MINNELUSA FORMATION, OVERLAIN BY OPECHE RED BEDS AND MINNEKAHTA LIMESTONE

Hot Brook, 2 miles west of Hot Springs, South Dakota. Looking north ered the typical upper Carboniferous forms *Productus semireticulatus* and *Chonetes?*, a very important occurrence, because the formation has not elsewhere yielded fossils. These remains indicate that the beds are of pre-Permian age.

In Beaver Canyon, 10 miles north, there is a complete section across the Minnelusa formation, as shown in fig. 276. This section was carefully examined by Mr. Richardson. It presents a long series of picturesque cliffs of brilliantly colored sand rocks, from under which, to the west, the Pahasapa limestone gradually rises into high, gray cliffs stained pink and reddish. The two formations are distinctly separable by a comparatively sudden change in the nature of the materials from arenaceous to more purely calcareous. The lower members of the Minnelusa formation are generally buff, slabby sandstones, often having a thickness of 100 feet. The breccias which occur in the higher beds are distinctive features seen throughout the southern Black Hills. The brecciated material is usually somewhat more calcareous than the matrix, but it is all of local origin. In the region west of Hermosa and thence northward, the Minnelusa beds consist of a thick mass of coffee-colored sandstone at the top, reddish-buff sandstone with some thin interbedded limestone layers next below, and a basal member of gray sandstone. On the western side of the Black Hills the formation consists of the members given in the record of the boring at Cambria, page 572. There are fine exposures of steep-dipping beds on the ridge east of Stockade Beaver Creek from Fanny Peak northward. These are shown in Pl. XCII. Here the formation exhibits a top series of light-colored massive sandstones, a thick medial member of bright red and buff sandstones, and a basal member of slabby, buffish-gray calcareous sandstone with reddish shale partings and considerable chert. The total thickness is about 450 feet. A chemical examination of the borings from the Cambria well shows that the materials are nearly all calcareous under ground, but in the outcrops the lime has been mostly leached out and porous sandstones remain.

OPECHE FORMATION.

This series of red beds, lying between the Minnelusa formation and the Minnekahta limestone, extends continuously around the Black Hills. Its exposures are almost always confined to the slopes below the escarpments of Minnekahta limestone. Its thickness averages slightly less than 100 feet. The material is a soft, red sandstone, mainly thin bedded, containing variable amounts of clay admixture. At the top of the formation, for the first few feet below the Minnekahta limestone, there are shales which are invariably a deep purple. The basal beds of the formation are usually red sandstones, varying in thickness from 4 to 15 inches. A few thin local beds of gypsum are sometimes observed in the formation, attaining in Gillette Canyon a thickness of several inches. On Spring Creek, Battle Creek, and

French Creek the formation averages about 100 feet in thickness. In Beaver Canyon it attains its maximum thickness of 150 feet. On Cold Brook, 4 miles northwest of Hot Springs, its thickness is 115 feet, with purple clay at the top, 50 feet of red, sandy clay below, and 60 feet of red sandstone at the bottom in beds 1 to 4 feet thick, with red clay partings. Farther down Cold Brook, at a point 1½ miles from Hot Springs, a thickness of 135 feet is exhibited. Along the southwestern side of the Black Hills the thickness averages from 90 to 100 feet. In the well at Cambria the following section was obtained:

Section at Cambria, Wyoming.

	Feet.
Purplish shales	4
Dark purple shales	4
Red clay (sandy)	62
Dark red-brown sandstone	2½
Light-red, sandy shale lying on a light pinkish sandstone at a depth of 1,096 feet, which is supposed to be the top of the Minnelusa formation	1½
Total	74

The name Opeche is applied to this heretofore nameless formation from the Indian name for Battle Creek, where the formation is typically developed, although not more so than at many other points in the region. The age of the formation has not been definitely determined, for so far it has yielded no fossils. From the facts that the overlying Minnekahta limestone is of Permian age and that there are extensive red beds in the upper part of the Permian in Kansas and eastern Nebraska, it is supposed that it may be Permian.

MINNEKAHTA LIMESTONE.

This formation, known in previous geological reports as the Purple limestone, is a prominent member of the Black Hills series. It is thin, averaging less than 50 feet in thickness, but it is hard and flexible and covers moderately extensive areas of the outer slopes of the Minnelusa formation. Southwest of Hot Springs it constitutes a prominent anticlinal ridge, which extends south to Cascade Spring. It is proposed to designate this formation the Minnekahta limestone, because a distinctive geographic name is required, and the region near the hot springs, originally known as the "Minnekahta" by the Indians, is a typical locality. The springs rise through crevices in the formation just west of the town of Hot Springs, and the exposures in the vicinity show all the characteristic features which the formation presents. The prominence of the Minnekahta limestone outcrops is due largely to the fact that the overlying formation is soft, red shale, which has been deeply eroded, leaving the underlying limestone bare on slopes up which the red shale originally extended. The underlying formation, the Opeche, also being soft, the limestone nearly everywhere presents an escarpment, and the many canyons which are cut through it have vertical walls of the limestone.

MINNEKAHTA LIMESTONE AT WILDCAT GULCH, WEST OF HERMOSA, SOUTH DAKOTA, LOOKING SOUTHWEST.

The Minnekahta limestone presents more details of structure than any other formation of the Black Hills. Normally it dips outward away from the central area at from 5° to 30°, but there are frequent variations in the amount and direction. These variations are due to the fact that the formation is a relatively hard bed of homogenous rock lying between masses of soft, red shales, so that it was free to flex wherever pressure was exerted, the plasticity of the inclosing beds favoring local flexing and warping. Its beds are sometimes traversed by small faults and minute crumplings, but considering the large amount of deformation to which the formation has been subjected the flexures are but little broken. The formation is uniform in character throughout, being a thin-bedded, light-colored limestone containing magnesia and more or less clay as an impurity. Its thin bedding is a characteristic feature, although the thin layers are so cemented together that the formation presents a massive appearance. On weathering and through the action of frost it breaks into slabs usually 2 to 3 inches in thickness. On the western side of the Black Hills, notably in the region from east of Clifton northward, its coloring is slightly darker, varying from dove color to lead gray, and some of the beds present a seminodular structure. An increased admixture of clay is also observed in some layers. The general appearance of the formation is always slightly pinkish with a tinge of purple, from which the term "Purple limestone" originated. The thickness of the formation was measured at many points; a few representative measurements are as follows:

	Feet.
Spring Creek	45
Battle Creek	40
Hot Springs	50
Stockade Beaver Creek	28–33
Cambria well	34

This relatively uniform thickness indicates very uniform conditions of deposition during the accumulation of the red bed deposits, the Opeche formation below, and the Spearfish formation above. An analysis of a typical sample of the Minnekahta limestone is as follows:

Analysis of Minnekahta limestone.

Constituent.	Per cent.
Lime	31.51
Magnesia	19.85
Alumina, iron, etc	.36
Water	1.25
Carbonic acid	44.66
Sulphuric acid (SO_3)	.07
Silica	1.12
Manganese, soda, and potash	None.

This analysis was made by Mr. George Steiger, United States Geological Survey laboratory, in March, 1900.

A characteristic feature of the Minnekahta limestone is the frequent occurrence of sink holes, a typical example of which is shown in Pl. LXXI. It is about 25 feet in diameter and 20 feet deep to débris which probably fills its bottom to a considerable amount. Other similar sink holes are to be seen on the road from Hot Springs to Cascade.

During the seasons of 1898–99 I discovered fossils in the Minnekahta limestone at several points in the area, which indicate that the age of the formation is Permian. The fossils were studied by Mr. Schuchert, who identified a small *Bakevellia* and with less certainty an *Edmondia* and a very thin-shelled *Nuculana*. The *Bakevellia* is similar to one occurring in the Permian on South Cottonwood Creek, Kansas. The most abundantly fossiliferous locality observed is in the railroad cut about 2 miles north of Minnekahta. Newton states that he made a specially extended but fruitless search for fossils in this limestone. He classified the formation provisionally as Triassic. Winchell referred it doubtfully to the Carboniferous. Hayden, who included the Purple limestone with some of the underlying formations in the "Red bed series," reported the occurrence of fossils in a bowlder which he supposed to be Purple limestone. They were distinctive Carboniferous forms, but in all probability he was mistaken as to the source of the bowlder.

JURATRIAS.

TRIASSIC.

SPEARFISH FORMATION.

The Spearfish formation is the conspicuous series of gypsiferous red beds encircling the Black Hills and usually giving rise to a wide red valley which in the northern Black Hills the Indians have designated the "race course." The formation consists of from 350 to 500 feet of red sandy clays, with intercalated beds of gypsum which sometimes are 30 feet thick. The bright red of the shales and the snowy whiteness of the gypsum are striking features of the formation. The Red Valley is treeless, and it usually presents wide areas of bare red slopes and red buttes with frequent outcrops of gypsum. If it were not for the beds of gypsum the formation would present no noticeable features of stratigraphy. The sedimentary material is almost entirely a red shale containing varying amounts of sand admixture and is generally thin bedded. The gypsum occurs in beds at various horizons, some of the larger beds extending continuously over wide areas. There is

SINK HOLE IN MINNEKAHTA LIMESTONE EAST-NORTHEAST OF CAMBRIA, WYOMING.

also throughout the formation more or less secondary deposition of gypsum in very small veins. The continuity of the outcrops of the red beds is considerably broken in the region west of Fairburn and Hermosa by overlaps of the Tertiary formations which in some places completely fill the Red Valley. The width of the outcrop of the formation varies from 1 to 3 miles, attaining its maximum in the region west of Buffalo Gap and in the broad belt extending from east of Minnekahta Station nearly to the north end of Elk Mountain. Owing to the local steep dip of the formation the outcrop is very narrow for 5 miles north from Cascade Springs and in a portion of the valley of Stockade Beaver Creek east of Newcastle. The thickness of the Spearfish formation can seldom be determined with any degree of accuracy, owing to the softness of its materials and the consequent difficulty in determining the dips of bedding planes. Along the eastern side of the Black Hills the formation appears to have a thickness of between 350 and 400 feet, so far as can be estimated from very indefinite dip observations. In this region the principal bed of gypsum occurs near the center of the formation. West of Hermosa it has a thickness of about 15 feet, but southward, in the region west of Fairburn, it thins out and may at some points be absent. West of Buffalo Gap the gypsum beds increase in thickness and attain their maximum prominence at Hot Springs, where the section shown in fig. 297 is exhibited. The exposure at this place is shown in Pl. CVI. The principal beds of gypsum have a thickness of 33½ feet, with a 10-foot parting of red shale between them. In the wide Red Valley extending south from Hot Springs to Sheps Canyon, the gypsum beds are a conspicuous feature, but they gradually diminish in thickness in that direction. At Cascade Springs, and thence north on the west side of the anticline, the dips are very steep, and the outcrop of the Spearfish formation becomes so narrow that the Red Valley is only a few rods in width from the springs north nearly to the railroad. Here a relatively accurate measurement of the beds was made from the steep slopes of Minnekahta limestone to the basal sandstone beds of the Sundance formation. At the base there are 150 feet of red beds, then a bed of gypsum in places 20 feet in thickness, overlain by 250 feet of red beds with a few thin layers of gypsum, the formation here having a total thickness of 420 feet. In the broad Red Valley extending from east of Minnekahta westward across the southern axis of the Black Hills and northward to Gillette Canyon there are red shales with intercalated gypsum beds, but the thickness could not be accurately determined. In the narrow valley of Stockade Beaver Creek east of Newcastle the upper portion of the Spearfish formation is mostly covered by alluvial materials, so that a precise measurement is difficult to obtain. Just west of Fanny Peak a measurement was made showing 450 feet, or possibly slightly more, of red beds, including two thick beds of gypsum near the middle. The lower bed of gypsum is about 150 feet above the Minnekahta limestone; then come about 40 feet of red clays, a 2-foot bed of gypsum, 15 feet of red clays with two thin gypsum beds near its top, a bed of gypsum which locally attains a thickness of 30 feet, and at the top about 200 feet of red shales and red sandy shales to the buff sandstone at the base of the Sundance formation. A short distance north of this point the dips diminish and the red beds spread out into a wider valley, followed by Stockade Beaver Creek to the northward. The contact with the Jurassic beds gradually rises on the west side of this valley and the red beds are exhibited in long slopes and picturesque red cliffs. The principal bed of gypsum continues in the center of the formation and another bed of it begins at the top of the formation, which soon attains a thickness of from 10 to 12 feet, gradually increasing in amount to the northward. This bed of gypsum is overlain by dark shales, here constituting the base of the Sundance formation. Northeast of Cambria there are exhibited 25 feet of gypsum at the top of the formation, several thick beds in its center, and a local thin bed of gypsum at its base, lying directly on the Minnekahta limestone. The top bed caps the picturesque Red Butte, shown in Pl. LXXII. In the boring at Cambria the Spearfish red beds were plainly recognized, having a thickness of 492 feet, with the following members:

Section of Spearfish formation at Cambria, Wyoming.

	Feet.
Gypsum	8
Red clay	28
Red and dark clay	28
Red clay	181
Gypsum	7
Red clay	58
Gypsum	4
Red clay and gypsum	78
Gypsum	12
Red clay lying on Minnekahta limestone	88

The name Spearfish formation has been applied to this red-bed series from the town of Spearfish, in the northern Black Hills, where there are extensive exposures. Throughout the hills the formation is distinctly separated from the underlying Minnekahta limestone and the overlying shales and red sandstone of the Jurassic Sundance formation. It is thought to be Triassic in age, because it lies unconformably beneath marine Jurassic deposits and is underlain by the Minnekahta limestone, which is known to be of Permian age. No fossils have yet been discovered in the formation except a small fragment of a fish, which was not sufficiently distinct for determination. It is pos-

3-COLOR PROCESS

FROM PHOTOGRAPH BY N. H. DARTON

SPEARFISH RED BEDS, CAPPED BY 30-FOOT BED OF GYPSUM

Red Butte, northeast of Cambria, Wyoming sible that the lower portion of the formation is Permian, but there is no evidence on this point one way or the other. The red beds in Kansas are sometimes supposed to be Permian, but their age is not proved. The distance also from Kansas to the Black Hills is too great for correlation without the guidance of distinct stratigraphic characteristics or other relations besides the red color.

JURASSIC.

The existence of Jurassic beds in the Black Hills was first ascertained by Hayden, who, in 1857, discovered marine fossils which were identified and described by Meek. Hayden's descriptions of the Jurassic beds were meager, and he included in the Jurassic the red beds, and at one point a limestone with fresh-water fossils which I have recently found to be Tertiary.

N. H. Winchell visited the region in 1874, and in his report recorded a few general facts as to character and distribution of some of the Jurassic beds along his line of travel. Henry Newton made a very much more extended survey of the Black Hills in 1875, and in his report added greatly to our knowledge regarding the Jurassic deposits. He described in considerable detail a number of typical exposures, but attempted no classification of the members. His principal statements are as follows:

> The Jura of the Black Hills consists primarily of gray or ash-colored clay or marls, with occasional bands of green and red. Interbedded with these are soft sandstones, more or less argillaceous, and a few restricted bands of limestone. * * * The thickness * * * is about 200 feet, but it shows a remarkable increase toward the north and northwest, attaining in the Belle Fourche Valley a depth of nearly 600 feet. * * * On the north and west, and to a less degree to the south, the formation is well exposed and characterized by a greater or less abundance of fossils. On the southeast and east it is less plainly seen, being usually covered by a broad talus, and so far as examined it was not found to be fossiliferous. * * * It was found impossible to base a subdivision of the formation either on persistent lithological characters or on the distribution of fossil forms. The Jurassic strata * * * are always easily distinguished from the red beds. * * * Everywhere a large proportion of the formation is composed of sandstones, which are usually light in color and even sometimes of a snowy whiteness.[1]

The upper limit of the Jura is so placed by Newton in most cases as to comprise only the beds containing Jurassic molluscan remains, but in places it includes a greater or less amount of overlying sandstones.

Several years ago O. C. Marsh collected saurian remains from the shales overlying the marine Jurassic beds near Piedmont, on the east side of the hills. Near Piedmont and other places he also obtained, through a local collector, a large number of cycads from the sandstone overlying the saurian-bearing shales, which was classified as Dakota

[1] U. S. Geog. and Geol. Survey Rocky Mountain Region: Geology and Resources of the Black Hills of Dakota, pp. 152 et seq.

by Newton. The saurian remains are generally regarded as Jurassic, but Marsh has been disposed to regard the cycads also as Jurassic in age. The cycad-bearing sandstones have been examined by L. F. Ward at several points in the hills, and W. P. Jenney has collected many plants from coals associated with these sandstones in the northern hills. It is Ward's opinion that this flora is Lower Cretaceous.[1] In 1898 I discovered saurian bones at or near the cycad horizon at Buffalo Gap. Dr. Lucas is now studying this material, but is not prepared to give a decided opinion as to whether it is early Cretaceous or late Jurassic, so it is that the upper limit of the Jurassic in the Black Hills is perhaps open to question. For the present the cycad-bearing sandstone here designated the Lakota formation will be included in the Lower Cretaceous, and the underlying Beulah shales, containing saurian remains, will be regarded as the top member of the Jurassic.

The base of the Jurassic is clearly defined throughout the area of the hills by an abrupt change in the character of the sediments, more or less slight erosion, and the evidence of an entirely different history from that of the underlying Spearfish red beds. From the results of recent studies there are offered for the Black Hills Jurassic the classification and nomenclature given on page 503.[2]

SUNDANCE FORMATION.

This member of the Jurassic extends continuously around the Black Hills uplift and throughout its course presents characteristics by which it can be easily recognized. It outcrops mainly along the outer side of the Red Valley on the lower inner slopes of the hogback range. It carries abundant marine fossils, not only to the north, as stated by Newton, but in profusion also around the zone of outcrop to the south. The formation comprises shales and sandstones, in greater part in alternating series, which vary somewhat in sequence in different portions of the region. The shales are mainly dark green and the sandstones pale buff, but there is an intermediate member of sandy shales and sandstones of reddish color, and often a local basal member of massive red sandstone. The shales usually include thin layers of limestone which are always highly fossiliferous. Fossils also occur in the sandstone. Molluscan fossils predominate, together with *Pentacrinites asteriscus* and bone fragments. The following is the list of the fossils so far reported:

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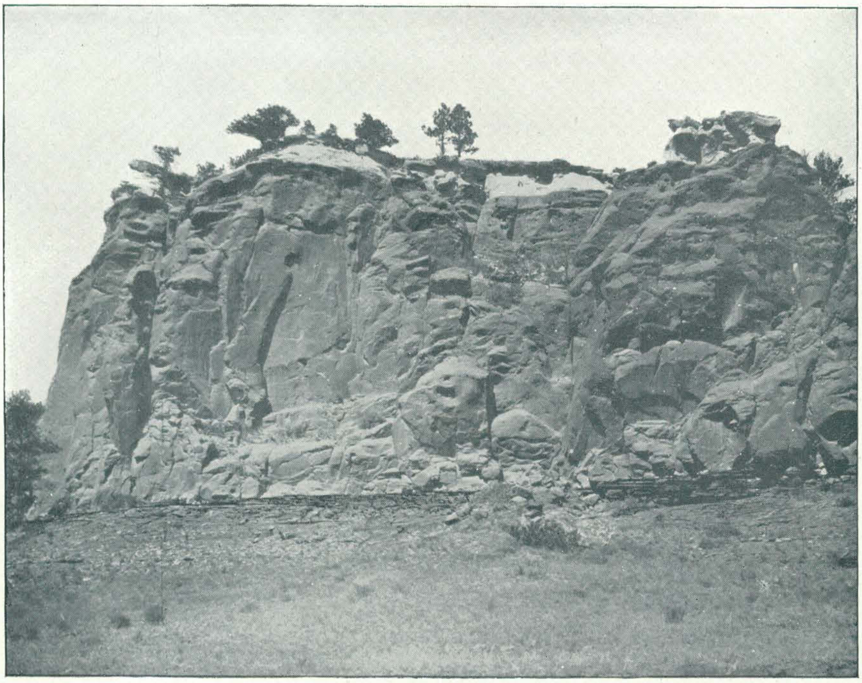
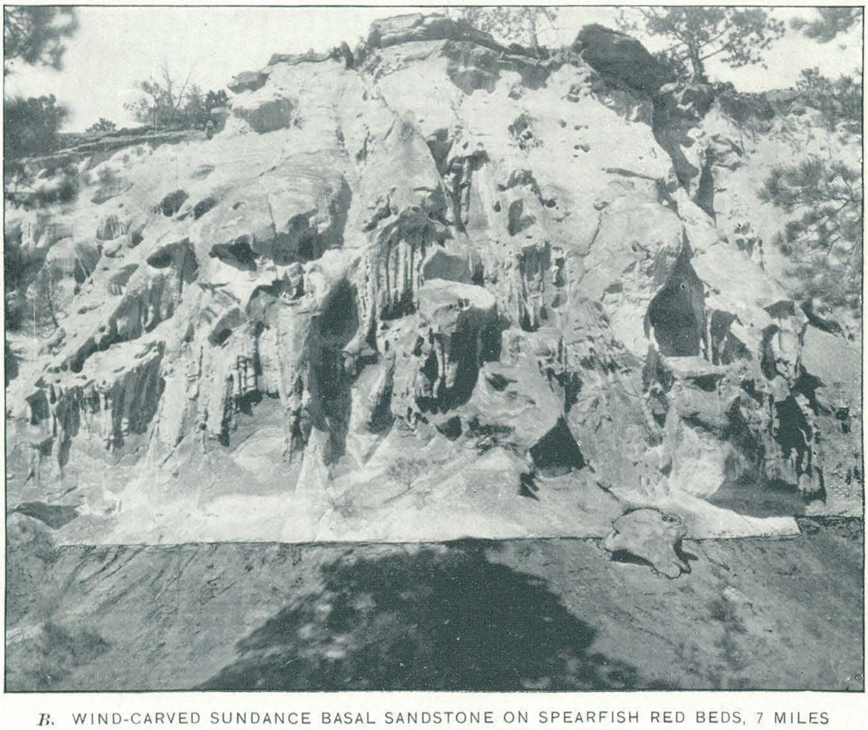
[1] Journal of Geology, Vol. II, pp. 250-266; and Nineteenth Ann. Rept. U. S. Geol. Survey, Part II, pp. 521-958.

[2] Jurassic formation of the Black Hills of South Dakota, by N. H. Darton: Bull. Geol. Soc. America, Vol. X, December, 1899, pp. 383-396.



A. SUNDANCE SANDSTONE ON SPEARFISH RED BEDS, 6 MILES WEST BY NORTH FROM MINNEKAHTA, SOUTH DAKOTA.



B. WIND-CARVED SUNDANCE BASAL SANDSTONE ON SPEARFISH RED BEDS, 7 MILES SOUTH OF HOT SPRINGS, SOUTH DAKOTA.

Fossils of the Sundance formation.

Ammonites cordiformis.	Pleuromya newtoni.
Ammonites henryi.	Protocardium shumardi.
Astarte fragilis.	Psammobia prematura.
Astarte inornata.	Pseudomonotis curta.
Asterias dubium.	Pseudomonotis orbiculata.
Avicula mucronata.	Rynchonella gnathophora.
Belemnites densus.	Rhynchonella myrina.
Camptonectes bellistriatus.	Saxicava jurassica.
Camptonectes extenuatus.	Tancredia æquilateralis.
Dosinia jurassica.	Tancredia bulbosa.
Gervillia recta.	Tancredia corbuliformis.
Grammatodon inornatus.	Tancredia inornata.
Lingula brevirostris.	Tancredia postica.
Lioplacodes veternus.	Tancredia warrenana.
Myacites nebrascenis.	Thracia arcuata.
Mytilus whitei.	Thracia sublevis.
Neæra longirostra.	Trapezium bellefourchensis.
Ostrea engelmanni.	Trapezium subequalis.
Ostrea strigilecula.	Trigonia conradi.
Pecten newberryi.	Unio nucalis.
Pentacrinus asteriscus.	Valvata scabrida.
Pholodomya humilus.	Viviparus gilli.
Planorbis veternus.	Volsella pertenuis.

The stratigraphic variations of the formation were traced with care, but the vertical distribution of the fossils has not as yet been determined. Certain members of the formation are of general occurrence, and there are others which are less persistent. The succession of a lower dark shale, a slabby, buff, ripple-marked sandstone next above, a reddish, sandy shale, and an upper green shale with fossiliferous limestone layers is continuous over a wide area. At the base of the formation there is often a massive red or buff sandstone occurring in extended lenses and frequently attaining a thickness of 25 feet. In the sandy layers at the base of the lower shales, near Hot Springs, fossil fish occur in small number. These have been described by Dr. Eastman.[1] The location is about 1 mile east-southeast from the Union railroad station, or one-half mile south of the Catholicon Springs Hotel, in a small draw which heads in the sandstone ridge lying east of the Red Valley. The succession at the fish locality is as follows:

Section near Catholicon Springs Hotel, South Dakota.

	Feet.
Unkpapa sandstones.	
Green shales with belemnites, etc	80
Red sandy shales	80
Greenish shales and thin sandstones	8
Buff, slabby, ripple-marked sandstone	15
Limestone filled with Ostrea	10
Green shales, very sandy	21
Soft, thin-bedded sandstone, fish-bearing layer	4
Buff sand	2
Spearfish red beds.	

[1] Bull. Geol. Soc. America, Vol. X, December, 1899, pp. 397-408.

The buff sand lies on a slightly eroded surface of the red beds. To the north and to the south it thickens and becomes a conspicuous bed of red to buff sandstone. A typical contact of this member with the Spearfish red beds is shown in Pl. LXXIII. The limestone with *Ostrea* is a local lens not found elsewhere. The fish appear to occur only on the surface of one of the sandstone layers, about 10 inches above the top of the buff sand. Although extensive excavations were made, only a small lot of material was found. A fairly extended scanning of the same horizon in the vicinity revealed only an occasional fish scale.

In the immediate vicinity of Hot Springs there is considerable stratigraphic variation in the Sundance formation. The general average section is as follows:

Section near Hot Springs, South Dakota.

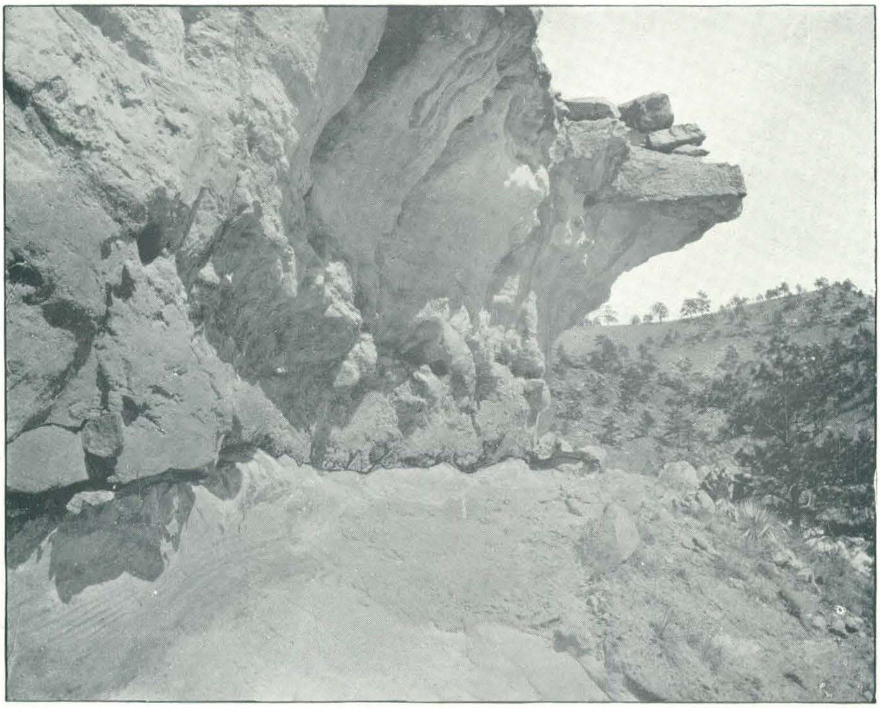
Unkpapa sandstone.	Feet.
Green shales, belemnites	90
Red sandy shales and sandstones	80
Green shales	8
Buff, slabby, ripple-marked sandstones	30
Dark shales	9
Red massive sandstone	25
Spearfish red beds.	

The fossils are very abundant both in the calcareous layers in the upper green shales and in the buff and ripple-marked sandstones. They occur in some of the other beds, but in much less number. In Buffalo Gap, where there are extensive exposures, the following beds are seen:

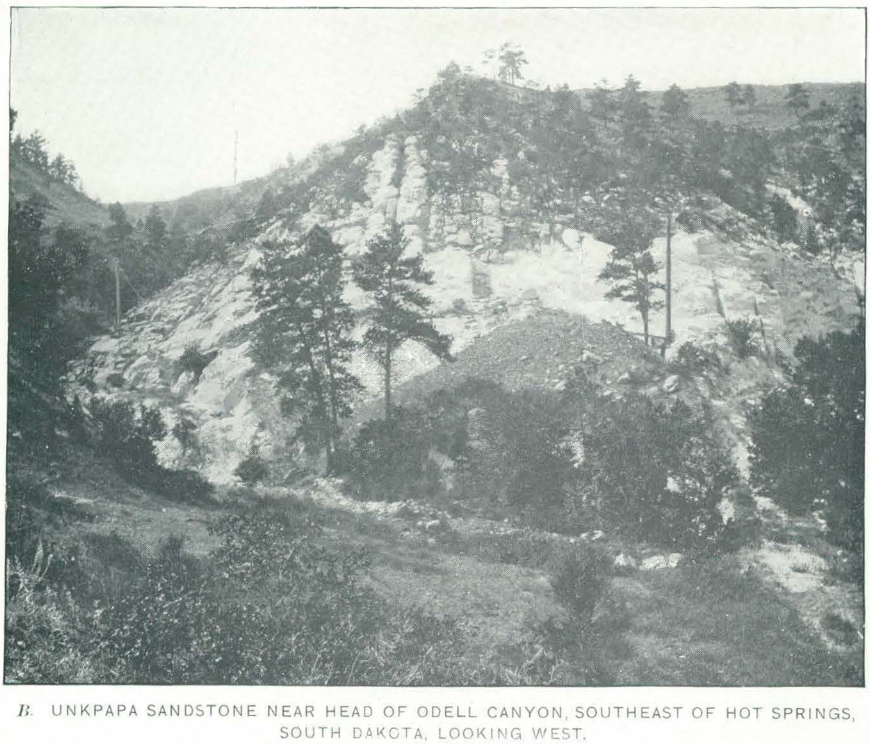
Section in Buffalo Gap, South Dakota.

Unkpapa sandstone.	Feet.
Green shales, with thin fossiliferous limestone beds	100+
Red sandy shales and soft sandstones	65
Greenish buff sandy shales and thin sandstones	15
Buff, slabby, ripple-marked sandstones	40
Pale-red, massive, soft cross-bedded sandstones	7
Purple and buff sandy clays, one-half foot of gray hard sandstone	4
Spearfish red beds.	

In the vicinity of Fuson Creek the exposures are not sufficiently continuous to afford a complete cross section. The beds outcropping are 8 feet of buff sandstone lying on the red beds and overlain by 15 feet of dark-gray shales with thin interbedded sandstones, which are succeeded by 20 feet of buff, slabby, ripple-marked sandstone. Some distance higher on the slopes there are exposed dark-green shales with abundant belemnites and other fossils in calcareous layers. The entire thickness to the base of the Unkpapa sandstone appears to be about 350 feet.



A. LAKOTA SANDSTONE LYING UNCONFORMABLY ON UNKPAPA SANDSTONE, NORTH SIDE OF SHEPS CANYON, SOUTH OF HOT SPRINGS, SOUTH DAKOTA.



B. UNKPAPA SANDSTONE NEAR HEAD OF ODELL CANYON, SOUTHEAST OF HOT SPRINGS, SOUTH DAKOTA, LOOKING WEST.

In the vicinity of Lame Johnny Creek the following section is exposed:

Section near Lame Johnny Creek, South Dakota.

	Feet.
Unkpapa sandstone.	
Buff sandstone, thin bedded below	15
Dark shales, with belemnites and other fossils	90
Buff sandstones	35
Red sandstones and sandy shales	80
Buff, slabby, ripple-marked sandstones	26+
Black shales	8
Buff sandstones	15
Dark shales	5
Red and buff massive sandstone	10
Spearfish red beds.	

In the first canyon south of French Creek, nearly due west of Fairburn, the formation is seen to be much thinner than it is elsewhere in this region, and it consists of more arenaceous materials. In the fine section on French Creek, a mile north, the formation presents more of its usual composition in the following section:

Section on French Creek, South Dakota.

	Feet.
Unkpapa sandstone.	
Red and buff soft sandstone	20
Shales, with few thin fossiliferous sandstone layers	80
Buff, soft sandstones and shales	20
Massive buff to red sandstone	30

In the canyon near the head of Dry Creek, northwest of Fairburn, the Sundance formation is represented by only 60 or 80 feet of beds, comprising green shales above and thin-bedded sandstones below, the former containing abundant fossils.

On Squaw Creek, southwest of Hermosa, the formation comprises a thin sandstone at the base, then a mass of dark shales, and a top member of buff and yellow slabby sandstone.

On Spring Creek the following features are exposed:

Section on Spring Creek, South Dakota.

	Feet.
Unkpapa sandstone.	
Buff sandstone, massive above, slabby below	25
Green shales, with three fossiliferous layers and some thin sandstones	25
Pale greenish, soft, massive argillaceous sandstone	25
Pinkish, massive soft sandstone	6
Talus	50
Buff, slabby, ripple-marked sandstone	12
Talus	20
Greenish shale	5
Buff sandstone	3
Spearfish red beds.	

The sandstone at the top of this section is a very conspicuous member for some miles on the south side of Spring Creek, and it appears to have developed out of the sandy beds which usually overlie the upper green shales to the south. It is possible, however, that it is a representative of the lower portion of the Unkpapa sandstone, which is thin in this vicinity.

Returning to the region south of Hot Springs there is found at Cascade a fairly complete section of the Sundance beds, having a thickness of 400 feet. They comprise from the top a succession of green shales with fossil-bearing layers, a considerable thickness of red sandy shales, the usual heavy bed of buff, slabby, ripple-marked sandstone, 60 feet of green shales, and a basal massive red sandstone lying on the red beds.

Along the southern margin of the uplift there are extensive exposures of the Spearfish beds, which present interesting features. The following section, made near Minnekahta Station, is typical for a wide area:

Section near Minnekahta Station, South Dakota.

Beulah shales.	Feet.
Grayish-green shales, with thin fossiliferous limestone layers	105
Red sandstone, with some red and green shales	75
Pale greenish buff thin-bedded sandstones	10
Pale grayish green shales	10
Buff, flaggy, ripple-marked sandstones	35
Gray shales	40
Red sandstone, coarse, massive, fossiliferous	25
Spearfish red beds.	

The basal red sandstone is a conspicuous member for several miles to the west, but toward Pass Creek it finally thins out and disappears. Its aspect near Red Canyon is shown in Pl. LXXIII, *A*, which shows also the contact with the red beds.

Along the western slope of the Black Hills in the vicinity of Newcastle and Cambria the Sundance formation presents the following average section:

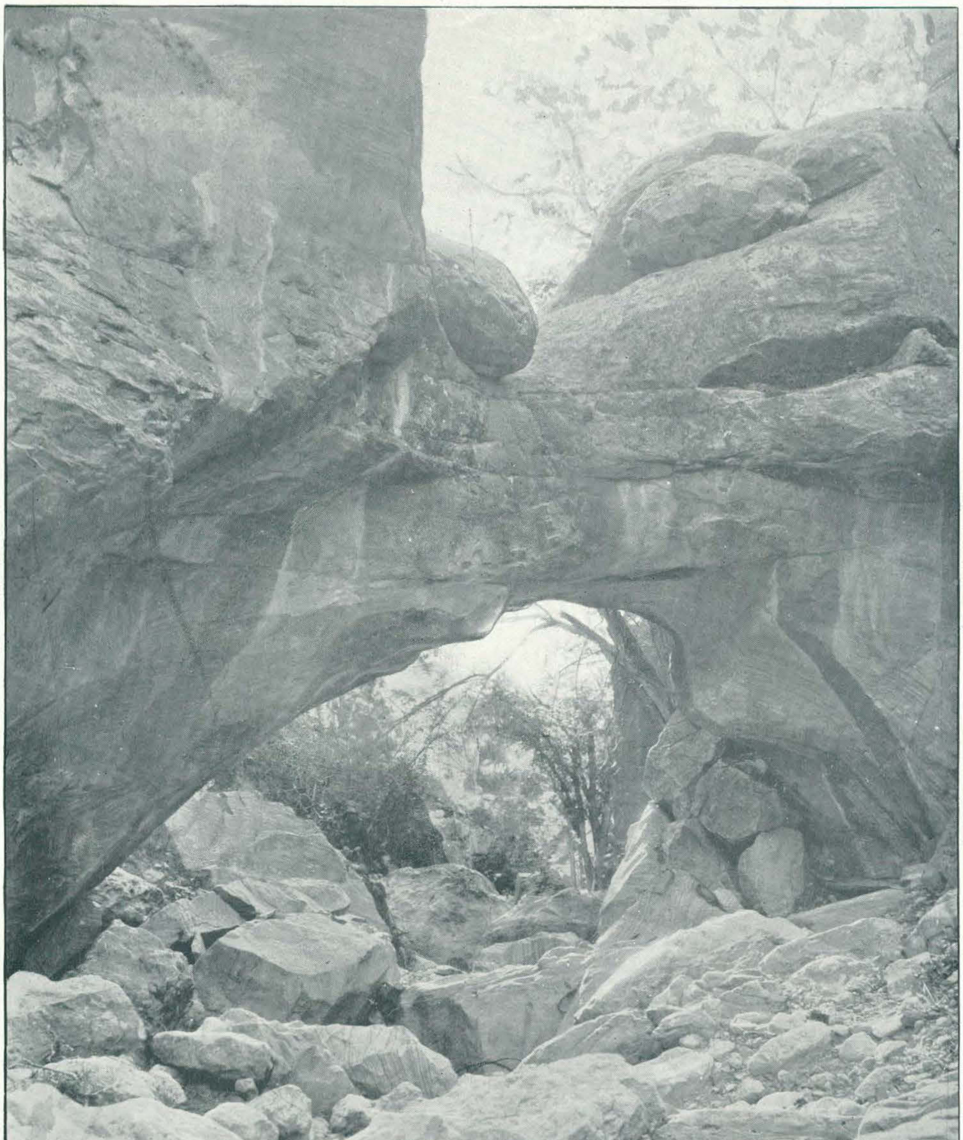
Section near Newcastle and Cambria, Wyoming.

Beulah shales.	Feet.
Greenish shales, with fossiliferous calcareous layers	120
Red, sandy shales	50
Thin sandstone and shales	25
Light-buff, slabby, ripple-marked sandstone	25
Greenish gray shales	60

These features continue far to the north, with some variations in thickness and minor changes in local included beds.

UNKPAPA SANDSTONE.

This formation is always clearly separable both from the Sundance shales below and the Beulah shales or Lakota sandstone above. It is a massive, fine-grained sandstone varying from white to purple and



NATURAL BRIDGE IN BANDED UNKPAPA SANDSTONE, 2 MILES WEST OF BUFFALO GAP STATION, SOUTH DAKOTA.

buff. Its greatest development is in the foothill ridges or hogbacks east of Hot Springs. Its first outcrops southward are observed about Cascade Springs, and it extends continuously from that region past Hot Springs, all along the eastern side of the hills, its thickness diminishing north of Buffalo Gap. Some of its exposures east of Hot Springs are very striking in their colorings of brilliant pink, purple, and pure white. The thickness is greatest in Sheps Canyon, southeast of Hot Springs, where 225 feet were measured. In three of the canyons between Fall River and Buffalo Gap it has been quarried to some extent for building stone. In Pl. LXXIV, *B*, is shown a typical outcrop of the Unkpapa sandstone, and in Pl. LXXV a natural bridge cut through the formation near Buffalo Gap. Portions of the rock are beautifully banded with various colors, in part along the stratification planes, but often diagonal to them. In the quarry west of Buffalo Gap these banded beds exhibit minute faulting in a most instructive manner, affording fine illustrations of block-fault phenomena. Pl. XCIII is from a photograph of a typical block of the faulted rock. The sandstone is characterized in general by its fine grain and very massive but uniform texture. Contacts with the overlying buff sandstones of the Lakota formation are frequently exposed, and they are seen to be marked by considerable unconformity due to erosion. One of them is shown in Pl. LXXIV, *A*. The name Unkpapa is that of one of the tribes of Dakota Indians, which was at one time located about the southeastern portion of the Black Hills.

BEULAH SHALES.

This Jurassic member has been designated the Atlantosaurus beds by Marsh and others, but recently Mr. W. P. Jenney,[1] in describing some of the overlying formations in the northern hills, has named it the Beulah shales. It is this member that has yielded the remains of a number of large saurians, collected for Professor Marsh on the north side of Piedmont Butte. The formation was regarded by Marsh as unquestionably Jurassic in age, a view which has been generally accepted. The Beulah shales first make their appearance northwest of Hermosa, lying between the Unkpapa sandstone and the Lakota formation. They thicken rapidly in their extension northward, and pass around the northern and western side of the hill as a prominent member of the series. Beyond the edge of the Unkpapa sandstone they lie conformably upon the Sundance formation, and, owing to the similarity of materials, might not be readily separated if their true relations had not been determined on the east side of the uplift. They finally thin out north of Edgemont. The formation is mainly composed of a dark shale, much more fissile and darker to the east than to

[1] Nineteenth Ann. Rept. U. S. Geol. Survey, Part II, p. 593.

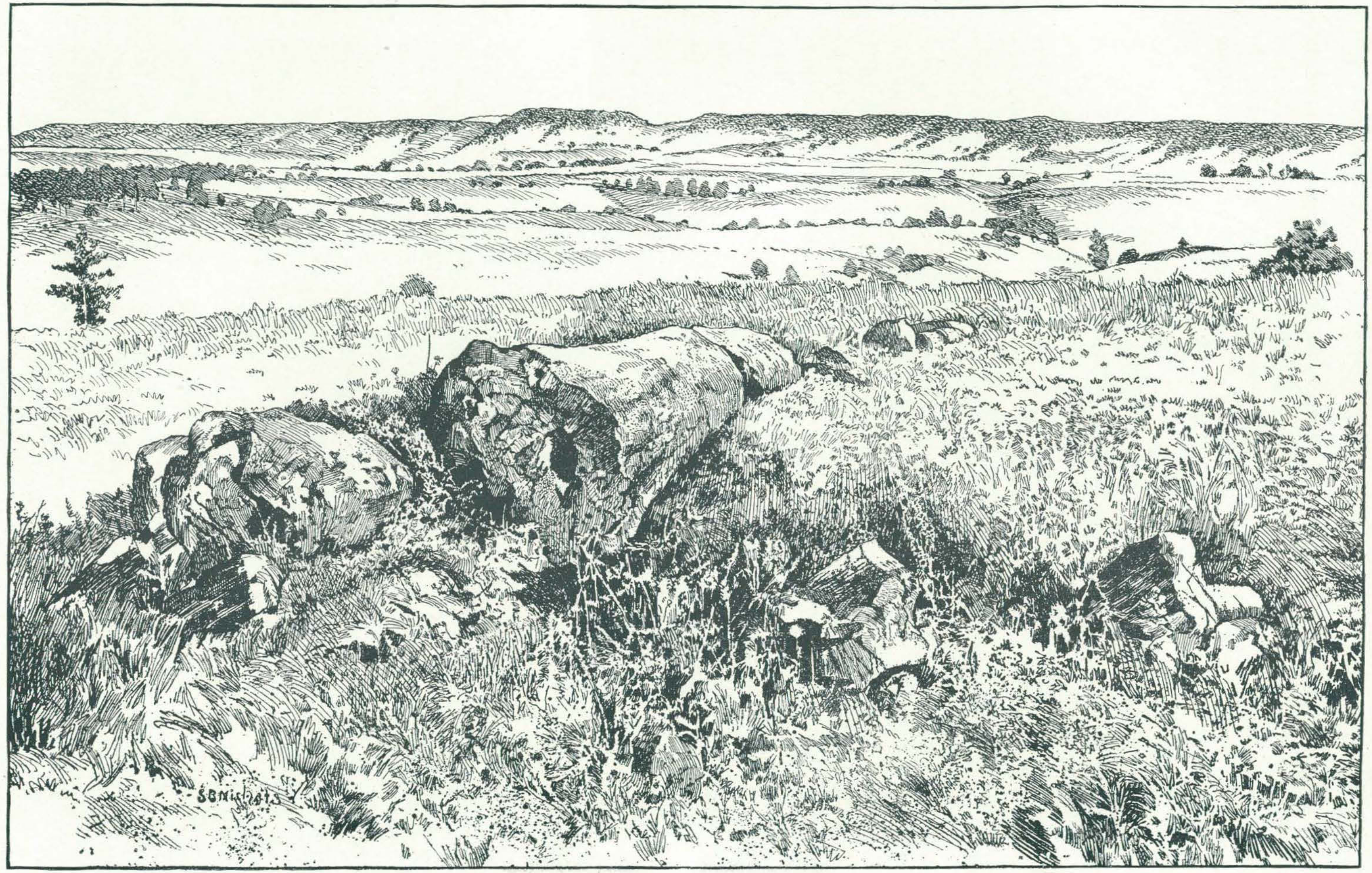
the north and west. From Sundance to Cambria and Minnekahta it is a light greenish gray, somewhat massive mixture of clay and sand, moderately hard, but crumbling more or less on weathering. In this area some of the beds exhibit purple tints. A few thin sandstone beds are included throughout.

CRETACEOUS.

All of Cretaceous time appears to be represented by the deposits in the region adjoining the Black Hills. The Lakota formation, if not of late Jurassic age, represents the earliest deposit of the Lower Cretaceous, while the uppermost members of the Laramie formation are generally regarded as extending to the end of the Cretaceous period. The deposition appears to have been essentially continuous throughout, for there are no important unconformities that are general over the entire region. The Fox Hills sandstones may possibly thin out to the northwestward, but this would not necessarily indicate either an uplift or a cessation of deposition, but probably a change from salt-water to fresh-water deposition. There are some suggestions of a possible time break at the top of the Dakota sandstone in the sudden change from sandstone to shale, and in the Lakota formation there are local unconformities probably indicating short periods of local uplift. The total thickness of the Cretaceous formations about the Black Hills is at least 5,000 feet, this estimate including a large portion of the Laramie formation. All of the formations are uplifted by the Black Hills dome, often to steep angles. The individual formations in greater part present the same features which they have over many thousand square miles in the Rocky Mountains and adjoining regions, particularly the Benton, Pierre, and Niobrara formations. The sandstone series formerly designated "the Dakota sandstone" or "Cretaceous No. 1," has in the last few years been found to comprise not only a formation carrying an Upper Cretaceous flora but an extensive series of Lower Cretaceous deposits as well. Accordingly, the term Dakota has been restricted to the upper sandstone, containing the Upper Cretaceous flora, while the much thicker lower series has been separated as Lower Cretaceous, and as it consists of several stratigraphic units these will here be differentiated as separate formations. The name Dakota will be restricted to the upper sandstones of which the upper beds have yielded plants of the well-known typical Dakota flora.

LAKOTA FORMATION.

This formation, which consists mainly of sandstone, gives rise to the crest and broader features of the hogback ranges forming the outer encircling rim of the Black Hills. It is also brought to the surface in the steep anticline on Old Woman Creek. The sandstones are hard, coarse grained, cross bedded, and massive, with partings of shale of



FOSSIL TREE TRUNK ON LAKOTA SANDSTONE, 3 MILES SOUTHWEST OF MINNEKAHTA, SOUTH DAKOTA.

no great thickness. Locally it includes beds of coal, which about Cambria and on Hay Creek are mined to some extent. Its thickness is usually from 200 to 300 feet, with certain local variations, most of which are shown in Pl. LXVI. Throughout its course it lies unconformably on the Jurassic Beulah shales to the north and west and on the Unkpapa sandstone to the east and south. The amount of unconformity is not known and the period of uplift it represents was not one of flexing of sufficient amount to give rise to any material discordance in dip. A typical exposure of the unconformity is represented in Pl. LXXIV, *A*. In this view may be seen irregularities on the surface of the Unkpapa sandstone, clearly due to channeling in the pre-Lakota interval. The name Lakota is derived from one of the tribal divisions of the Sioux Indians. It was first used in the later part of 1899 in my preliminary account of the Jurassic formations of the Black Hills.[1]

The formation has yielded a large number of cycads, notably those described by Mr. Lester F. Ward.[2] These and the associated plants are regarded by Mr. Ward as Cretaceous in age. In 1898 I discovered saurian bones in or near the cycad horizon at Buffalo Gap, but as they are of new species it is difficult to obtain from them any evidence bearing on the age of the formation. If it were not for the evidence of the flora, these bones would be regarded as late Jurassic in age. They will soon be described by Dr. F. A. Lucas, of the United States National Museum. The bone-bearing beds are in the middle of the Lakota formation, or about 90 feet above the unconformity on the Unkpapa sandstone, which is at approximately the horizon that has yielded cycads in the region between Edgemont and Minnekahta, near Blackhawk, and elsewhere about the hills.

Throughout its course the Lakota formation presents predominantly the features above described, but there are frequent local variations in the thickness of the beds and in the occurrence of intercalated fine-grained members. In the canyon of Fall River the formation has a thickness varying from 225 to 250 feet. The beds of sandstone are very massive, but they are separated by greenish-gray shales 15 to 20 feet thick at several horizons. The uppermost member, a dull yellow sandstone, is immediately overlain by the Minnewaste limestone, of which the relations are shown in Pl. LXXVIII. This view represents a fine exposure just west of Evans's quarry, near the mouth of the canyon. It exhibits the greater part of the Lakota formation, the Minnewaste limestone, with a steep slope of Fuson beds overlain by talus, and a thick capping of massive buff sandstone of the Dakota formation, which is worked near by, at Evans's quarry. In the high ridges and their numerous deep canyons east of Hot Springs the Lakota formation is the prevailing feature. Many of the surfaces of the ridges are

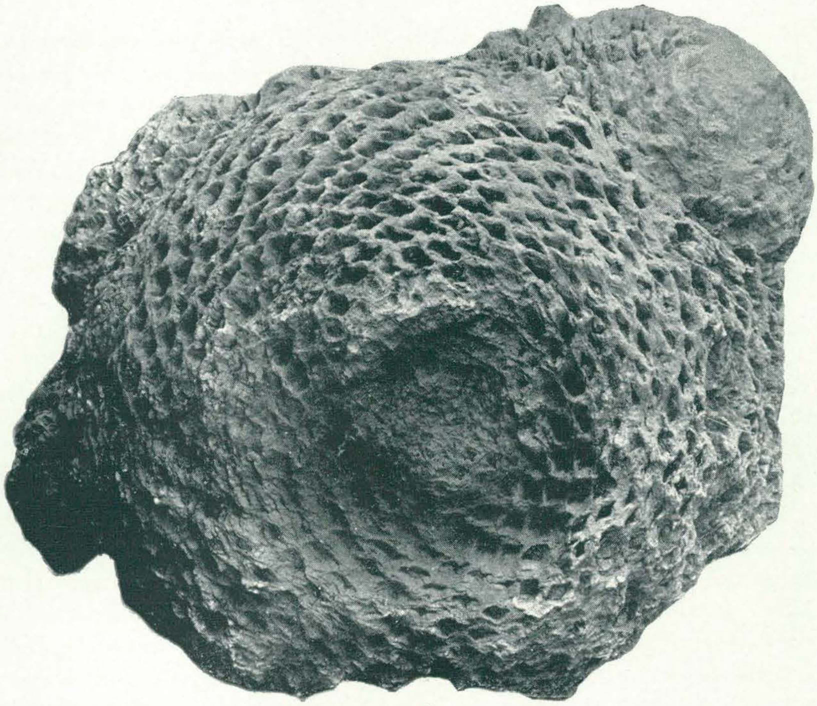
[1] Bull. Geol. Soc. America, Vol. X, p. 387.
[2] Jour. Geol., Vol. II, pp. 250-266; and Nineteenth Ann. Rept. U. S. Geol. Survey, Part II, pp. 521-958.

strewn with fragments of fossil trees which have been weathered out of the sandstone. The occurrence of these trees appears to characterize a horizon high in the formation over a considerable area in the southern portion of the Black Hills. In a locality 3 miles southwest of Minnekahta, described in considerable detail by Mr. Lester F. Ward, some of these trunks are alluded to. One of the finest is shown in Pl. LXXVI. It has a diameter of nearly 3 feet at the butt, and more than 20 feet of the trunk remains. It was in the vicinity of this locality that a large number of cycads were obtained a few years ago. As these cycads are a very distinctive feature of the formation, the accompanying illustration (Pl. LXXVII) is reproduced from Ward's report. In the vicinity of Cascade Springs the Lakota and associated formations stand nearly vertical, but the exposures are not particularly good. A thickness of about 275 feet is exhibited. A short distance west, where the dips rapidly diminish, the formation spreads out into a wide table sloping to the south, with a high escarpment on the north side overlooking the wide Red Valley about Minnekahta. In this locality the formation is extensively exposed in the walls of numerous canyons which empty into Cheyenne River. This river, in cutting a gorge through the end of the anticline below Edgemont, has given an excellent exposure of the entire thickness of the formation from the underlying Beulah shales to the overlying Fuson formation. The principal members are coarse-grained, cross-bedded, massive, light-colored sandstones, here containing a number of basins of coal. That these deposits lie in shallow, eroded basins is clearly exposed in some of the cliffs of the canyon. The coal varies in thickness from a few inches to 4 feet, and occurs about 60 feet above the base of the formation. Apparently, in earlier Lakota times there was in this vicinity an uplift of the sandstone attended by some channeling of its surface, and in these channels there accumulated coal, which was buried by the subsequent deposits of sand. From here for many miles northward along the west side of the hills coal occurs at intervals, culminating in the thick deposit about Cambria. The coal basin at that place will be described on page 582. The general section there is as follows:

General section at Cambria, Wyoming.

	Feet.
Thin-bedded sandstones	20
Massive buff sandstone	40
Shale and talus	40
White sandstone with conglomerate	45
Sandstones, in part covered	65
Massive, light-gray, soft sandstone	40
Coal	7
Sandstone	10

On the wide, tabular surfaces about Cambria and northwest of Newcastle the Lakota and Dakota formations are the prevailing feature,



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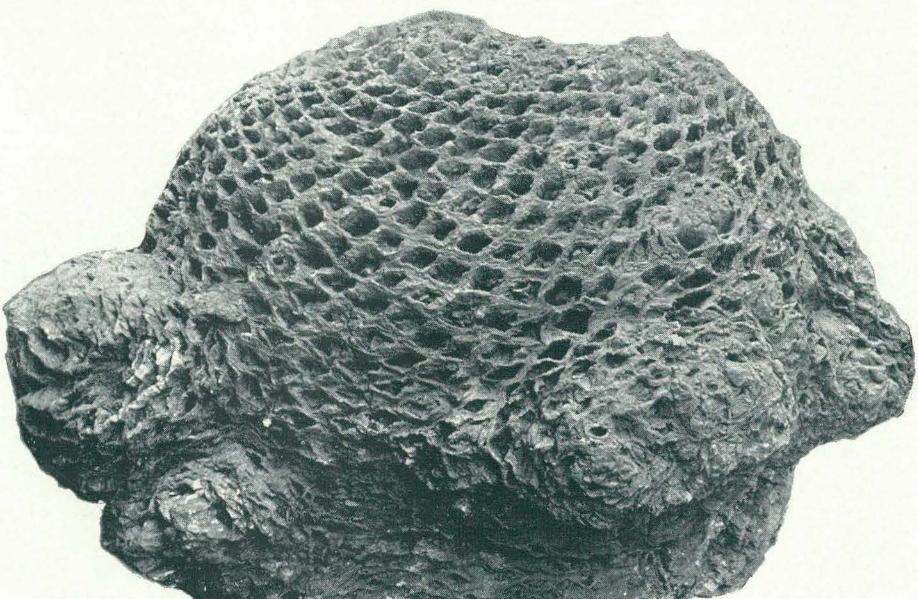

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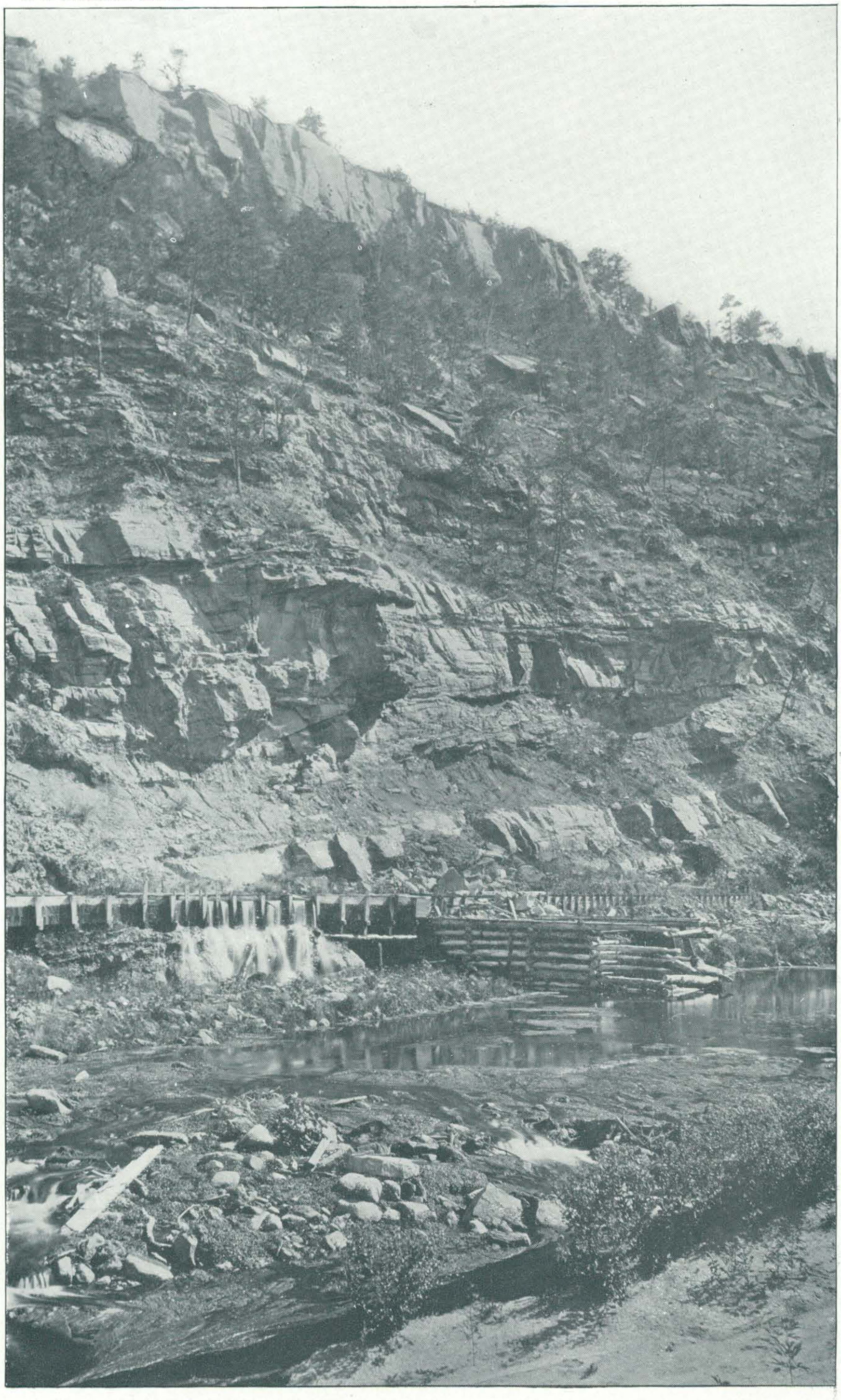
CENTIMETERS

CYCADEAN TRUNK FROM THE LAKOTA FORMATION IN THE BLACK HILLS.



DAKOTA SANDSTONE, FUSON FORMATION, MINNEWASTE LIMESTONE, AND LAKOTA FORMATION ON SOUTH SIDE OF FALL RIVER CANYON, AT EVAN'S QUARRY, 4 MILES BELOW HOT SPRINGS, SOUTH DAKOTA.

their wide extension being due to the hardness of the sandstones and the low dips. Numerous canyons traverse this plateau, cutting through the Lakota beds more or less deeply into the underlying Beulah shales. In the deep ravine behind the Mount Zion ranch the following section is exposed, beginning not far below the top of the Lakota formation:

Section near Mount Zion ranch, Wyoming.

	Feet.
Light-colored massive sandstones, with a conglomeratic layer near its base	200
Bony coal	½
Hard sandstone	3
Coal	4
Sandstone, with coaly streaks	1
Coal	2
Sandstone, with stems, etc	2
Sandstones, mainly light colored and massive	40
Beulah shales.	

In the uplift on Old Woman Creek the Lakota sandstone is clearly defined, lying between the light-colored shales of the Fuson formation above and the greenish-gray Beulah shales below. It is mainly a coarse conglomeratic sandstone, varying in thickness from 40 to 70 feet.

MINNEWASTE LIMESTONE.

This formation overlies the Lakota sandstone from the vicinity of Cascade Springs northward to Buffalo Gap. For the greater part of its course it has a thickness of only 25 feet, but it is conspicuous on the hogback ranges east of Hot Springs, extending far up the slopes on some of the higher divides. Its occurrence was not mentioned by Ward in his description of the section at Evans's quarry, where, as shown in Pl. LXXVIII, it is a conspicuous feature. It is a nearly pure light-gray limestone, presenting a uniform character throughout. An extended search has failed to detect any fossils in it, but it is supposed that it is of Lower Cretaceous age, because it lies considerably below the Dakota sandstone. The formation thins out rapidly north of Buffalo Gap, and appears to be entirely absent in the canyon of Fuson Creek. It is thin at Cascade Springs and disappears a short distance to the west, but appears again locally at the head of Bennet Canyon, east of Argentine siding. One of the most extensive exposures of the limestone is at the falls of Cheyenne River. These falls are due to this formation, the water falling over a ledge of it about 20 feet high. The name Minnewaste is the Dakota Indian name for Cheyenne River. Extensive exposures may be seen in the anticline 2 miles east of Hot Springs, where, with a steep dip to the west, it covers a wide area of the western slope of the anticlinal ridge. In the anticline on the east side of Old Woman Creek there is exposed at one point a thin layer of limestone which appears to be an extension of the Minnewaste. It lies immediately above the Lakota sandstone and is overlain in regular order by mudstones of the Fuson formation.

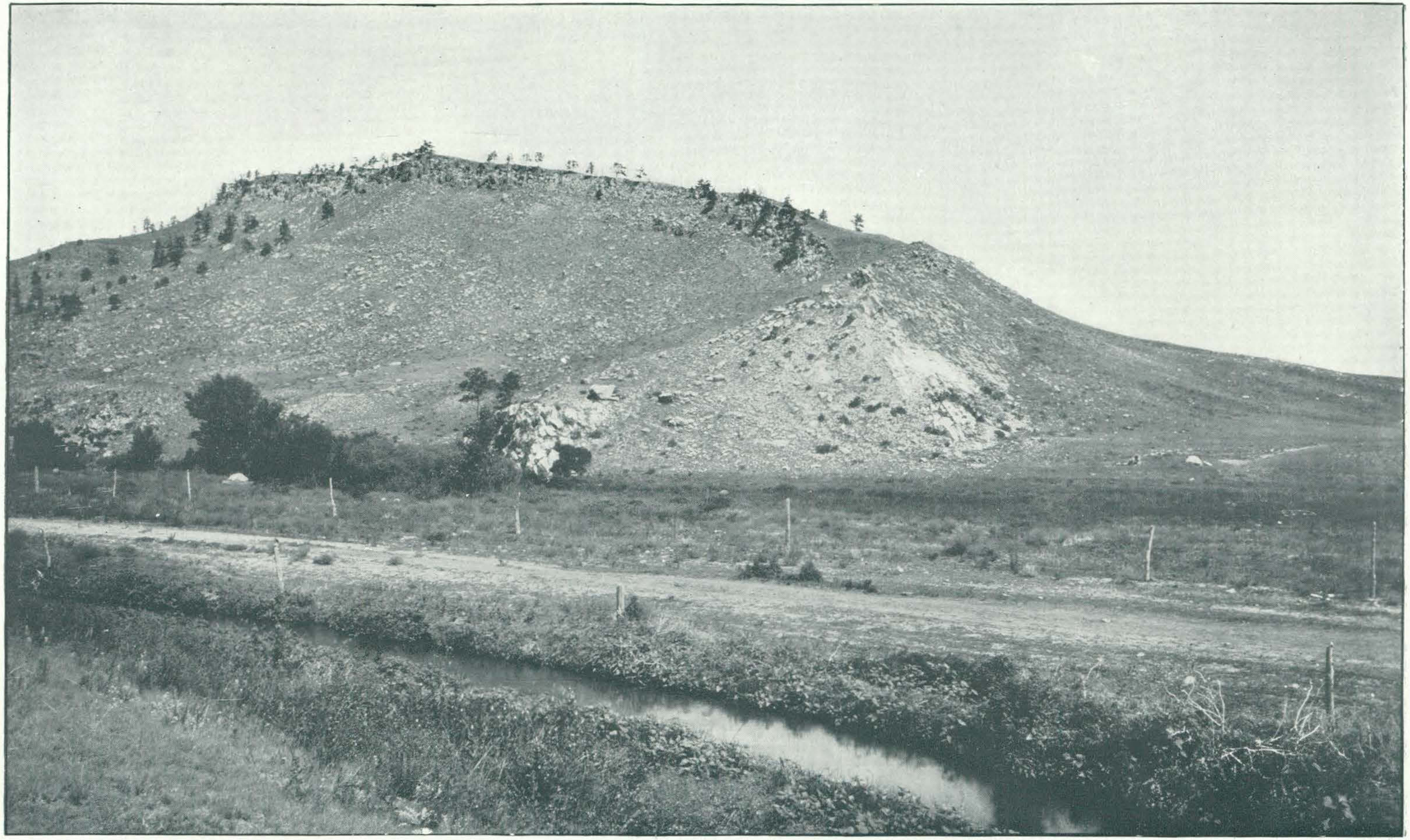
FUSON FORMATION.

This is a series of fine-grained deposits lying between the Dakota sandstone and the Lakota sandstone and nearly encircling the Black Hills. Its thickness averages about 100 feet. The material consists of a mixture of fine sand and clay, usually massively bedded and weathering out in small cylindrical blocks like dry starch. Some beds of coarser sandrock are locally included and other portions are nearly pure shale. The predominant color is white or gray, but buff, purple, and maroon tints are often conspicuous. As the formation is relatively soft as compared with the adjoining sandstones, it usually gives rise to a depression between a low crest of Dakota sandstone on the one hand and the higher summits of the Lakota sandstones on the other. No fossils have been found in the formation, so that we have no evidence as to its precise age. One of the most extensive exposures is at the falls of Cheyenne River, shown in the bluff to the left on Pl. LXXX. The section at this interesting locality is as follows:

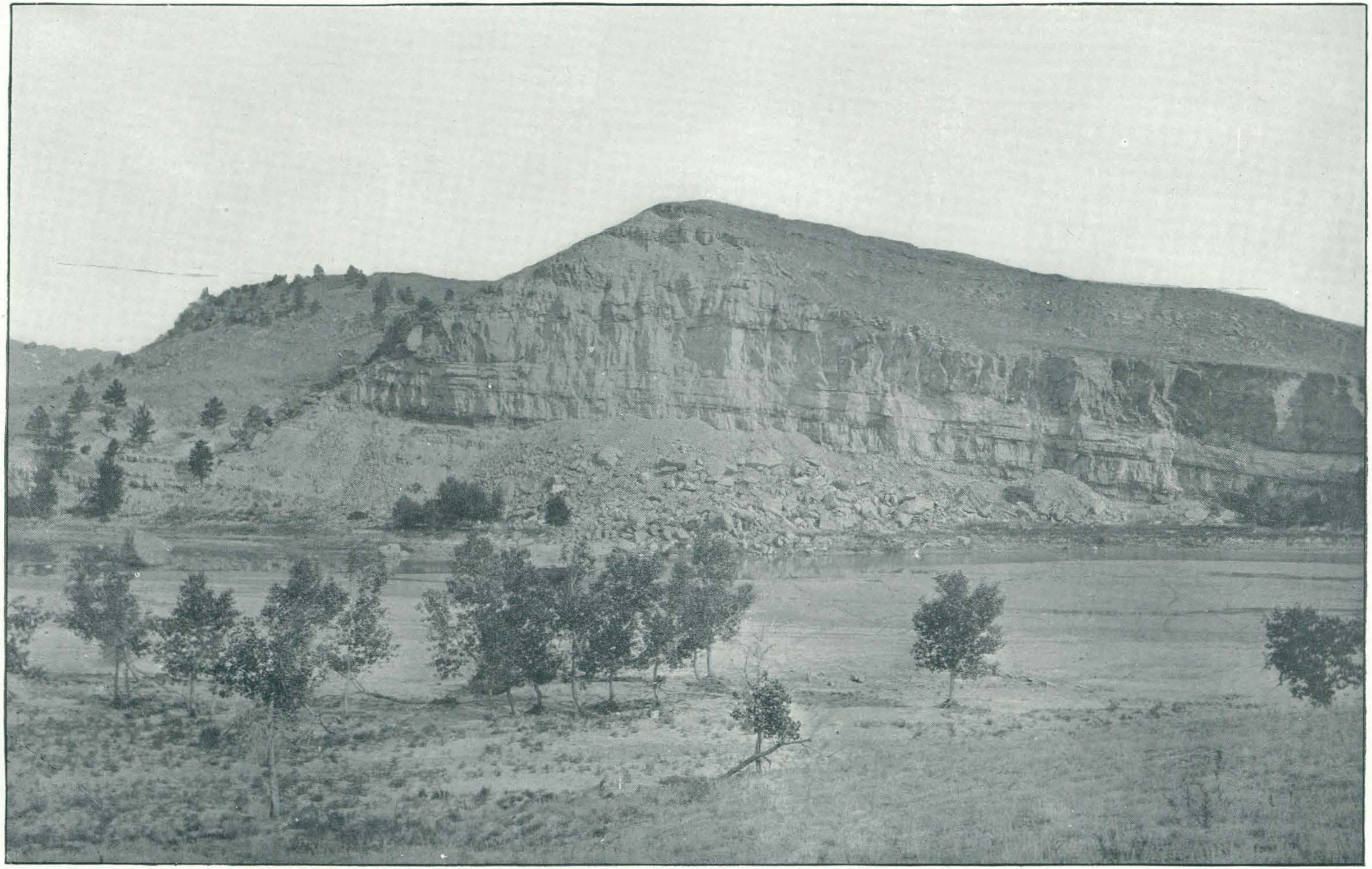
Section at falls of Cheyenne River, South Dakota.

	Feet.
Dakota sandstone.	
Dark sandy shale	4
Soft, gray, slabby sandstone; plants	6
Compact white mudstone	8
Dark-green clay	1
Dark-gray compact mudstone	25
Very compact white mudstone	2½
Gray mudstone	6
Harder white mudstone	9
Purplish shale	1
White fine-grained sandstone	5 to 12
Purple shale	6 to 8
Light-buff massive sandstone	25
Dark-buff coarser sandstone, much honeycombed by weathering	25
Minnewaste limestone.	

Outcrops of the formation are considerably obscured by talus along the canyon of Fall River, but there are extensive exposures in the sides of the canyons in this vicinity, notably in the canyon on the steep side of the anticline 2 miles due east of Hot Springs, where much of the material is bright purple and strongly resembles a shale which has been subjected to alteration by the presence of igneous matter. Fuson Canyon affords some striking exposures of a portion of the Fuson formation in cliffs capped by the Dakota sandstone. The uppermost bed is a moderately hard sandstone underlain by 10 feet of purplish-gray shale, then 10 feet of white mudstone and 20 feet of bright purple shale. The name of the formation is derived from that of this canyon. On Dry Creek the formation is represented by 50 feet of white mudstone. On Squaw Creek the Dakota sandstone is overlain by about 50 feet of buff and purple mudstones, grading upward to the Dakota sandstone through several feet of shale and thin sand-



DAKOTA SANDSTONE ON NORTH SIDE OF BUFFALO GAP; IRRIGATION DITCH IN FOREGROUND.



DAKOTA SANDSTONE AND FUSON FORMATION AT FALLS OF CHEYENNE RIVER, LOOKING NORTHEAST.

stone. Northwest of Hermosa mudstones of bright color prevail, much of the material being purple. One section exhibits the following components:

Section northwest of Hermosa, South Dakota.

	Feet.
White and dark mudstones	20
Buff massive sandstone	0–10
Gray clay	3
Light-buff thin sandstone	3
Sandy light-gray shale	18
Soft white sandstone	0–20
Mottled purple mudstone	30

The Fuson formation extends around the southern and western side of the hills, but north of Elk Mountain it becomes thinner and often so sandy as to be difficult to distinguish from the Dakota sandstone. In a section on Cheyenne River northeast of Edgemont the following measurements were made by Mr. Richardson:

Section of Fuson formation on Cheyenne River northeast of Edgemont, South Dakota.

	Feet.
Purplish mudstone	3
Greenish mudstone	4
Drab mudstone	3
Calcareous mudstone	1½
Dark mudstone	3½
Purple mudstone	1
Dark shale	1
White cherty limestone	1½

The Fuson mudstones are brought to the surface by the anticline on the east side of Old Woman Creek, where the material is mainly gray and has a thickness of about 60 feet.

DAKOTA FORMATION.

This formation is the uppermost member of the series formerly designated, in the Black Hills region, the Dakota sandstone. It is thin, being rarely over 100 feet thick, and constitutes only a small part of the mass of the hogback range. It is, however, a conspicuous formation, because the foothills to which it usually gives rise slope steeply out of the adjoining valley or level plain underlain by the Graneros shales. It generally consists of a brown sandstone, hard and massive below but thinner bedded above. It appears to extend continuously around the hills. The fossil plants which have been obtained from it are impressions of dicotyledonous leaves occurring in the upper portion of the formation. Prof. L. F. Ward has described their occurrence at Evans's quarry, east of Hot Springs, South Dakota. Some aspects of the Dakota sandstone are shown in Pls. LXIV, LXXVIII–LXXX. The more massive variety of the rock is shown in Pl. LXXVIII, at the top of the cliff. Here the dip is steep and soon carries the formation down to the floor of the canyon, where it gives rise to a series of cascades in the bed of Fall River. This is the ledge that is worked extensively for building stone at the quarries adjoining the cascades, and furnishes the grindstones at Edgemont.

GRANEROS SHALE.

This shale is the lowest member of the Benton group, and it is believed to be the precise equivalent of the Graneros shale of southeastern Colorado, for it lies between the Dakota sandstone and a very characteristic limestone layer which in both regions is filled with impressions of the same *Inoceramus*. It extends entirely around the Black Hills uplift, with a course usually marked by lowlands and valleys all the way. In some areas it contains, near its base, a thin layer of hard sandstone which often rises in a ridge of considerable prominence. This sandstone is a noticeable feature in the vicinity of Newcastle, where it contains petroleum and has been explored as an oil sand. It there attains a thickness of 30 feet and lies 275 feet above the Dakota sandstone. To the north, in the vicinity of Pedro, it thins to less than a foot in thickness, and in the vicinity of Edgemont it disappears. In the Newcastle region it is overlain by 600 feet of black shales, constituting the remainder of the formation which here, consequently, has a total thickness of 900 feet. The formation thins slightly toward Edgemont, but to the northeast its thickness is about 900 feet, and, so far as could be ascertained from numerous cross-section measurements, with rather uncertain dip determinations, this amount continues uniform for many miles. These measurements may be in error a hundred feet either way. West of Hermosa the sandstone again comes in about 200 feet above the base of the formation and attains a thickness of about 15 feet, being traceable for about 4 or 5 miles and then thins out again. At a point 2 miles north of Hermosa the sandstone contains abundant impressions of fossil leaves.

At several localities the Graneros shale is traversed by sandstone dikes. The first of these is at the southern end of the anticline east of Maitland, where dikes from the underlying Dakota sandstone extend for some distance through the lower beds of the shale. The largest of the dikes at this locality is 20 feet wide. The dikes have a linear arrangement occurring in a narrow zone about a mile in length having a north-northeast-south-southwest direction. Several small dikes are observed in the shale on the north bank of Cheyenne River a little more than a mile southeast of Evans's quarry. Another group of them may be seen north of Lame Johnny Creek, 7 miles north of Buffalo Gap.

GREENHORN LIMESTONE.

One of the most prominent features in the plains immediately adjoining the Black Hills is a low but distinct escarpment due to a hard limestone bed in the middle of the Benton group. It usually lies from a mile to 4 miles distant from the hogback ridge of the Dakota sandstone and presents its face toward the hills. The limestone is thin but persistent and is characterized by large numbers of impressions of *Inoceramus labiatus*, which is of infrequent occurrence in the adjoining formations. As this limestone occurs at apparently the same horizon about the Black Hills as in southeastern Colorado, I have applied to it the name Greenhorn, by which it has been designated by Mr. Gilbert in the Pueblo region.

The Greenhorn limestone contains a considerable amount of clay and fine sand. It appears to gain hardness on weathering, breaking out into hard, thin, pale-buff slabs covered with impressions of the distinctive fossil. (See Pl. XCVIII.) Its thickness averages about 50 feet. At its base it is usually distinctly separated from the dark shales of the Graneros formation. The upper portion of the limestone appears to grade into shales of the Carlile formation through 6 or 8 feet of passage beds. The most extensive exposures of the Greenhorn limestone are in the prominent escarpments west and northwest of Edgemont, where they rise high above the slopes extending up from the west side of Cheyenne River. Owing to the low dip in this vicinity the limestone is spread out in plateaus extending back for some distances from the edge of the escarpment. In Weston County, Wyoming, where the dip soon increases in amount, the escarpment ceases, giving place to a small but very persistent ridge of nearly vertical beds, which continues for many miles to the north. In the ridge south of Newcastle there is a local diminution of dip in which the formation again spreads out into a narrow sloping plateau for a few miles. In the region about Fairburn the formation is traversed by a syncline which spreads it out into a bifurcated ridge south of the town. On the adjoining divides, notably in those between French Creek and Battle Creek and Battle Creek and Spring Creek, the formation is buried beneath the overlapping White River deposits. It is well exposed in the banks of Battle Creek 1½ miles below Hermosa, where in its but slightly weathered condition in the fresh stream cut it is seen to be a hard, calcareous, light-gray shale filled with inocerami.

CARLILE FORMATION.

The series of shales, with thin sandstone and impure limestone layers, lying between the Greenhorn limestone and the Niobrara chalk is so similar in character and relations to the deposits occupying the same position in southeastern Colorado that it is here designated by the term which was applied to it by Mr. Gilbert in the Pueblo region. The formation consists mainly of shales, with two thin hard beds of sandstone, the upper one calcareous, and at the top several layers with oval concretions. The thickness varies from 500 to slightly over 700 feet, the larger amount being in the region about Newcastle. Some typical sections are as follows:

Section of Carlile formation near Buffalo Gap, South Dakota.

	Feet.
Niobrara chalk.	
Shales, with large buff concretions	150
Hard, slabby sandstone	2
Gray shale	130
Thin, coarse sandstone	4
Gray shale	75
Concretions in gray shale	2
Gray shale	40
Calcareous beds, with Ostrea, etc	4
Shale and talus	180
Greenhorn limestone.	

Section of Carlile formation 1½ miles southeast of the falls of Cheyenne River, South Dakota.

	Feet.
Niobrara chalk.	
Gray shale, with large buff concretions	50
Gray shale	70
Light-gray sandstone	4
Dark-gray shale, with thin sandy layers	160
Sandstone	2
Gray shales	150
Greenhorn limestone.	

Section of Carlile formation 3 miles west of Newcastle, Wyoming.

	Feet.
Niobrara chalk.	
Dark shales, with light-colored concretions	130
Dark shales	200
Calcareous concretions	3
Sandy shales, with thin sandstones	170
Brown sandstone	4
Dark shales	200
Greenhorn limestone.	

Section of Carlile formation north of Pedro, Wyoming.

	Feet.
Niobrara chalk.	
Drab shales, with numerous concretions near top	550
Thin-bedded sandstone	5
Shale	30
Sandstone, drab below, reddish above	30
Dark shale	50
Thin-bedded, light-brown sandstone	35
Gray shales	90
Greenhorn limestone.	

The thickening of the sandstones in this section is due mainly to intercalations of sandy shales.

The stratigraphy of the Carlile formation in the uplift on Old Woman Creek presents the usual features above described. They are set forth in detail in fig. 283.

NIOBRARA FORMATION.

The calcareous deposits of the Niobrara formation completely encircle the Black Hills, presenting their distinctive features throughout the region to which this report relates. The material is a soft, shaly limestone or chalk, containing greater or less admixture of clay and fine sand. Its weathered outcrops have a bright-yellow color which usually renders them conspicuous, although, owing to the softness of the materials, they rarely give rise to noticeable ridges. The thickness of the formation is about 225 feet. In unweathered exposures the material is usually light gray. Thin beds of hard limestone are often included, consisting of an aggregation of shells of *Ostrea congesta*, a fossil very distinctive of the formation when it occurs in this manner. (See Pl. XCVIII.)

PIERRE SHALE.

Many thousand square miles of the country adjoining the Black Hills are occupied by the Pierre shale. It is a thick mass of dark-colored shale, weathering light brown, and relatively uniform in composition throughout. It gives rise to a dreary monotony of low, rounded hills, sparsely covered with grass and not very useful for agriculture. The formation is about 1,200 feet thick, so far as can be ascertained, but it is only rarely that its thickness can be measured. Where it dips gently away from the hills it is almost impossible to measure the rate of dip of the shale. Fortunately it has been found that the formation includes, at a horizon about 1,000 feet above its base, scattered lenses of limestone usually containing numerous shells of *Lucina occidentalis*. The greater number of these lenses occur at the definite horizon just mentioned, and as in some places they occupy the surface over a wide area, they throw light on the structure of the formation. It is from evidence of this sort that we have made some of the determinations of structure which afford an important part of the data for Pls. XCVI and XCVII. The limestone lenses with *Lucina* vary in size from 2 or 3 cubic feet to masses 20 feet in diameter and 6 or 8 feet thick, usually of irregular lens shape. A typical occurrence of one of these lenses in a bank of shale is shown in Pl. LXXXI, *B*. Owing to their hardness these lenses when they are uncovered by erosion give rise to low conical buttes resembling in form a very squat tepee. Accordingly they have been designated tepee buttes, a term used by G. K. Gilbert for similar occurrences in the Pierre shale of southeastern Colorado.[1] They occur in large numbers in the vicinity of Oelrichs, varying in height from 10 to 150 feet above the surrounding slopes. The lenses occur at irregular intervals horizontally, so that the Tepee buttes are scattered very irregularly and are sometimes separated by many miles. They occur in considerable number west and southwest of Newcastle. Some are shown in Pl. LXXXI, *A*. The occurrence of these tepees in some of the steeply tilted sections of the Pierre and underlying formations in Converse and Weston counties, particularly

[1] Tepee buttes, by G. K. Gilbert and F. P. Gulliver: Bull. Geol. Soc. America, Vol. VI, pp. 333–342, Pl. XVII.

near Old Woman Creek, has afforded opportunity for determining the distance of the horizon above the base of Pierre shales. Numerous concretions occur in the Pierre shales at various horizons and usually contain large numbers of very distinctive fossils, of which the more abundant are of the following species: *Baculites compressus*, *Inoceramus sagensis*, *Nautilus dekayi*, *Placenticeras placenta*, *Heteroceras nebrascense*, and an occasional *Lucina occidentalis*. The most fossiliferous horizon is in the upper part of the formation. The concretions are generally of small size, of a siliceous nature, and break into small pyramidal fragments which are more or less scattered over all the Pierre surfaces. At the base of the formation, overlying the Niobrara chalk, there is always a very distinctive series of black, splintery, fissile shales containing three beds of concretions, which I have included in the Pierre shales, although they have not yet been found to contain distinctive fossils. The series is about 150 feet thick, and it gives rise to a steep slope that often rises conspicuously above lowlands eroded in the Niobrara chalk. The concretions exhibit a curious sequence. The lower ones are biscuit shaped, hard, and siliceous. Those in the layers next above are similar in shape and composition but are traversed in every direction by deep cracks filled with calcite and sometimes scattered crystals of barite. Next above are two or three layers of large, lens-shaped, highly calcareous concretions of a light straw color, with beautifully developed cone-in-cone structure.

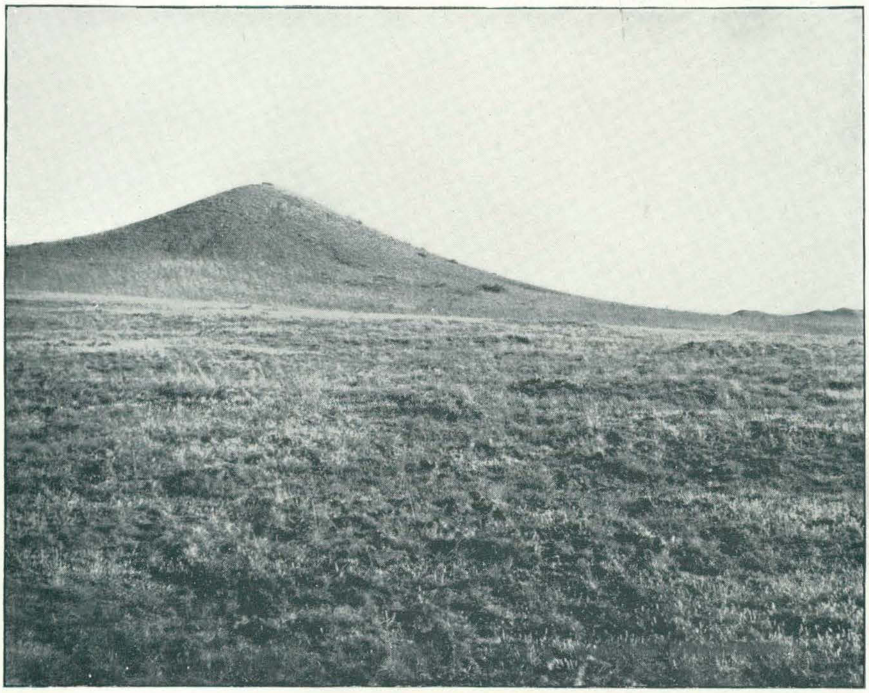
FOX HILLS AND LARAMIE FORMATIONS.

These formations occupy a vast area of the plains adjoining the Black Hills in all directions except to the east and southeast. They approach nearest to the hills in the eastern portion of Weston and Converse counties, Wyoming, where they occupy several hundred square miles of the area to which this report relates. It is from the Laramie formation in this district that Hatcher and Marsh obtained the large collection of remains of Ceratopsidæ in deposits which have been designated locally[1] the Ceratops beds. These Ceratops beds extend northward from Buck and Lance creeks into Weston County. They have been described by Hatcher,[2] and by Stanton and Knowlton,[3] who have shown conclusively, from faunal, floral, and stratigraphic evidence, that they are of Laramie age. The underlying Fox Hills formation is fully characterized by its distinctive marine fauna, and the overlying beds are found by Knowlton to contain a typical Fort Union flora. The precise boundary between the Ceratops beds, or

[1] The skull of the gigantic Ceratopsidæ, by O. C. Marsh: Am. Jour. Science, 3d series, Vol. XXXVIII, pp. 501-606, Pl. XII, 1889.

[2] The Ceratops beds of Converse County, Wyoming, by J. B. Hatcher: Am. Jour. Science, 3d series, Vol. XLV, pp. 135-144, 1893. Some localities for Laramie mammals and horned dinosaurs, by J. B. Hatcher: Am. Naturalist, Vol. XXX, pp. 112-120 and map, 1896.

[3] Stratigraphy and paleontology of the Laramie and related formations in Wyoming, by T. W. Stanton and F. H. Knowlton: Bull. Geol. Soc. America, Vol. VIII, pp. 127-156, 1897.



A. TYPICAL TEPEE BUTTES, DUE TO LIMESTONE LENS, WITH LUCINA OCCIDENTALIS, IN PIERRE SHALE, VALLEY OF BEAVER CREEK, WEST NEWCASTLE, WYOMING.

B. LENS OF LIMESTONE, WITH LUCINA OCCIDENTALIS, IN PIERRE SHALE, NEAR CHEYENNE RIVER, 5 MILES SOUTHEAST OF BUFFALO GAP, SOUTH DAKOTA.

Laramie formation, and the Fox Hills has not yet been ascertained, but on the map (Pl. LXV) the approximate line has been represented at the top of the deposits which have yielded a marine fauna. In the Laramie formation this includes a series of sandstones and shales of no great thickness, in which no fossils have been discovered, but which appear more closely allied to the well-defined Ceratops beds above than to the Fox Hills below.

The Fox Hills formation in Converse and Weston counties, Wyoming, presents an alternation of slabby sandstones and sandy shales, apparently in conformable succession to the Pierre shale. The sandstones give rise to an escarpment which faces eastward, overlooking the lower lands of the Pierre, Niobrara, and Benton formations. It is about 15 miles distant from the foothills of the Black Hills at Newcastle and through Weston County, but lies much farther west in Converse County, as the hogback range bears to the southeast.

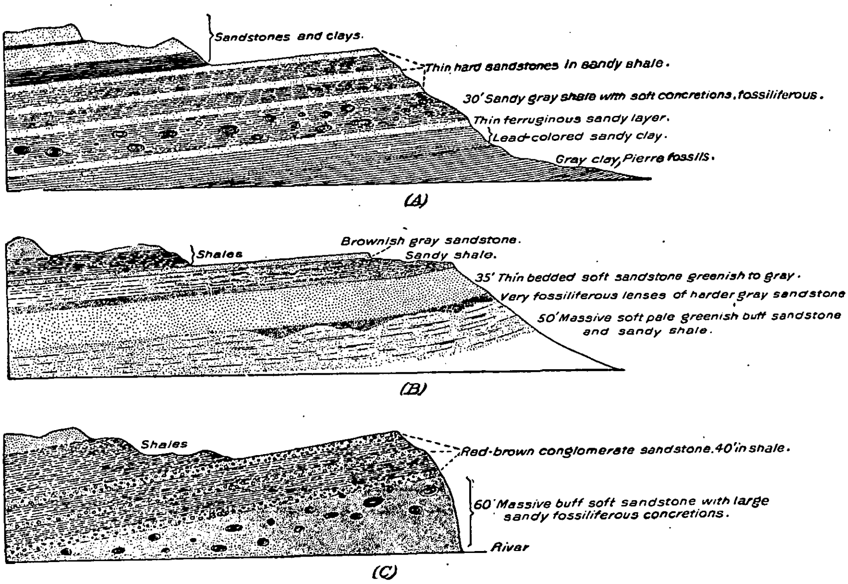


FIG. 277.—Sections of Fox Hills escarpment in Weston and Converse counties, Wyoming. A, southwest of Newcastle; B, west of Clifton; C, on Cheyenne River.

The escarpment has a height of from 150 to 200 feet in greater part, comprising lower slopes of Pierre shale, a gray sandstone or sandy shale series in the middle slopes, and a capping of three thin but hard beds of slabby sandstone intercalated in sandy shales. The sandstones or sandy shales next above the Pierre shales usually contain large, faintly defined concretions, due to local increase of lithification, and they carry abundant fossils, mainly *Veniella*. The thickness is from 250 to 500 feet.

The sections given in fig. 277 illustrate the principal features of the formation in southern Weston and northern Converse counties.

The members as shown in A thin somewhat to the north, but they retain their thickness southward. The sandy shales under the series containing the thin sandstone layers become thicker and more sandy to the south, where they are finally represented by the lower member exhibited on Cheyenne River (C). Here also the upper thin sandstones become bright red-brown and in part conglomeratic with small quartz pebbles. These two members are finely exposed in the north bank of Cheyenne River just below the mouth of Lance Creek, where the massive sandstone outcrops in high cliffs capped by the red conglomeratic beds, all profusely fossiliferous. A portion of these cliffs is shown in Pl. LXXXII. The dip is to the west at a moderate angle. Across the river the amount of dip increases and the red sandstone outcrops as a monoclinal ridge of some prominence, which continues far to the south, crossing Old Woman Creek 5 miles above its mouth and extending along the west side of the Old Woman Valley for 10 miles. In this region the dip changes abruptly to a pitch to the northwest, causing the ridge to trend off to the west, and giving rise to an escarpment on the divide between Buck and Old Woman creeks, and to the "narrows" in Buck Creek Valley.

Next above the sandstones of the Fox Hills escarpment and ridge

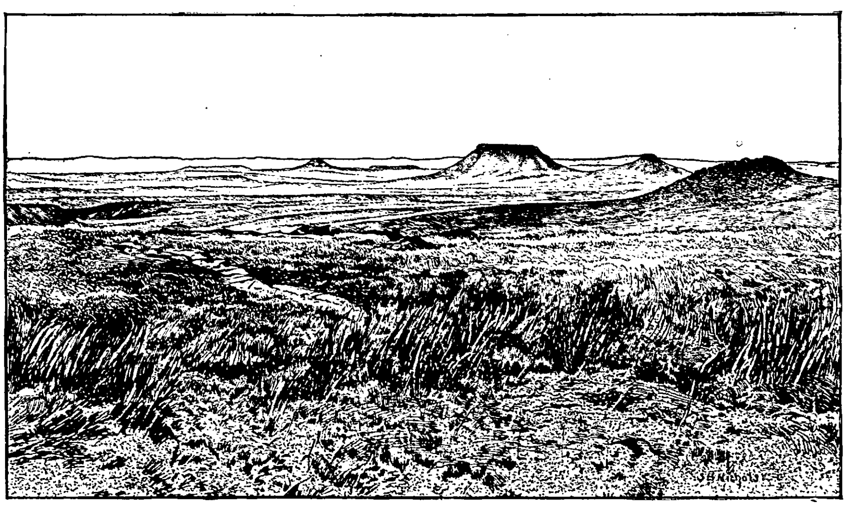
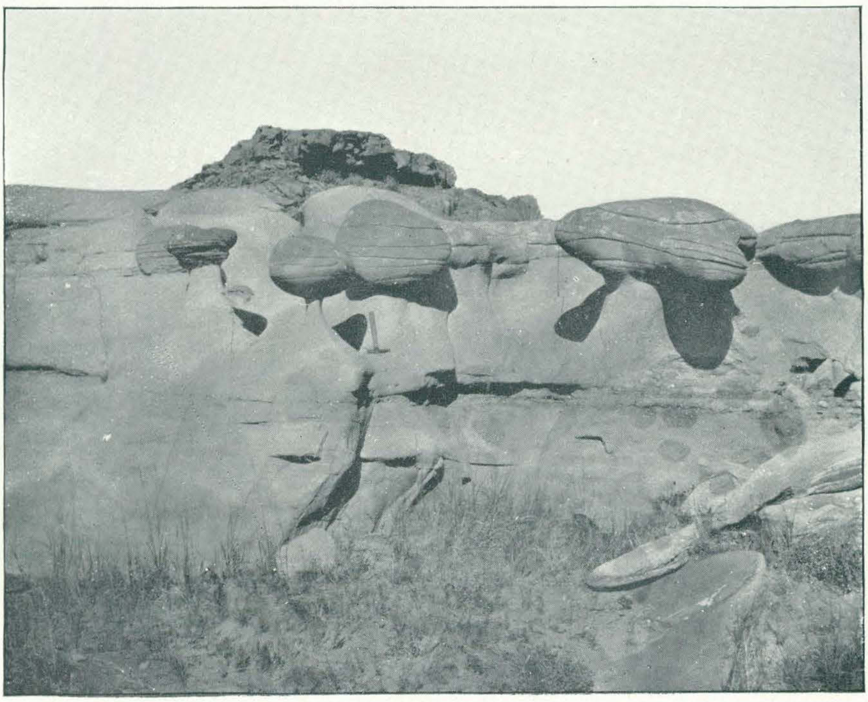


FIG. 278.—Alkali Butte, Weston County, Wyoming, from the southeast.

are slopes of sandy shales surmounted by high hills of the succession of sandstones and shales constituting the Ceratops beds. These deposits alternate through a series several thousand feet thick, the component beds varying greatly in thickness and extent. No stratigraphic order of beds has yet been detected, and none of the strata are continuous for any great distance. Sandstones predominate, consisting mainly of fine-grained, loosely cemented beds of light-buff color, often

A. FOX HILLS SANDSTONE ON NORTH SIDE OF CHEYENNE RIVER, JUST BELOW MOUTH OF LANCE CREEK, CONVERSE COUNTY, WYOMING.



B. CONCRETIONS IN SOFT LARAMIE SANDSTONE, 20 MILES SOUTHWEST OF NEWCASTLE, WYOMING.

having a thickness of 40 feet. They contain very characteristic concretions of gray color and great variety of shapes. The material is simply the sand of the soft sandstone, locally lithified to increased hardness and slightly darkened. The sizes vary from a few inches to many feet. The forms are usually elongated, with rounded outlines, but spherical and lens-shaped concretions abound. In Pl. LXXXII, *B*, some representative forms are shown. Shales occur interbedded among the sandstones of the Laramie formation and are often 30 to 50 feet thick. They are usually of dark-gray color and in places lignitic. Coal was not observed in the area to which this report relates, but it is found extensively to the north and west.

Alkali Butte is one of the most prominent features in the Laramie area of Weston County. Its aspect is shown in fig. 278. It is a landmark for many miles to the east, but it is found to be only 200 feet high above the adjoining rolling hills. It exposes the following section:

Section at Alkali Butte, Weston County, Wyoming.

	Feet.
Light-brown sandstone, hard	20
Light-buff, massive sandstone, coarse but soft	50±
Brownish buff, massive sandstone, with a few large, irregular concretions	20
Dark, sandy, and lignitic clays, with thin sandstone partings	60±
Hard, brown sandstone	3
Soft, massive sandstone	25±
Hard, brown sandstone	2
Light-gray sandstone, with dark-gray, hard sandstone layers and concretions	40±

Mr. Hatcher described the sections of Fox Hills and Ceratops beds on Buck Creek as follows:

Along the southeastern border, especially between Lance and Buck creeks, are many fine exposures of the Ceratops beds and the underlying Fox Hills. Perhaps the best exposure is that made by a small tributary emptying into Buck Creek about 4 miles east of Lance Creek and one-half mile northwest of the Buck Creek pens used by the cattlemen for round-up purposes. This water course has here cut its way in a southerly direction, at right angles to the strike, down through the lower half of the Ceratops beds, through the underlying Fox Hills sandstones and into the Fort Pierre shales. At this place the bed of Buck Creek and the rounded hills of that region at the head of this stream, embraced between the border of the Ceratops beds and Fox Hills sandstones on the north and the bluffs of Miocene clays and conglomerates on the south, are composed of Fort Pierre shales. All the strata of this entire section dip to the northwest at an angle of 16°. The exposure is a continuous one and, commencing from below, the section is as follows:

At the base are the Fort Pierre shales, of unknown thickness, several hundred feet of which are exposed. They consist of argillaceous, finely laminated, dark shales, quite soft and easily eroded. They contain many limestone concretions and numerous invertebrates. Among others are *Baculites ovatus*, *B. compressus*, *Scaphites nodosus*, *Placenticeras placenta*, *Nautilus dekayi*, etc.

Overlying the Fort Pierre deposits is an alternating series of sandstones and shales with an estimated thickness of 500 feet. In the lower portion of this series the shales predominate, but toward the middle the sandstones are in excess, and in the upper 50 feet they entirely replace the shales. The sandstones are of a yellowish-brown color, very fine grained, firm, and well stratified below, but softer and quite massive at the top, where they contain numerous large concretions and a rich marine invertebrate fauna. Representatives of this fauna have been sent to Mr. T. W. Stanton, of the United States National Museum, and were pronounced by him to be characteristic of the uppermost Fox Hills, in direct conformity with their stratigraphical position.

The Ceratops beds.—Next come the Ceratops beds, with an estimated thickness of 3,000 feet, resting directly upon the Fox Hills series. Immediately above the Fox Hills is a very thin but persistent layer of hard sandstone, well stratified, and easily cleavable along the lines of stratification. This stratum of sandstone is about 6 inches thick, and is regarded as the dividing line between the marine and fresh-water beds. It is overlain by about 150 feet of yellowish-brown, well-stratified sandstones, apparently nonfossiliferous. These are in turn overlain by about 250 feet of almost white, fine-grained, massive sandstones with numerous concretions, but no fossils were found in them. Next comes the fossiliferous portion of the Ceratops beds, consisting, as before stated, of alternating sandstones, shales, and lignites.

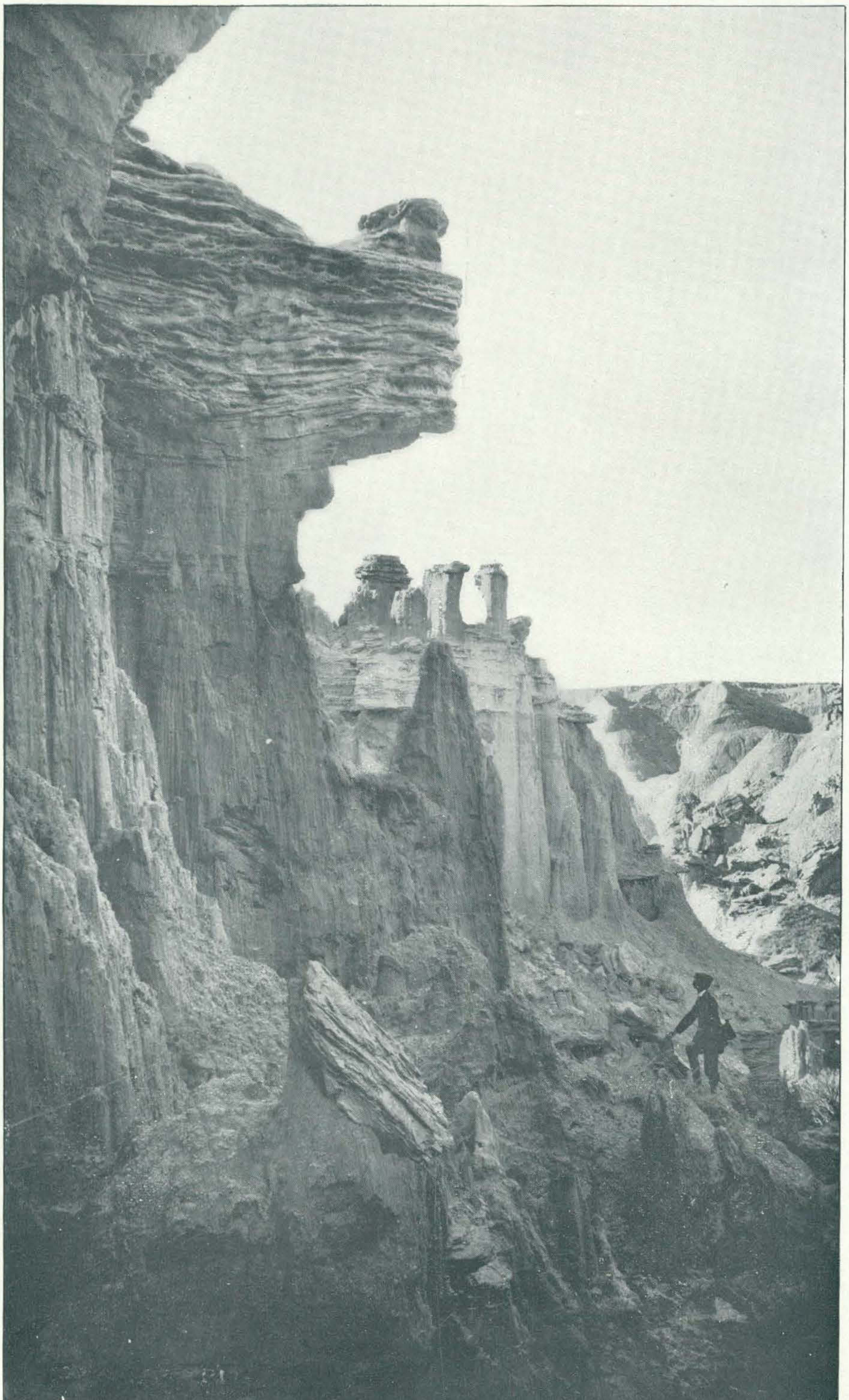
All the beds of the entire section are conformable and bear evidence of a continuous deposition from Fort Pierre shales up through the Fox Hills sandstones and the overlying fresh-water Ceratops beds. The Fort Pierre shales are not suddenly replaced by the Fox Hills sandstones, but the transition is a gradual one, and it is impossible to say just where the one ends and the other commences. The same is true of the beds overlying the Fox Hills. The thin seams of hard sandstone, just referred to as separating the fossil-bearing Fox Hills sandstones below from the very similar nonfossiliferous sandstones above, is here regarded as the dividing line between the Fox Hills and the Ceratops beds. But this decision, it must be admitted, is quite arbitrary, and the evidence in its favor is negative rather than positive. The only reason for placing the overlying 400 feet of nonfossiliferous sandstones in the fresh-water series is the absence of fossils in them, which may perhaps be accounted for by the destruction of the marine forms brought about by the change from salt to fresh waters. The overlying nonfossiliferous beds may have been deposited in the fresh waters before fresh-water forms had distributed themselves over this region. The sandstones of the entire series are very similar, and since there is entire conformity throughout, it is absolutely impossible to determine just where the marine beds end and the fresh-water beds commence. The Ceratops beds of this region are a natural sequence of the Fox Hills. The materials composing both were evidently derived from a common source. The only safe criteria for distinguishing one from the other are their fossils.

A short distance farther down Buck Creek there is the following section, as given by Stanton and Knowlton:[1]

Section on Buck Creek, Wyoming.

	Feet.
Sandstone	10
Clay	25
Sandstone with bands of clay	20
Clays with lignitic seams	15
Clays with concretions containing *Ostrea glabra*, *Corbula subtrigonalis*, *Anomia*, and *Corbula cytheriformis* (Laramie brackish-water fossils)	20
Massive, nearly white, sandstones with brown concretions	40
Shaly sandstone	5
Lignite and clay	15

[1] Stratigraphy and paleontology of the Laramie and related formations in Wyoming, by T. W. Stanton and F. H. Knowlton: Bull. Geol. Soc. America, Vol. VIII, pp. 129–130.



IN THE BAD LANDS EAST OF HERMOSA, NEAR HEAD OF COTTONWOOD DRAW, WASHINGTON COUNTY, SOUTH DAKOTA. PROTOCERAS SANDSTONE OF WHITE RIVER GROUP.

Massive, light-colored sandstone	60
Clay	8
Sandstone	10
Clay	5
Massive, light-colored sandstone	100
Brownish and gray sandstone in alternating bands, massive and thin bedded	130
Gray thin-bedded sandstone	20
Brown micaceous sandstone	20
Yellowish gray argillaceous sandstone with large concretions containing *Veniella humilis*, *Sphæriola*, and other Fox Hills fossils; dip northwest	30
Sandy clay shales with occasional bands of brown sandstone; thickness unknown, as base is not opened.	

All the Laramie beds in this region appear to be of fresh-water origin, although farther west in Wyoming they have been found to include some marine beds, with recurrence of many of the Fox Hills fossils. The fresh-water fossils reported in the Converse County area by Hatcher and by Stanton are as follows:

Fossils from Converse County, Wyoming.

Unio danæ, M. and H.
Unio brachyopisthus, White.
Unio couesi, White.
Unio holmesianus, White.
Unio proavitus, White.
Unio endlichi, White.
Unio cryptorhynchus, White.
Unio (about eight undescribed species).
Anodonta parallela, White.
Anodonta propatoris, White (?).
Sphærium planum, M. and H.
Sphærium sp.
Viviparus trochiformis, M. and H.
Tulotoma thompsoni, White.
Campeloma producta, White.
Campeloma multilineata, M. and H.
Goniobasis tenuicarinata, M. and H.
Thaumastus limnæiformis, M. and H.
Physa copei, var. canadensis, Whiteaves.
Helix vetusta, M. and H.
Limnæa sp.

TERTIARY.

The earliest deposits of Tertiary age—those of the Eocene period—are not found in the region adjoining the Black Hills, and there are many reasons for believing the principal epoch of uplift in the Black Hills region was in early Tertiary time. Early Eocene deposits may have been laid down and removed by erosion in consequence of uplift in later Eocene time, but it is much more probable that the entire area was above water throughout the portion of Eocene time prior to the Oligocene. During the Oligocene epoch there was widespread inundation in the West, and adjoining the Black Hills there was deposited a thick mantle of the sands and clays which will be described below. The Arikaree[1] formation, of Miocene age, which caps Pine Ridge, has not been found on the Black Hills, and nothing is known as to its former extension in their direction. According to Prof. J. E. Todd, a representative of the formation occurs north of the hills in

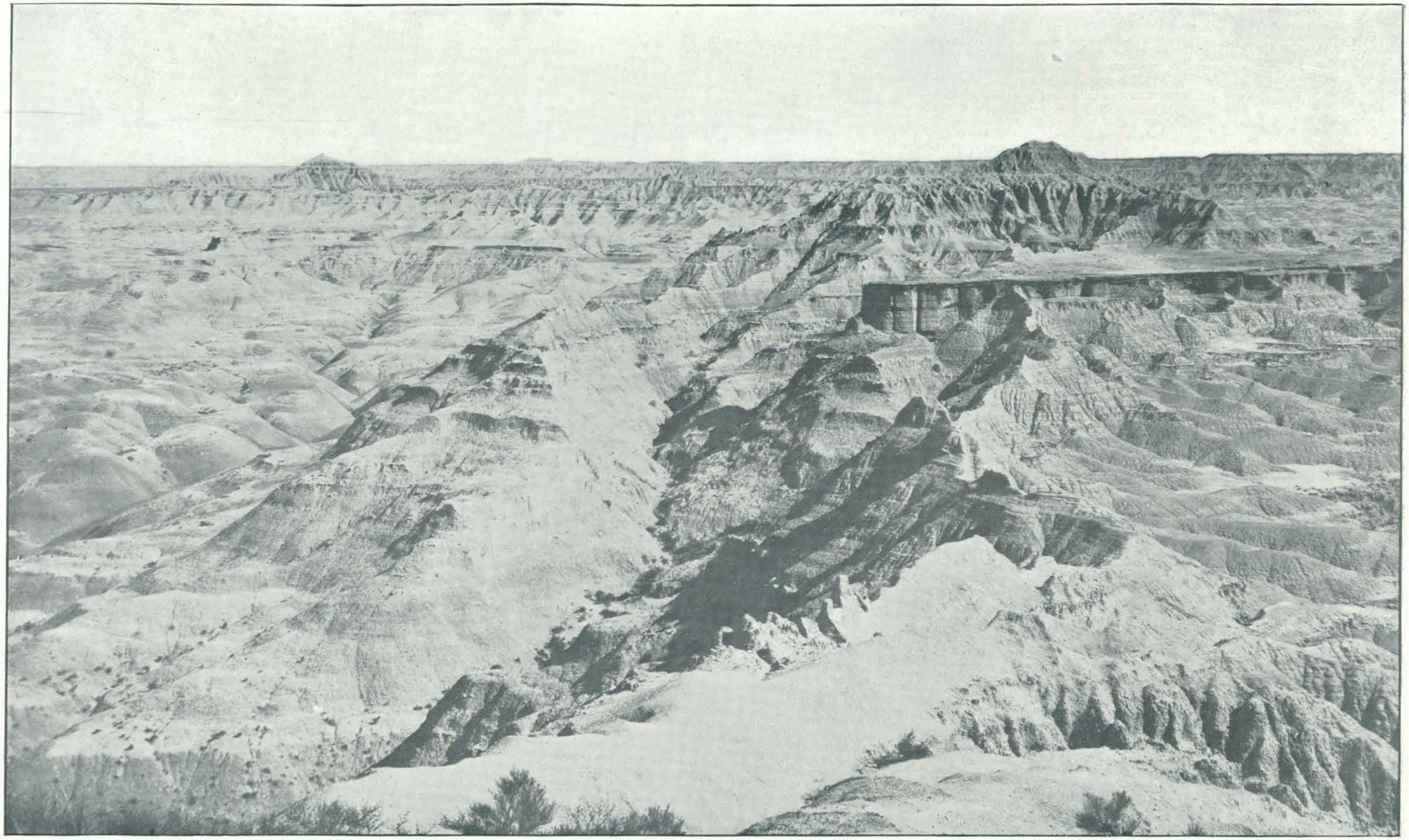
[1] Report on Nebraska west of the one hundred and third meridian, by N. H. Darton: Nineteenth Ann. Rept. U. S. Geol. Survey, 1897-98, Part IV, p. 735.

the high buttes beyond the Belle Fourche River, in the northwestern corner of South Dakota.

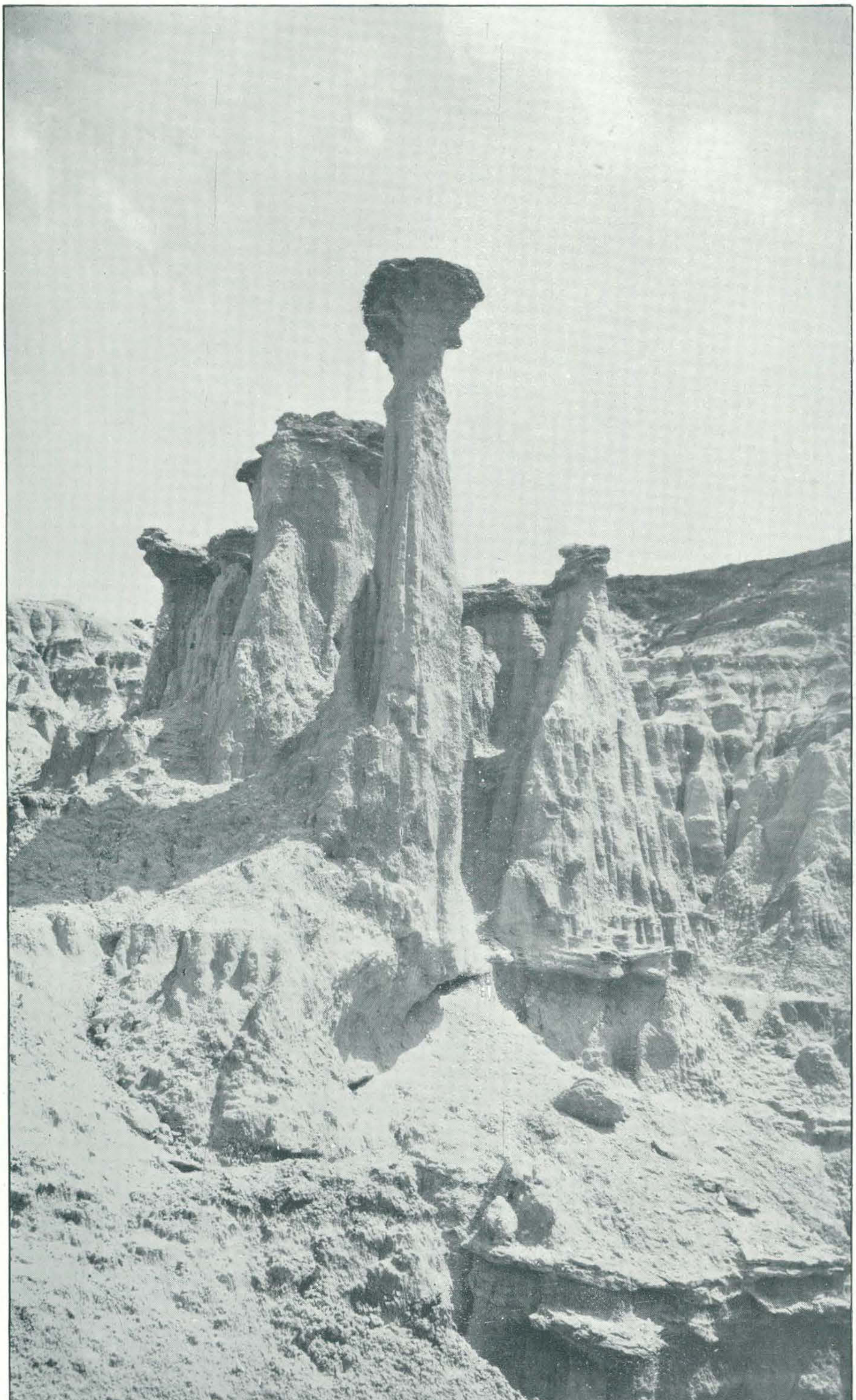
WHITE RIVER GROUP.

The well-known formations of the bad lands lying between the Cheyenne and White rivers in western South Dakota and underlying Pine Ridge have been found to extend to the Black Hills and high up onto their flanks in a portion of the region. About Fairburn and Hermosa wide areas of the highlands are occupied by the White River formations, which often give rise to miniature bad lands of considerable extent. The deposits comprise fine-grained materials, apparently laid down in a large body of water that had its shores far up the slopes of the Black Hills, and coarser materials marking the courses of some of the streams of the period. There are large areas of fullers' earth, sand, limestone, calcareous grit, and channels filled with conglomerate, in some places silicified and in others cemented by carbonate of lime. The principal areas now remaining are on the high divides between Lame Johnny and Rapid creeks, but there are also extensive masses in the broad Red Valley behind the hogback range, and there are narrow valleys filled with the deposits which extend several miles back over the Carboniferous sandstones onto the Algonkian crystalline rocks. Some of the details of their distribution are shown on the geologic map (Pl. LXV). To the southwest there are scattered areas at a number of points between Edgemont and Pringle, notably on the Minnelusa formation west of Argyle, in the Red Valley north and west of Minnekahta, and on the Dakota sandstone not far north of Edgemont. South of Oelrichs there is a narrow basin which has been preserved in a syncline extending toward the bad lands. In Converse County, Wyoming, the formation extends from the foot of Pine Ridge over portions of the anticline rising along the east side of Old Woman Creek.

The deposits of the White River group exhibit considerable diversity of composition. The principal material is a porous, crumbling clay of pale flesh color when dry, but a light-brown color when damp. Some portions of it are pale green when dry or olive when wet. It is a hydrosilicate of alumina with some admixture of sand and clay, being in reality fullers' earth, and differing from ordinary clay in being much less plastic. In the lower beds of the group it merges into sand on the one hand and into clay on the other. It is often associated with or gives place to coarse materials occupying channels or broad sheets. In the vicinity of Hermosa the principal material is coarse sandstone and conglomerate, mainly of dark, brown color, which mantles extensive plateaus. On the high level ridge north of Spring Creek there are coarse conglomerates which extend entirely across the hogback range. About Fairburn, and to the westward, there



CHADRON AND BRULE FORMATIONS OF WHITE RIVER GROUP, BAD LANDS NEAR HEAD OF BATTLE DRAW, WASHINGTON COUNTY, SOUTH DAKOTA, NORTHEAST OF FAIRBURN.



SANDY LAYERS IN WHITE RIVER GROUP ON EAST SIDE OF CEDAR DRAW, WASHINGTON COUNTY, SOUTH DAKOTA, NORTHEAST OF FAIRBURN.

are long channels filled with conglomerate consisting of limestone pebbles and a calcareous matrix. These extend up several of the depressions through the hogback range, either displacing the fullers' earth deposits, or being intercalated among them. The limestone pebbles appear to have been derived from Tertiary limestones, for they do not represent any of the Mesozoic or Paleozoic rocks of the hills. On the higher lands in the Red Valley, between Hermosa and Rockerville, there is an extensive deposit of nearly pure limestone giving rise to a high plateau of considerable extent. The total thickness of the beds is nearly 30 feet at some places, the limestone being underlain by fullers' earth. Limestones of various degrees of purity are abundantly intercalated in the fullers' earth deposits in the region west and southwest of Fairburn, lying in depressions on the older rocks. These limestones usually contain fresh-water fossils, mainly gasteropods, often in great abundance. The most southerly occurrence of the limestone is on the ridge a short distance northwest of the western entrance of Fuson Canyon, and on the high divide just north of Lame Johnny Creek and a short distance west of the Fremont, Elkhorn and Missouri Valley Railroad. There are extensive exposures of coarse materials of White River age in the railroad cuts through this divide south of Fairburn, where the materials are mainly cross-bedded coarse sands with a large proportion of gravel largely derived from the crystalline rocks of the hills. The thickness of the White River deposits on the flanks of the Black Hills varies from a thin remnant to 200 feet or more. In the divide just south of Lame Johnny Creek, in the Red Valley, at a point 10 miles southwest of Fairburn, over 200 feet were measured, consisting mainly of pale flesh-colored sandy clay and fullers' earth. East of the hills the White River group is usually divisible into two formations—the Titanotherium beds or Chadron formation below, and the Oreodon beds or Brule clay above. The Chadron formation consists of fullers' earth of light-gray, drab, pale-green, or pinkish tints, traversed by channels filled with gray sandstone. At the base there is usually a bed of coarse gravel composed of rocks derived from the Black Hills. The Brule clay is a thickly laminated sandy clay of pale-flesh and drab colors. These formations are most extensively exhibited in the large area of bad lands lying southeast of Cheyenne River. Some typical features in these bad lands are illustrated in Pls. LXXXIII–LXXXV.

All of the White River beds have yielded fossil bones of various kinds which are typical of the White River group. The following bones, determined by Prof. F. A. Lucas, were obtained in beds high up on the flanks of the Black Hills west of Fairburn: *Oreodon culbertsoni*, *Poebrotherium wilsoni*, *Stylemys nebrascensis*, and *Hyracodon nebrascensis*.

The White River deposits southwest of Argyle consist mainly of fullers' earth. A few turtle bones were found in them, but no extensive search was made for fossils. North and west of Minnekahta the material is a mixture of fine sand and clay. The outlier northwest of Edgemont caps an area of Graneros shale high on the slope of the Dakota sandstone. It consists mainly of gray conglomeratic sandstone.

During White River time in the Black Hills and adjoining regions there was deposition of considerable volume of volcanic ash. It appears to have been a period of volcanic activity in the region west, and the ashes were borne on the winds and dropped into the waters so as to be deposited over a wide area of country adjoining the Black Hills. There is more or less volcanic ash throughout the White River deposits as an admixture with the clay and sand. Accumulations of the pure material are often found at various horizons from the lower Chadron beds to the highest formation in Pine Ridge. In the Chadron formation the ash occurs in local lenses and general admixture. The most notable occurrence is in the fullers' earth deposit southwest of Argyle, where there is a bed of relatively pure ash having a thickness of 3 feet. Its composition is given in the following analysis, made by Mr. George Steiger in the laboratory of the United States Geological Survey:

Analysis of ash from near Argyle, South Dakota.

Constituent.	Per cent.
Silica	64.47
Alumina	14.74
Iron (Fe_2O_3)	2.73
Iron protoxide	0.78
Magnesia	0.29
Lime	4.00
Soda	2.55
Potash	3.31
BaO	0.13
TiO_2	0.76
P_2O_5	0.29
H_2O	5.71
Total	99.76

Its local extent could not be determined, owing to lack of exposures. The material consists of fine shreds of volcanic glass or pumice, mainly of pure white color and translucent, mixed with occasional flakes of dark-colored glassy materials. It represents a rock of rhyolitic character. A thinner deposit occurs in the Chadron formation, near its base, 6 miles southeast of Oelrichs, probably at about the same horizon as the one above described. Its thickness is only 10 inches and its extent small.

PLEISTOCENE.

EARLIER PLEISTOCENE DEPOSITS.

A mantle of bowlders, gravel, and sand is found occupying extensive areas on many of the divides along the lower slopes of the Black Hills and portions of the adjoining plains, and also extending up the older valleys far into the central area. This deposit is presumably of early Pleistocene age, laid down at the period which followed the deposition and uplift of the White River deposits. The streams from which it was derived had courses somewhat different from the present drainage, and much of the original area of the deposits has been removed by subsequent uplift and erosion. Portions of these gravel and sand deposits may readily be recognized as old stream courses, although they lie high above the newer valleys of the present time. One notable example of this is on the divide between French Creek and the drainage basin next south, southeast of Fairburn, where at an altitude of 400 feet above the valley of French Creek there is a broad valley carved mainly in the soft deposits of the White River group and floored by a thick mantle of sand and gravel with many bowlders. It is a valley with sloping and terraced sides descending gently into a central trough now occupied for several miles by a small stream which is dry the greater part of the year. Due south of Fairburn this elevated valley is cut away for some distance by branches of French Creek. Standing on its western edge and looking toward the Black Hills one may see how it originally extended out of narrow valleys among the schist ridges, now elevated far above the present drainage; a predecessor of the present French Creek, having in general the same drainage basin, but with many differences in course and branches (see Pl. XCV). These old high valleys are usually found to be floored with gravel, sand, and bowlders, but in the higher hills they have been extensively bared and cut down by erosion, especially where they coincide with the course of the present valleys. In the Red Valley southwest of Fairburn there are extensive flat surfaces mantled by these earlier Pleistocene deposits, as shown in Pl. LXXXVI and figs. 279 and 280. Both these figures also show old stream channels extending out of the Black Hills through gorges cut in the Algonkian schists, Cambrian sandstone, and Pahasapa limestone.

They also show the old shore line at this earlier Pleistocene period of deposition carved mainly on the limestone slopes. To the eastward, this earlier Pleistocene plain abuts against the slopes of the Lakota sandstone of the hogback ridge, excepting where it extends out to the plains through wide, high gaps not now occupied by water courses.

These earlier high-level Pleistocene valleys extend far back among the ridges of crystalline rocks, their course being now defined by many low, gravel-floored saddles. One of these saddles is shown in Pl. LXXXVI, *A*. It was formerly the bed of French Creek, which now

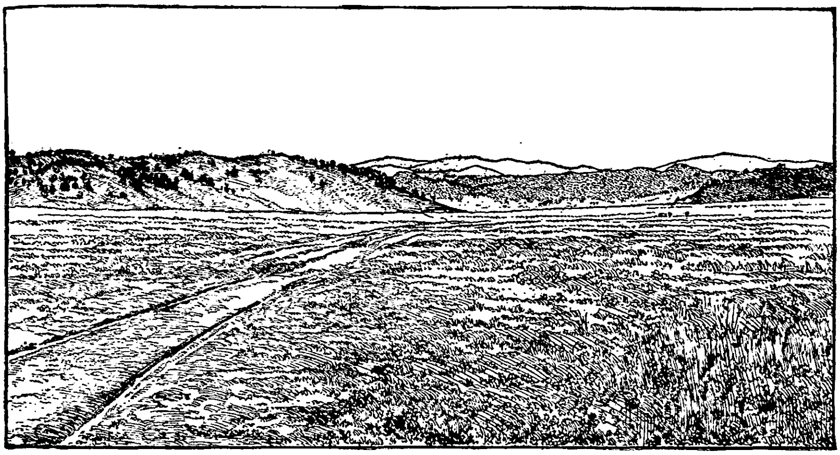


FIG. 279.—Earlier Pleistocene plain and valley 10 miles northwest of Buffalo Gap, South Dakota, looking west through gap in ridge of Pahasapa limestone to high ridges of crystalline rocks.

has a course more to the northeast and occupies a canyon 200 feet below the saddle. To the east of the Black Hills in Custer and Pennington counties, South Dakota, nearly all of the higher divides are

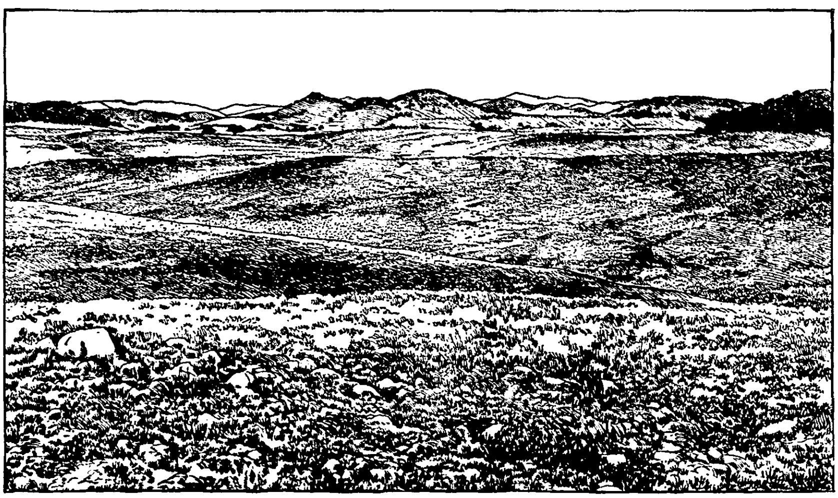


FIG. 280.—Earlier Pleistocene plain with old valley heading in region of crystalline rocks north of Wind Cave, South Dakota.

mantled by these earlier Pleistocene deposits lying on the White River sediments. Probably they were originally a continuous covering over this region, but the present streams have cut wide valleys through them. They appear not to have extended far into Fall River County, where the

A. EARLIER PLEISTOCENE VALLEY (OLD CHANNEL OF FRENCH CREEK) SOUTH OF FRENCH CREEK, 10 MILES WEST BY NORTH OF FAIRBURN, SOUTH DAKOTA, LOOKING NORTHWEST.

Hill of deadwood sandstone on right. Ridges of crystalline rocks in the distance.

B. EARLIER PLEISTOCENE (?) PLAIN, 9 MILES WEST OF FAIRBURN, SOUTH DAKOTA, LOOKING SOUTHWEST.

divides are bare, excepting occasional small gravel sprinklings on the hilltops which are remnants of the former capping of the Chadron formation at the base of the White River group. East of Custer County the earlier Pleistocene deposits extend across the divide between Cheyenne and White rivers, for they occur as cappings on remnants of the original plateau surface now remaining in the big Bad Lands. South and west of the Black Hills there are high-level gravel deposits on the slopes adjoining Cheyenne River and Beaver Creek valleys, and a wide area of tabular surface representing an old valley is found in the extended area of the Sundance formation beginning 8 miles west of Minnekahta. Pleasant Valley is also occupied by high terraces indicating deposition by a large stream in an early period of the development of the stream which now empties through Red Canyon.

At several points about the Black Hills some of the valleys contain gravel and sand which are not as ancient as the high-level deposits above described, but are much older than the alluvial deposits of the last few centuries. One of the most remarkable instances of this sort is the filling in an old valley of Fall River, extending across the Red Valley at Hot Springs. It gives rise to a plain at about the level of the adjoining slopes of the Red Valley to the north and south, and Fall River has cut a narrow canyon through it to a depth of about 80 feet. The material is largely cemented into a hard conglomerate which outcrops in picturesque ledges at the town of Hot Springs. In Pl. LXXXVII, *A*, is shown the old wide valley filled with this Pleistocene deposit to a relatively low floor, the new canyon now occupied by the river, and the canyon walls of massive conglomerate. In *B* of the same plate is shown an exposure of conglomerate in the river bank, in the center of the town. The materials are mainly bowlders of sandstones and fragments of Minnekahta limestone from the hills west, cemented by a matrix of sand and carbonate of lime. The lithification is only local, for in the lower part of the town the conglomerate may be seen merging into loose gravel and sand. The deposit lies on a very irregular surface with a maximum thickness of about 55 feet. To the east it is seen lying on and abutting against the lower portion of the Sundance formation. In the center of the town of Hot Springs it lies on red beds and gypsum of the Spearfish formation, and in the extreme upper portion of the town, near the warm springs, it overlaps and abuts against the east-sloping Minnekahta limestone. It extends but a short distance north and south of Fall River, where it abuts against slopes of the older and wider Fall River Valley as originally excavated in the soft red beds. The calcareous cementing material of the conglomerate was probably supplied by the warm water which issues from the great springs just west of the town and which contains much lime. Another deposit of this conglomerate, of which some small masses still remain, appears to have extended through Buffalo Gap.

LATER PLEISTOCENE DEPOSITS.

All of the wider valleys in the Black Hills and adjoining plains are more or less extensively floored by alluvial deposits of relatively recent origin. The chief of these are along Cheyenne River, in the wide valleys in the Pierre and Graneros shales, where the deposits are often 3 miles in width on each side of the stream, rising in gentle

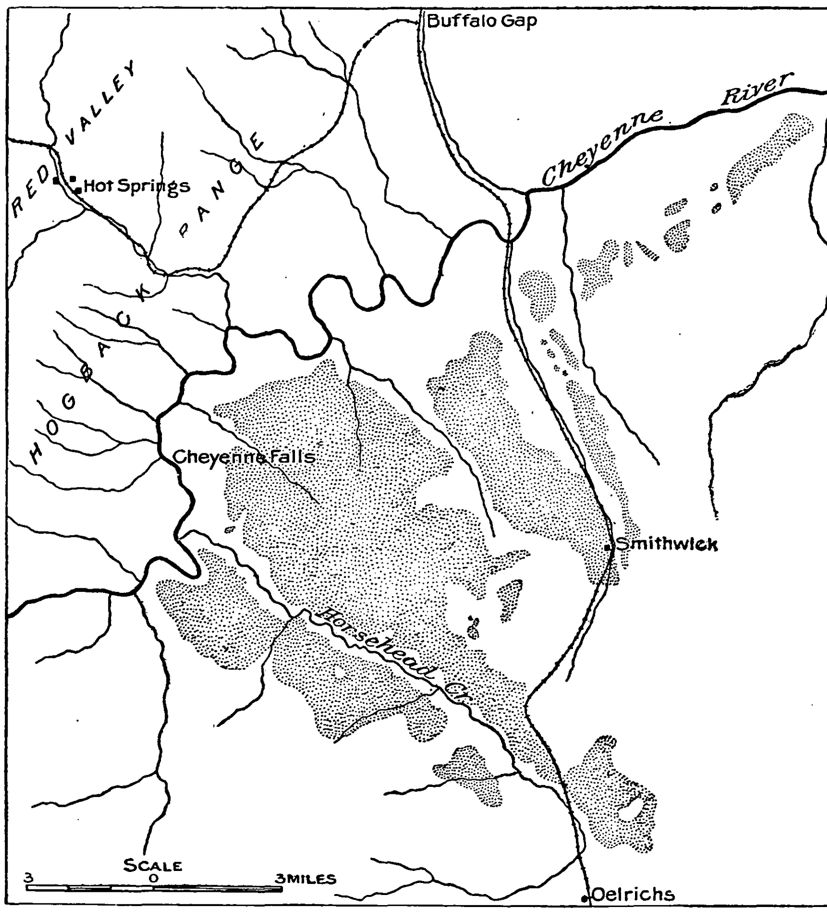
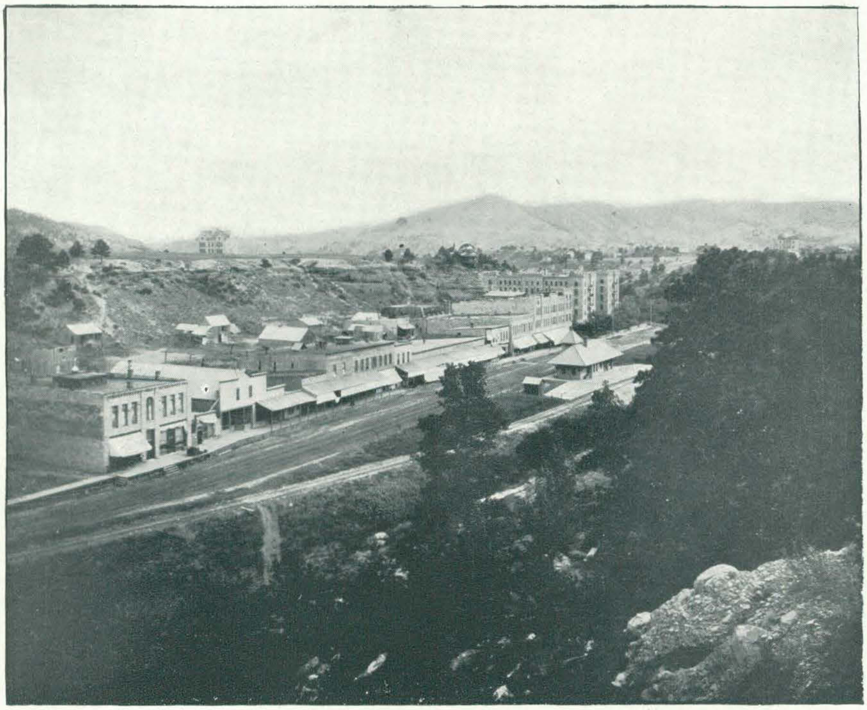


FIG. 281.—Map of region north of Oelrichs, South Dakota, showing distribution of dune sands.

slopes from low banks. Hat, Beaver, Lance, Lame Johnny, French, Battle, and Spring creeks all are widely bordered by alluvial deposits where they traverse the softer formation. These deposits consist mainly of sands and loams, with scattered pebbles and bowlders. The materials were derived from various sources along the streams and naturally vary somewhat in composition, according to the rocks which the streams traverse.



A. HOT SPRINGS, SOUTH DAKOTA, SHOWING NEW CANYON OF FALL RIVER CUT IN WIDE OLD VALLEY FILLED WITH PLEISTOCENE DEPOSITS, MAINLY CONGLOMERATIC, LOOKING SOUTHEAST.

B. PLEISTOCENE CONGLOMERATE LEDGES ON BANKS OF FALL RIVER AT HOT SPRINGS, SOUTH DAKOTA.

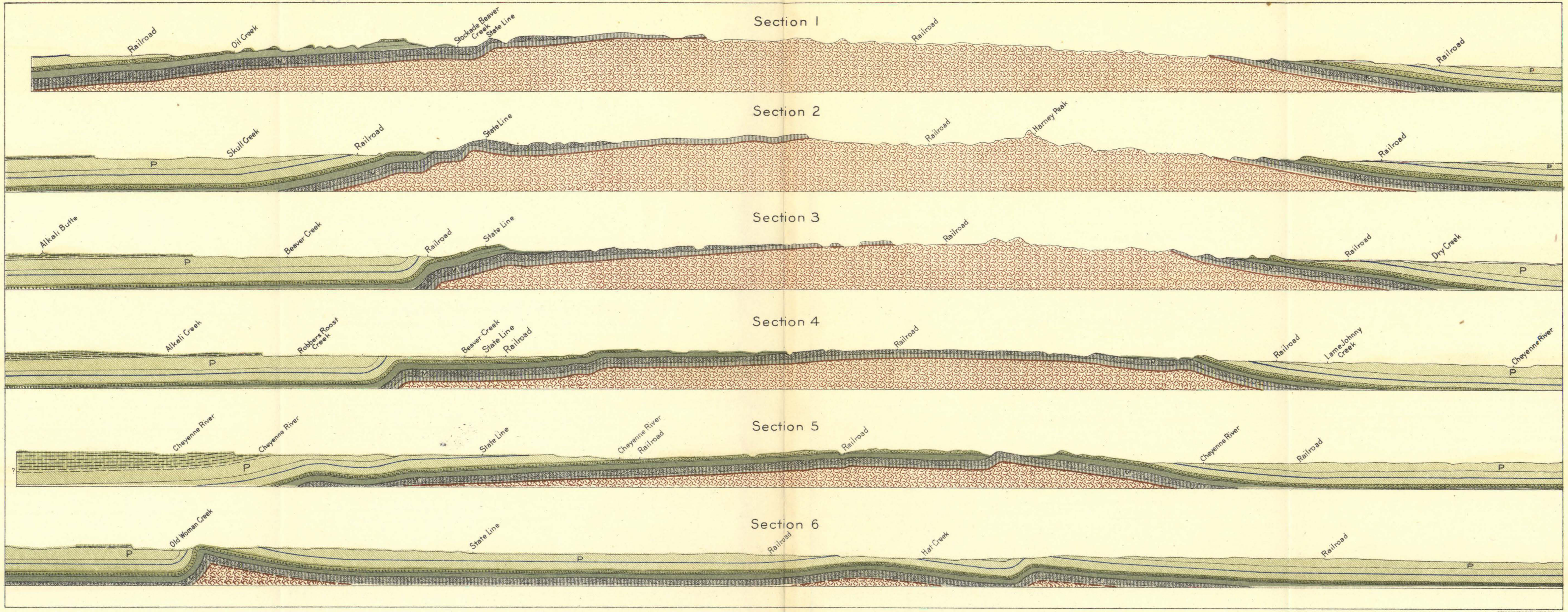
One of the latest geological formations in the region is represented by the sand dunes which have been accumulating in the region north and west of Oelrichs. The sand is principally derived from the alluvial flats bordering Cheyenne River where it flows out of the hog-back range southeast of Hot Springs. It has been carried to the south-east by the strong northwesterly winds, and accumulated in extensive dunes, which now extend in long fingers to and beyond the railroad. Portions of these dunes are grassed over, but in much of the area the sand is loose and advances along its course with every wind that blows. The accumulations are not thick, but as they cover a wide area their bulk is considerable. On the wide terraces north of Edgemont and along the bottom lands of Cheyenne River at various places some low sand dunes are accumulating, but they are of very restricted occurrence.

Fall River and Cascade Creek, and other streams to a less degree, deposit calcareous sinter in large amount, giving rise to great masses of spongy rock, usually filled with impressions of various kinds of vegetation.

STRUCTURE.

The Black Hills uplift is a dome rising high on the irregular zone of uplift extending from the Laramie Range of the Rocky Mountains. It is elongated to the south and northwest and bears a number of subordinate flexures or crenulations. In its greatest elevation north of Harney Peak the uplift amounts to about 9,000 feet vertical displacement. In Pl. LXXXIX there is shown the configuration of the greater part of the Black Hills uplift, including also its connection to the southwest with the high, sharp anticline of Old Woman Creek, a northern extension of the range of uplifts which extends more or less continuously southwestward into the Laramie Range. In Pl. XC the principal features are shown in cross section. These plates represent the present attitude of the Minnekahta limestone at the surface and in its extension under ground, together with its hypothetical contour over the area from which it has been removed by erosion. Data for the underground relations of this limestone are definite, for we have numerous determinations of the thickness and structure of the overlying formations within moderate limits of error. For the eroded area now occupied by outcrops of the underlying Carboniferous formations the approximation is well within reasonable limits, since it is based on many measurements of the thickness of these formations as they pass beneath the Minnekahta limestone, and the structure is clearly exhibited. In the relatively small area of the bared pre-Cambrian crystalline rocks, however, there is less definite guidance, excepting the probability that the slopes of the dome continued upward with symmetrical form, and that the base of the sedimentary series was somewhat above such summits as are now represented by Harney Peak and Sheep Mountain. The facts for the center of the northern portion of the area were obtained from manuscript maps of the geology of the Spearfish and Sturgis quadrangles by Dr. T. A. Jaggar, jr. For the extreme northern and western portion of the uplift no data are available, and for the region southeast of Sundance we have at present only some general information, shown by the dotted lines.

In the southern portion of the Black Hills region it will be seen that the dome is steeply compressed on the sides but broadly extended in the center, where it slopes off gently to the south-southwest. Adjoining the central area there are gentle dips on the west side giving rise to the wide sloping plateau of "the limestone," and steeper dips on the east side carrying the formations from Cambrian to Niobrara rapidly beneath the surface. One of the most striking structural features is the steep compression of beds along the middle of the western slope of the dome in the eastern part of Weston County, Wyoming, where from Spencer southward there are nearly vertical dips in the Greenhorn limestone and associated formations in a belt about a mile wide. The relations in that vicinity are shown in sections 3 and 4, Pl. LXXXVIII. East of Newcastle these steep dips pass into lower beds and soon involve the Minnekahta limestone, the Minnelusa sandstone, etc., along the valley of Stockade Beaver Creek. Some features of the structure in this locality are shown in Pl. XCII, in which the sudden steepening of the dips is beautifully exhibited. A branch of this steep-dipping limb passes south of Newcastle, extending southwest of a broad, gently sloping monocline which spreads out the Lakota sandstone in a wide plateau about Cambria, affording most favorable conditions for working the coal. From the S. and G. ranch, where there is a faint cross flexure, to beyond Edgemont the formations all dip gently to the southwestward, with frequent local variations in the amount of dip. To the southwest of Edgemont the dips are very low, and there is a shallow basin which extends across to the flank of the anticline of Old Woman Creek and contains a moderate thickness of Pierre shale, as shown in section 6, Pl. LXXXVIII. Under the axis of this syncline the crystalline rocks are just about at sea level, over 5,000 feet below their elevation in the ridge at Lusk, as shown in Pl. LIX, and over 7,000 feet below the summit of Harney Peak. A short distance east of Edgemont there is the southern prolongation of the main north-south axis of the Black Hills uplift. This is broad and flat in greater part, but for several miles opposite Edgemont presents steep dips along its western side. Next east is the syncline, the axis of which passes near Maitland and extends north up the valley of Cascade Creek. On its east side is a prominent anticline, which may be regarded as a bifurcation of the southern extension of the central axis of the Black Hills dome. It begins a short distance north of Hot Springs and extends southward into the plains. Its first



SECTIONS ACROSS THE SOUTHERN BLACK HILLS

BY

N. H. DARTON

1899

HORIZONTAL SCALE

5 0 5 10 MILES

VERTICAL SCALE

5000 0 5000 10000 15000 20000 FEET

EXPLANATION

Tertiary

Laramie and Fox Hills formations

P — Pierre shale. "Inoceramus bed"

Pierre Niobrara and Benton formations

Dakota, Fuson and Lakota formations

Juratrias (Beulah, Sundance, Unkpapa and Spearfish formations)

Minnekahta limestone and Opeche formation

M — Minnelusa formation

Pahasapa limestone

Deadwood formation

ALGONKIAN

Crystalline rocks

feature is a prominent ridge exhibiting an anticline of Minnekahta limestone deeply trenched by the canyon of Hot Brook, tributary to Fall River, and pitching beneath the surface at Cascade Springs. Next west of this anticlinal ridge of Minnekahta limestone there is a narrow valley of Spearfish red beds and a high, narrow ridge of Unkpapa and Lakota sandstones, all dipping from 75° to 85° to the west. To the southward these beds pass over the anticline in regular succession, and on the eastern side are spread out widely by relatively gentle dips, as shown in section 5, Pl. LXXXVIII. The prolongation of the anticline to the southward in the Benton and Niobrara formations is shown in section 6 of Pl. LXXXVIII. East of Hot Springs the east-dipping limb of this anticline bears a subordinate anticline which extends for several miles with the contour shown in Pl. LXXXVIII and fig. 290. It is exhibited mainly in the Minnewaste limestone north of Fall River Canyon, and dies out a short distance to the south in the Dakota sandstone. The dips on its western side are very steep for about 2 miles, but on the eastern side they are low. The northern extension of this flexure is clearly shown in the western end of Buffalo Gap, by a low arch of Minnekahta limestone, from which the red beds have been eroded over a small area, and again a short distance north of Fuson Creek Gap, where two small exposures of the limestone are seen. Just west of the town of Buffalo Gap the eastern slope of the Black Hills dome is locally steepened, giving increased prominence and steepness to the hogback range of Dakota sandstone, as shown in Pl. LXIV. It is in this vicinity that is found the local area of faulting in the Unkpapa sandstone which has yielded most instructive specimens illustrating small block faults traversing the bright-colored layers of the rock. Some of the features of these faults are shown in Pl. XCIII. The faults are all of very small amount and do not traverse the entire thickness of the formation. They make their first appearance in Elm Creek quarry, 2 miles southwest of Buffalo Gap, but attain their greatest development in the old sandstone quarries in the first small gap south of the main Buffalo Gap, where a large amount of the material is exposed. Faults are rarely observed in the Black Hills, so that these dislocations near Buffalo Gap are especially interesting. They appear to be due to movement that is entirely taken up within the Unkpapa formation in part by cross faulting and in part by diago-

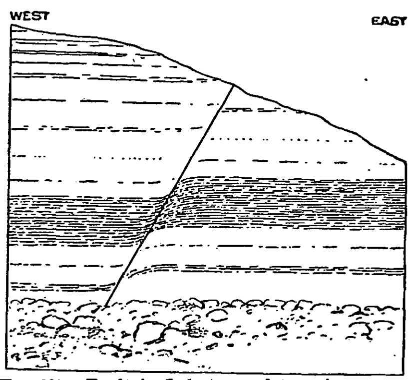


FIG. 282.—Fault in Lakota sandstone in canyon of Dry Creek, northwest of Fairburn, South Dakota.

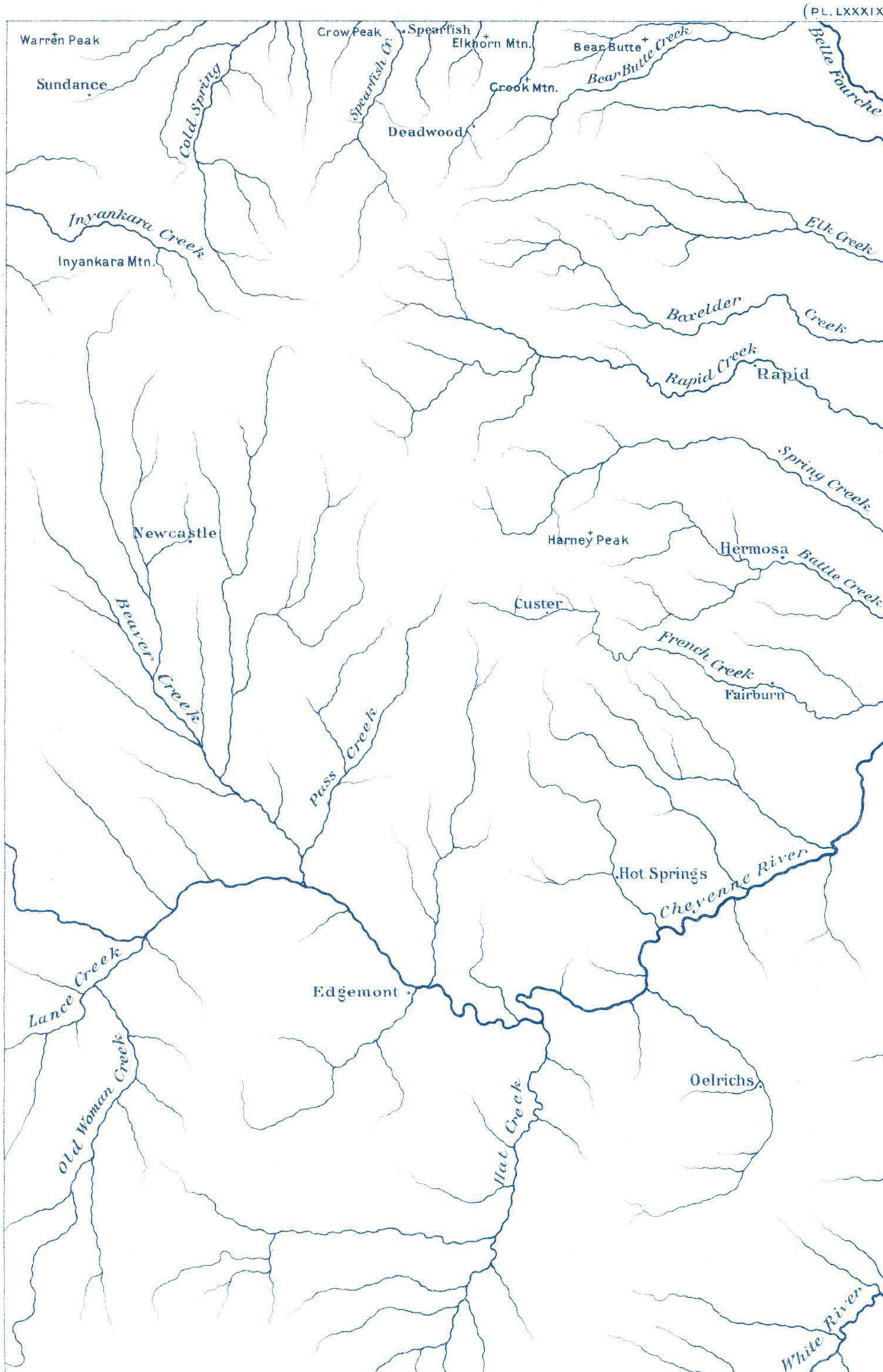
nal shearing. In the gap of Dry Creek, north of Buffalo Gap, there is exposed a small fault in the Lakota sandstone, of which the principal features are shown in fig. 282.

At Fairburn the general east-sloping limb on the eastern side of the Black Hills dome bears a small local anticline and syncline, giving rise to a double ridge of Greenhorn limestone just south of the town. Another slight irregularity is a small dome-like anticline on Dry Creek, 7 miles northwest of Fairburn, in the Minnekahta limestone.

In Pls. LXXXIX and XC the contour of the Minnekahta limestone surface is only carried down to sea level, below which it soon flattens out on both sides of the dome. Some features of this flattening are shown by the contour of the upper surface of the Dakota sandstone about Oelrichs, as represented in fig. 290 and by cross section 6, Pl. LXXXVIII.

ANTICLINAL AREA ON OLD WOMAN CREEK.

This uplift, which has not heretofore been noted, lies south of the Black Hills, on the eastern side of the valley of Old Woman Creek, in Converse County, Wyoming. It is a single anticline, with gentle dips on the east and nearly vertical beds on the west, which brings to the surface an extensive series of Upper and Lower Cretaceous beds and the upper members of the Jurassic, the Beulah shales, and the Sundance formation. The Dakota and Lakota sandstones here give rise to a ridge 7 or 8 miles long, of which the higher summits are elevated about 500 feet above Old Woman Creek. To the north the anticline extends across Cheyenne River, where it upturns Fox Hills and Laramie beds, and dies out a short distance north of Alkali Creek. To the south the uplifted beds pass beneath nearly horizontal White River deposits, which hide the relations in that direction. Doubtless the anticline is an extension of the uplift which brings to the surface the crystalline rocks in the vicinity of Lusk and in the high mountain known as Rawhide Butte, a spur of the Laramie Range rising in the midst of the wide Tertiary plain south of Lusk. As shown in Pls. LXXXVIII and LXXXIX, the anticline is separated from that of the the Black Hills by a low saddle west of Edgemont, but it is to be regarded as a link in the chain which connects the Black Hills with the Rocky Mountains. In Pl. XCI are shown the relations and distribution of the formations brought to the surface by this anticline. The area is one in which the exposures are extensive and the steep dips on the west side of the flexure afford an excellent opportunity to obtain measurements of all of the Cretaceous formations from Lakota to Fox Hills. It was in this area that the Pierre shale was ascertained to be 1,200 feet thick, with the tepee zone 1,000 feet above its base. The Fox Hills beds are upturned by this flexure so that cross-section measurements can be made at numerous localities. To



MAP SHOWING THE PRINCIPAL DRAINAGE OF THE BLACK HILLS.

the west, in the lower part of Buck Creek, the dips gradually diminish, and apparently the flexure dies out in the Ceratops beds or the Laramie formation. On the east side of Old Woman Creek the formations from the Niobrara to Lakota present dips from 70° to 80° for several miles. The results of cross-section measurements in this vicinity are given in fig. 283.

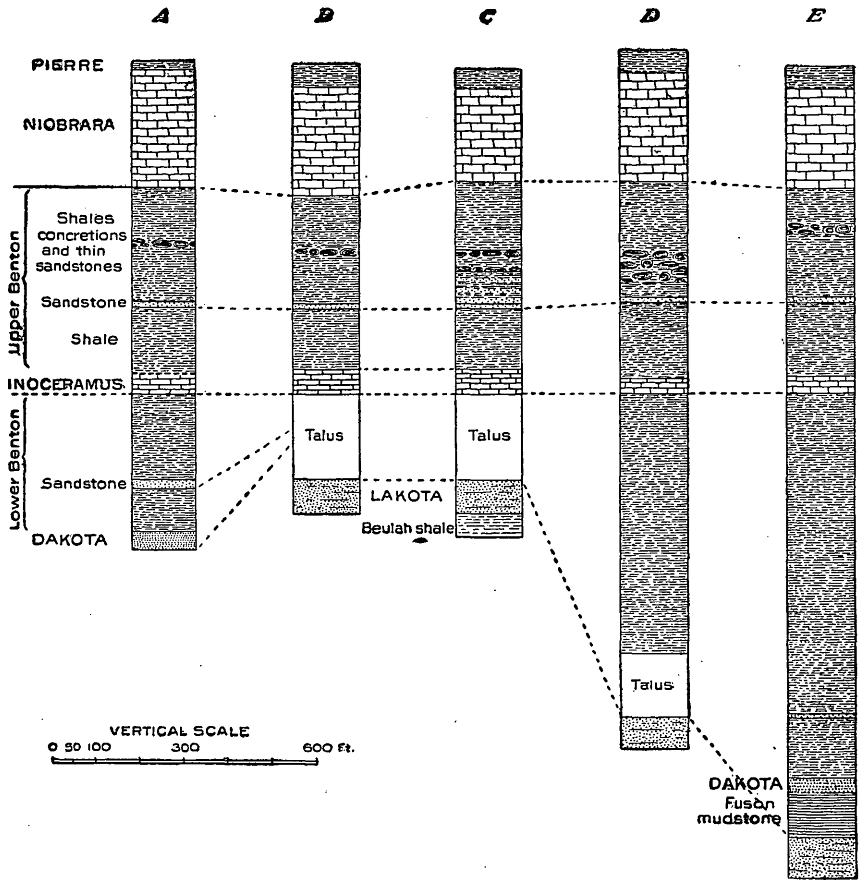
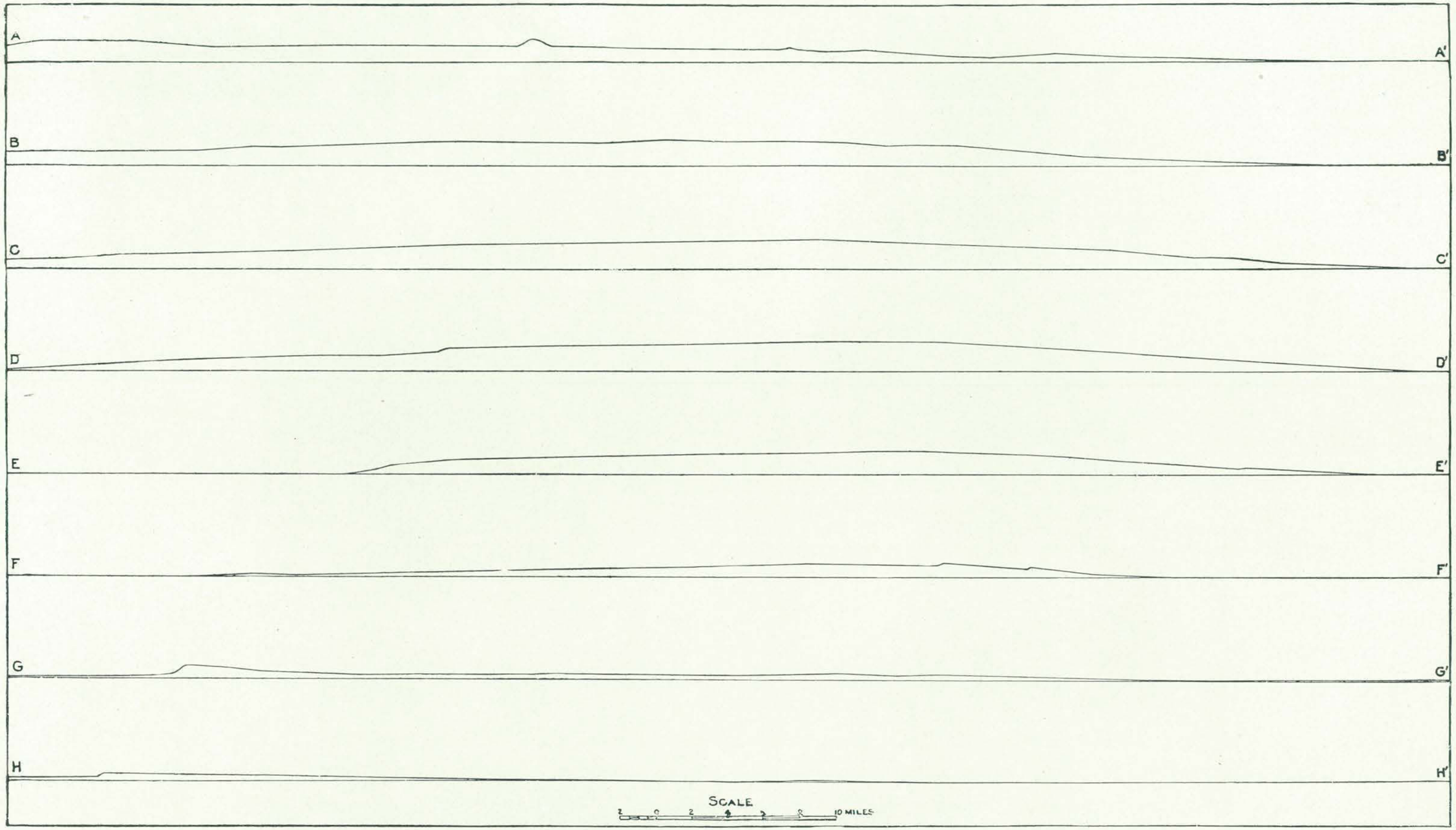


FIG. 283.—Columnar sections of Cretaceous formations in the anticline on east side of Old Woman Creek, Converse County, Wyoming.

These measurements are very satisfactory and consistent, except for the Graneros shale, which varies so greatly in apparent thickness in the different sections as to lead to the belief that it is traversed by a fault along a portion of one side of the anticline. The Dakota sandstone, the Niobrara chalk, the Pierre shale, and the formations of the Benton group present their usual characteristics in this area, even to the occurrence of a local lens of hard sandstone in the lower portion of the Graneros shale. The Fuson formation is well characterized, and it is probable that a thin layer of impure limestone underlying this formation near the southern end of this uplift represents the Minnewaste limestone. The Lakota sandstone is much thinner here than in the hogback ranges of the Black Hills, averaging less than 100 feet. The Beulah shales are well characterized, and the upper portion of the Sundance formation exposed in a small area in a canyon in the central part of the range presents the usual succession of thin-bedded buff sandstones and drab shales with typical marine Jurassic fossils.

GEOLOGIC HISTORY.

In the rocks uplifted in the Black Hills there is recorded an interesting geologic history extending from Cambrian to the present time. There has been considerable diversity of conditions, but an extensive stratigraphic record is presented. Some of the chapters of the history appear plain, but for others much additional study is required before we can know the complete sequence of events. It is probable that throughout Cambrian time there were extensive exposures of crystalline rocks about the present location of the Black Hills, but the relations of these to other pre-Cambrian land areas is not known. The Cambrian sands were deposited mainly on sea beaches and in the shallow waters offshore, and in their earlier stages, at least, also in estuaries bounded by shores of the crystalline rocks. Very little can be suggested regarding the extent of the land surface or the precise configuration of its shores. That shores were present is clearly shown by numerous exposures of the conglomerates and sandstones abutting against irregular surfaces of the crystalline rocks, and by the presence of a large amount of local material in the deposits. In the southern portion of the present hills deposition did not proceed sufficiently for the accumulation of a large body of sediments, or if they were laid down they were subsequently removed by erosion. To the northward, where the deposits attain a thickness of several hundred feet, it is possible that the crystalline rock area was eventually buried as the land subsided, an idea further borne out by the presence of widespread sheets of fine-grained materials which the Deadwood formation contains in the northern hills. For the time extending from the close of the Cambrian to the early Carboniferous the Black Hills area presents a scanty record. In the southern hills, where Silurian and Devonian are absent, there may have been long-continued but slight submergence with no near land and no currents to bring deposits, or there may have been alternations of deposition and erosion, which left nothing of the scanty Silurian and Devonian deposits and yet did not remove much of the Cambrian. Possibly this latter hypothesis would best account for the relative thinness of the Cambrian now remaining in the southern part of the Black Hills, and the supposition that there was less uplift and erosion to the north would explain the thicker Cambrian and the remaining Silurian in that region. Probably more



CROSS SECTIONS OF THE BLACK HILLS AT THE SURFACE OF THE MINNEKAHTA LIMESTONE.

[The letters refer to lines of cross section shown on Pl. LXXXIX.]

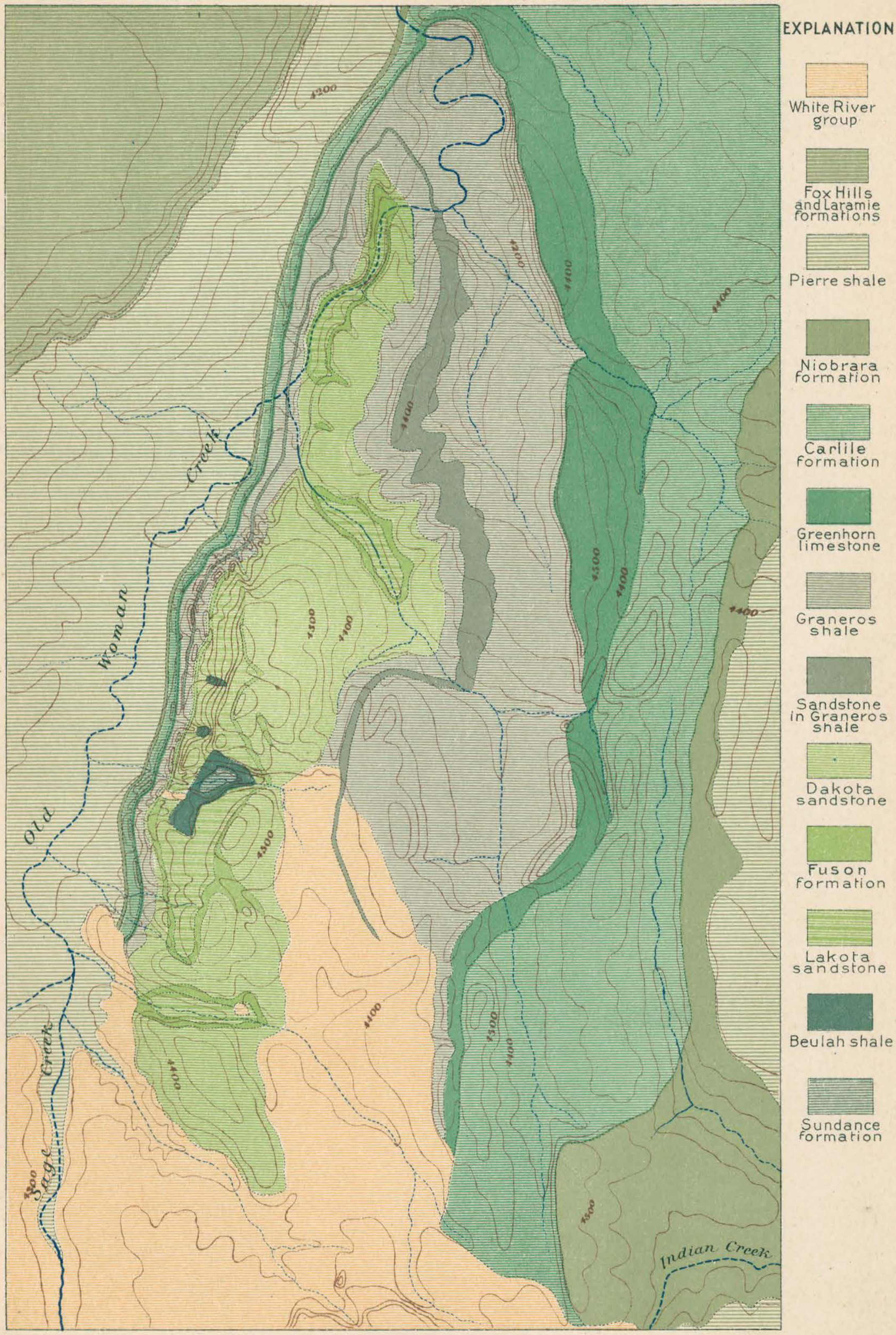
extended study of the Carboniferous-Cambrian contact will give additional evidence, but at present no definite theory can be proposed. The Carboniferous period began with relatively deep-water and marine conditions under which was laid down a great mass of calcareous sediments now represented by several hundred feet of nearly pure limestones. As no coarse deposits occur in the Pahasapa limestones, it is probable that no crystalline rocks were exposed above water in this region in the early Carboniferous, although it is possible that the limestone was deposited immediately upon them in some places.[1] In the latter part of the Carboniferous there was a change of condition that brought into the region a large amount of fine sand which was deposited in thick but regular beds, apparently with a large mixture of calcareous precipitates. More or less ferruginous material was also deposited at the same time, as is indicated by the color of much of the Minnelusa formation, the color apparently being due to the presence of iron in the original deposits. Minnelusa deposition was followed by the accumulation of materials of the Opeche formation, with its bright red sandstones and sandy shales. Next came the Minnekahta limestone, which was laid down in thin layers, but only to a thickness now represented by from 30 to 50 feet of the limestone. It was deposited from sea water, and from its fossils we know with fair degree of certainty that it is a representative of Permian time. The very great uniformity of this formation over the entire Black Hills area is an impressive feature, probably indicative of increased submergence with a cessation of those currents which brought the coarser materials of the two preceding formations. A great change of condition began suddenly at the close of the period represented by the Minnekahta limestone, for without apparent unconformity or time interval there began the deposition of the great mass of red shales constituting the Spearfish red beds. Vast lakes of saline waters were inclosed probably by a general uplift of a wide area of the West, and the red mud was laid down in thin layers to a thickness of from 350 to 500 feet, as now represented by the formation. That the red color is indigenous seems certain, for it is impossible to believe that it could have been subsequently segregated from exterior sources over so wide an area. The deep-red color is not due to later or surface oxidation, for, as shown by deep borings, it extends throughout the formation. Either the original sediments were red or they were colored by precipitation of iron oxide in the waters which deposited the sediments. At various times, which were not synchronous throughout the region, the clay sedimentation was interrupted by chemical precipitation of gypsum in beds ranging in thickness from a few inches to 30 feet.

[1] Recent observations in the uplifts in the Hartville region and northern end of the Laramie Mountains farther south in Wyoming show extensive areas of crystalline rocks which were bare through the greater part of Carboniferous time, so it appears probable that from these were derived more or less of the sandy sediments of the Minnelusa formation in the Black Hills.

It is believed that these beds are the products of evaporation due to increased aridity of climate, which at the same time temporarily suspended erosion and the general influx of the red-clay sediment; otherwise it is difficult to understand their nearly general chemical purity or freedom from admixture with red clay. Although there is no direct evidence, it is believed that the red beds above the Minnekahta limestone represent a whole or a part of Triassic time. It appears to have been everywhere followed by uplift without local structural deformation, but with general planation and local channeling, which represents a period of time of unknown duration. Then followed the deposition of the great series of deposits of the Jurassic.

The geologic history of the Jurassic deposits in the Black Hills region can be outlined in a general way. They represent conditions of deposition intermediate between those under which the red beds were laid down and those which gave rise to the Lakota and Dakota sandstones. It was mainly a time of submergence, in which sands and clays were deposited, but apparently in waters without strong currents. The isolated masses of coarse basal sandstones indicate shore conditions which varied locally and were a transient feature in the early part of the submergence. The ripple-marked sandstones following the lower shales were evidently laid down in shallow waters, probably marking a time of more rapid sedimentation than submergence, if not an arrest in the submergence. The extensive marine fauna and limestone layers in the later shales are indicative of deeper water conditions. At this stage sedimentation commenced to gain on submergence, the deposits became sandy, and there soon began the accumulation of sands now represented by the Unkpapa sandstone, which, as above described, has in places a thickness of 225 feet. Apparently the area of deposition at this time was to the east and southeast, for there is no evidence of degradation of Unkpapa beds where that formation thins out to the west and north. The Unkpapa sands were deposited in relatively quiet water, for the material is uniformly fine grained and rarely shows current bedding. Next came the deeper waters, in which were deposited a widespread mantle of sandy clay, now represented by the Beulah shales. Although these shales are absent in the southeastern portion of the hills, yet it is probable that they were originally deposited there to a greater or less thickness and then removed by erosion. This erosion resulted from the uplift which constituted the next stage. The extent of this degradation is not known, but it has given rise to a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit. In fig. 284 an attempt has been made to represent the principal stages in the cycle of events in Jurassic times, as above described. The diagram has little or no quantitative status, but it shows the general nature and sequence of events.

In Cretaceous time the region of the present Black Hills received a great succession of deposits of various kinds, but in greater part uni-



GEOLOGIC MAP OF THE ANTICLINAL AREA ON OLD WOMAN CREEK, CONVERSE COUNTY, WYOMING

BY

N. H. DARTON

Contours based entirely on barometric observations

SCALE

1 0 1 2 MILES

CONTOUR INTERVAL 50 FEET

1899

SEIBERT COMPANY, LITHO. N.Y.

form over a wide area. The variety of materials indicates considerable diversity of conditions, but in general there was a cycle beginning and ending with sands, with a long period of clay deposition in the middle. The first formation, the Lakota, consisted mainly of coarse sands, in greater part deposited by strong currents in beds 30 to 40 feet thick, with short intervening periods of deeper water or slackened currents in which several partings of clay were laid down. Probably the submergence at the time was slight, and there were periods of emergence, with slight planation in some regions and local accumulations of coal in others. At the end of the Lakota there accumulated a thin layer of calcareous deposit, now represented by the Minnewaste limestone, which may not have extended far beyond its present limits. Then followed deposition of the light-colored fire clays of the Fuson formation, which were much intermixed with sand to the northwestward. In the time of Dakota deposition the conditions were similar to those of Lakota time, but the accumulation of sand was not so long continued. There was everywhere in the region a rapid change from

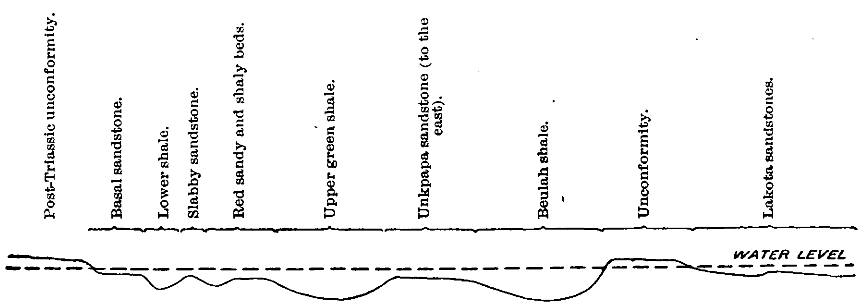


FIG. 284.—Outline of history of Jurassic deposition in the Black Hills region.

sand to clay deposition at the beginning of the Benton, doubtless due to sudden increased submergence.

In Benton, Niobrara, and Pierre times there was a long-continued, deep submergence, with the accumulation of several thousand feet of clay. In Benton time there were occasional interruptions by sand depositions, two of them in the later part of the epoch that were general over the greater part of the Black Hills region, and one in the earlier part that was local, giving rise to the lenses of sandstone which are now found in the vicinity of Newcastle and northwest of Hermosa. Another marked date was a relatively transient but general deposition of the calcareous bed of the Greenhorn limestone in the middle of the Benton sedimentation. The shale deposition of the Benton was followed by the accumulation of several hundred feet of impure chalk, now constituting the Niobrara formation. This was succeeded by the very uniform conditions attending the deposition of the great mass of clay now represented by over a thousand feet of Pierre shale. In Fox Hills time there was a gradual change to conditions which produced alternations of clays and coarse sand of marine origin. This period gave place gradually, doubtless through uplift, to deposition in a wide fresh-water basin of the alternations of thick masses of sands and clays of the Laramie formation. Whether these formations were deposited over the area now occupied by the Black Hills dome is not definitely known, but it is probable that they were, as they extend around two sides of the uplift and are upturned by it. The Black Hills dome was uplifted in early Tertiary time, and the larger topographic outlines of the region were developed before the Oligocene. The dome was truncated and its larger valleys excavated in part to their present depths, as is indicated by the occurrence in them of White River deposits, even in some of their deeper portions. Where the great mass of eroded material was carried is not known, for in the lower lands to the east and south we have no Eocene deposits nearer than those on the Gulf coast and the Mississippi embayment. The great lake which deposited the White River sediments of the Oligocene had its early shores on the Black Hills, and the higher portions of these hills were probably an island throughout that period. Arms of the lake extended part way up the larger valleys, receiving from various streams products of erosion from the Black Hills rocks, which now are prominent among the constituents of the early White River sediments. Some conditions at an early period in this Oligocene deposition are shown in Pl. XCIV (oversheet), which has been constructed largely from observed deposits and shore lines. Some of the drainage of the period is also shown on the oversheet, but with much less certainty, as it has not always been practicable to differentiate between the Oligocene and earlier Pleistocene drainage in the higher portions of the hills, where the White River deposits are absent. It is probable that the maximum submergence was much greater than is shown in the plate above referred to, for there are evidences in the relations of the drainage that many of the valleys and lower divides of the central portions of the hills were completely filled with White River deposits. They are found up to high altitudes—in the vicinity of Lead at an elevation over 5,200 feet and on the north end of the Bear Lodge Mountains, a thousand feet higher—and they are believed to have caused a superimposition of drainage at various points in the central and southern hills which can not be accounted for in any other way. It would not be safe at present to draw a map suggesting the maximum submergence of Oligocene times, but possibly later studies will afford means for doing so. Post-Oligocene erosion has removed most of the more elevated areas of White River deposits and probably the maximum submergence was so transient that no conspicuous shore lines were cut. No one who has observed extensive exposures of the finer-grained White River sediments would regard them as other than lake deposits. It has been suggested that their materials were carried by the wind, and also that they were

3-COLOR PROCESS

FROM PHOTOGRAPH BY N. H. DARTON

FLEXURES IN MINNEKAHTA LIMESTONE AND MINNELUSA SANDSTONE

West side of Black Hills uplift, east of the valley of Stockade Beaver Creek, 5 miles east of Newcastle, Wyoming

BLOCK OF FAULTED UNKPAPA SANDSTONE FROM WEST OF BUFFALO GAP, SOUTH DAKOTA.

deposited by running water on broad slopes by a network of streams; but the formations present features which are entirely at variance with these hypotheses. They consist mainly of very fine-grained materials, usually spread out in thin beds with perfectly even stratification, in which precisely the same sequence of beds may be traced for miles. This is an impressive feature in the big Bad Lands, where in widespread exposures the very even and uniform bedding of the Oreodon or Brule clays is everywhere to be observed. In the lowest member, the Chadron formation, the extensive deposits of fullers' earth are almost certainly of chemical origin and afford no suggestion of stream deposition. At the base of this formation there are extensive areas of very coarse materials, the products of streams which immediately preceded the general submergence by the advancing lake waters. There are also in that formation certain stream deposits which meander across the fine-grained materials, occupying channels which often are traceable to and through the pre-Oligocene gaps in the hogback range of the Black Hills. These stream deposits, however, are generally completely inclosed by the fine-grained sediments, and they represent episodes in some stages of the deposition when the subsidence was slightly retarded and surface streams or strong currents extended out over the lake-laid deposits for a short time. It is in these channels of coarser material that the greater number of titanotherium bones are found. These remains are of animals that died on the shores or in the waters of the early Oligocene streams in the Black Hills, and while their bodies were inflated by the gases of decomposition were carried out into the lake a greater or less distance or deposited along the courses of the streams. This condition of deposition is one that is to be seen at the present day, and I think fully accounts for the conditions under which the remains are found in the White River formations. In the Oreodon beds, or Brule clays, where the products of currents are in evidence only locally, at two widely separated horizons, it is easy to understand that the bodies floated part way across the lake before they dropped to its bottom, eventually to be buried by the sediments. The eastern margin of this lake has not been traced for any distance, but there is no great difficulty in seeing that it consisted of low hills of Pierre shale and Fox Hills beds against which the Tertiary formations now abut to the east. The region adjoining the Black Hills and Laramie Range was uplifted several thousand feet at a period subsequent to the deposition of the White River and overlying Miocene formations, an uplift which amounts to as much as the present upslope of the plains now partly underlain by Tertiary formations in Nebraska and Dakota. The deposition extended far to the north of the Black Hills, as shown by Professor Todd in his discovery of extensive areas of White River beds in the extreme northwestern part of South Dakota. To the southwest I have traced them along the foot of Pine Ridge to Douglas, in central Wyoming, where they abut against hills of Laramie sand-

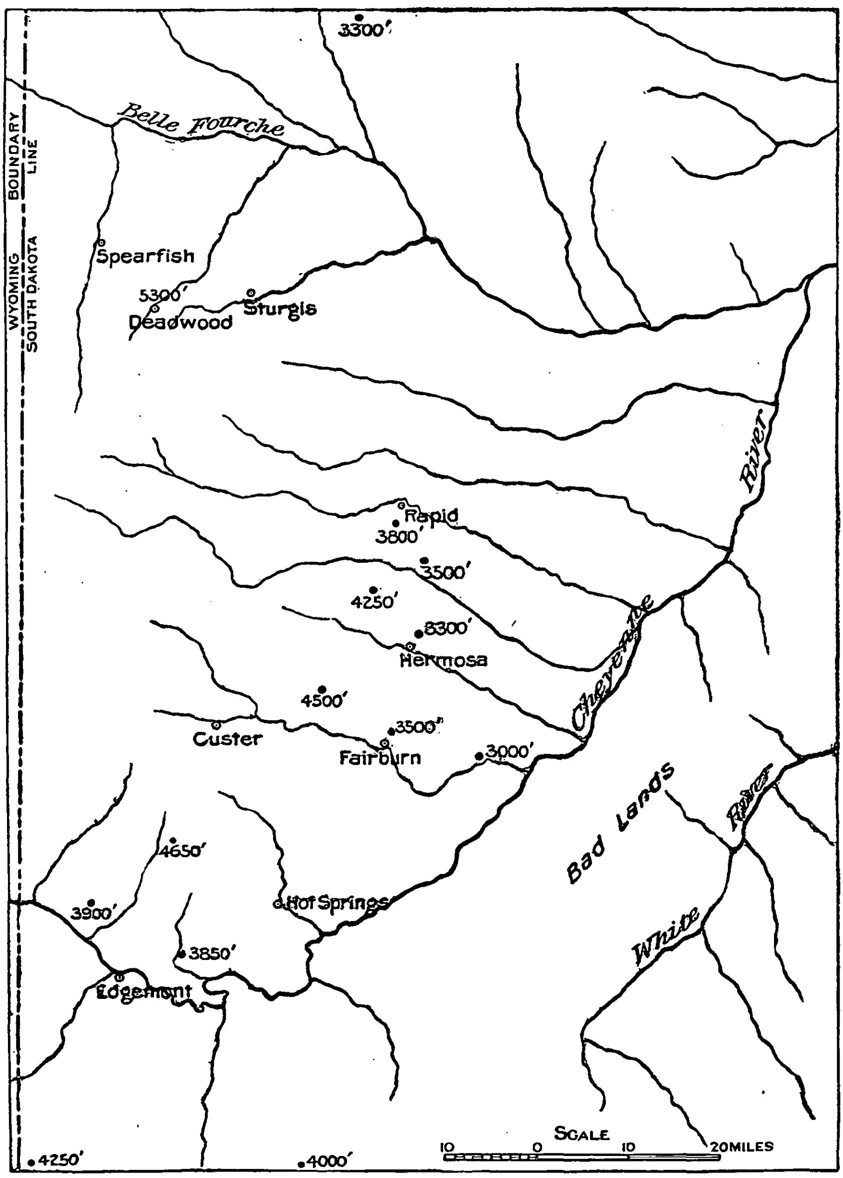


FIG. 285.—Map of the Black Hills and adjoining regions, giving altitudes of White River deposits at various points in order to show the amount and distribution of post-Oligocene uplift.

stone. They have not yet been discovered directly west of the Black Hills, unless, possibly, there is a small, thin remnant on top of the

APPROXIMATE AREA OF DEPOSITION OF LOWER BEDS OF WHITE RIVER GROUP IN THE SOUTHEASTERN PORTION OF THE BLACK HILLS

ALSO THE COURSE OF THE PRINCIPAL DRAINAGE

Laramie sandstone capping the summits of Pumpkin Buttes, at the head of Belle Fourche River. I have recently (1900) found them on the high ridges extending north from Warren Peak, in Bear Lodge Mountain, at an altitude of over 6,000 feet.

Following the deposition of the White River formations there were several hundred feet of uplift, with erosion and probable complete draining of the lake. No representatives of the Loup Fork group—the Arikaree and Ogallala formations—have been discovered in the immediate vicinity of the Black Hills, but they are extensively developed in Pine Ridge on the south and remain in portions of the area of the high buttes to the north in the northwestern corner of the State of South Dakota. There was probably slow but continuous uplift during the Loup Fork period, and the Black Hills contributed materials from its higher slopes at that time, but whether they ever were deposited in the immediate vicinity of the hills is not ascertained. The present altitude of the base of the White River deposits in the Black Hills and adjoining regions is shown in fig. 285, which indicates the amount of uplift, mainly of late Tertiary date. During the early portion of the Pleistocene period there was widespread planation of the Tertiary deposits, and many of the old valleys were revived. There was at this time, however, considerable rearrangement of the drainage, probably caused on the eastern side of the hills by increased tilting to the northeast during the late Tertiary uplift. Some of the streams superimposed upon the White River deposits cut across old divides, and in some cases connected valleys with their next neighbor to the north. This history is clearly indicated by the offsetting of pre-Oligocene valleys to the northward through canyons of post-Oligocene age, leaving numerous elevated saddles to mark the original course of the valleys to the southeastward. Some of the offsetting in the present drainage has been largely increased by early Pleistocene erosion and recent stream robbing. The early Pleistocene streams had in greater part the course shown in the oversheet of Pl. XCV. The erosion of the White River deposits in the higher valleys was easily effected, owing to their softness, so that the upper portions of most of the old valleys were completely cleaned out. In the lower lands to the east of the hills there was wide planation, but apparently it was not sufficiently long continued to cut en-

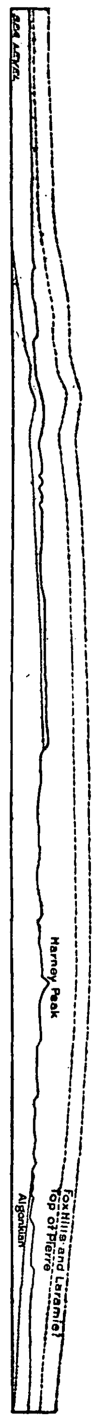


FIG. 286.—Section across center of Black Hills uplift to show extent of degradation.

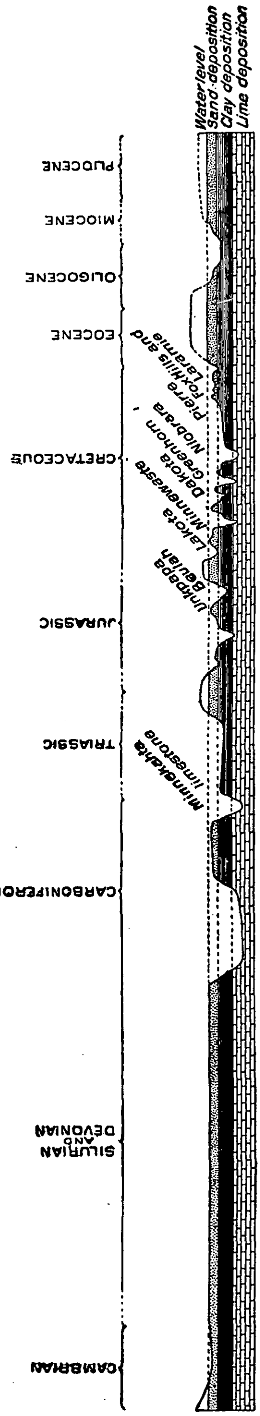
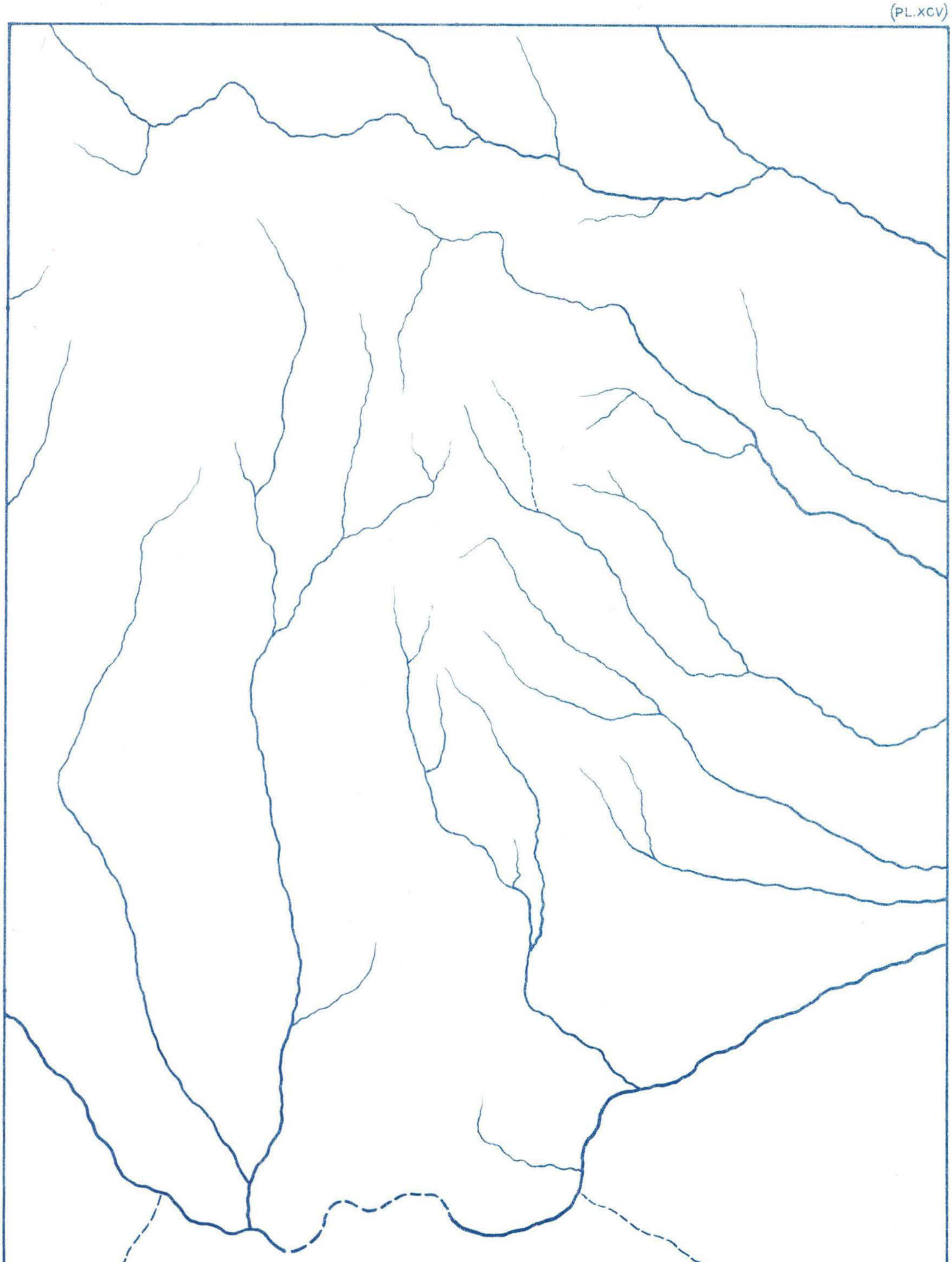


FIG. 287.—Diagram of the principal events in the geologic history of the southern Black Hills region.

tirely through the White River formations. The Pleistocene streams were in narrow valleys in the hills, but they spread out widely in the Red valley, then mostly filled with White River sediments, and east of the hogback range excavated wide valleys, probably shifting more or less laterally, which extended far east to beyond the present valley of White River. There appears to have been further uplift in late Pleistocene time, for the present valleys below the level of the earlier Pleistocene high-level deposits seem to be cut deeper than would result simply from the natural progression of a lower plain of base leveling up the Missouri and Cheyenne rivers. The result has been the cutting of wide, shallow valleys in the soft deposits and canyons of moderate extent and depth in the harder rocks. The erosion has progressed with regularity in the main, but in some cases, with the shifting of channels, there have been accumulations of local deposits on small terraces at various levels. The more notable of these are the terraces along Cheyenne River, the deposit of conglomerate, etc., at Hot Springs, and the gravel accumulations on the "high bars" at different points in the higher canyons. Stream robbing has been constantly in progress in the eastern portion of the hills, nearly always to the northeast, the more northerly streams here often having the advantage of increased declivity over their neighbors on the south.

In fig. 287 a diagram is given to show the geologic history of the Black Hills mainly as represented by the nature of the sediments. The principal periods of uplift are also indicated. The diagram has no quantitative scale, either horizontal or vertical, for we do not know the relative lengths of geologic periods, and the nature of the materials does not always indicate the depth of water in which they were deposited.



APPROXIMATE COURSE OF EARLY PLEISTOCENE DRAINAGE IN THE SOUTHEASTERN BLACK HILLS
BY
N. H. DARTON
1899

WATER RESOURCES.

UNDERGROUND WATERS.

GENERAL RELATIONS.

The underground water problem in the region to which this report relates is mainly in the plains adjoining the Black Hills. There extend

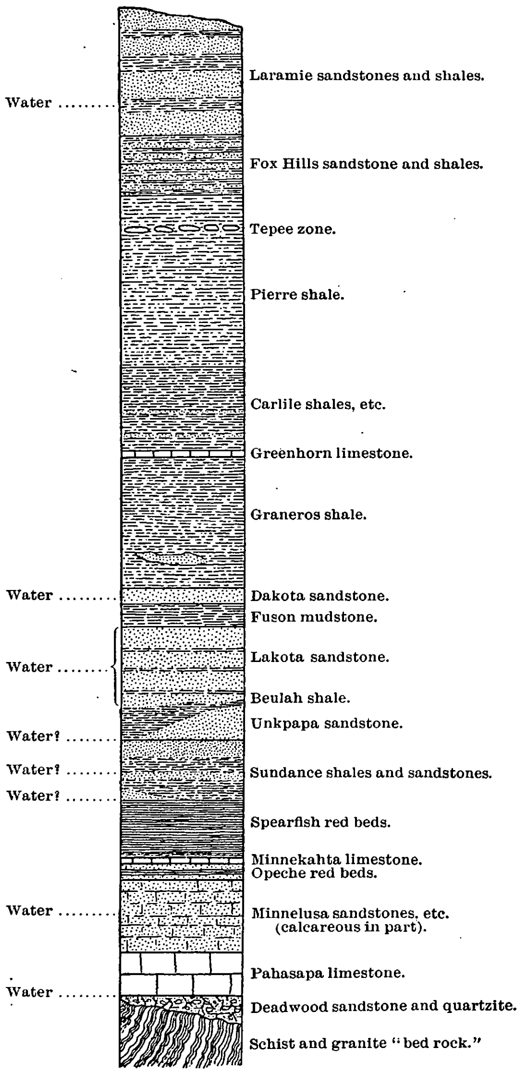


FIG. 288.—Columnar section of sedimentary formations in Black Hills region, showing the water-bearing beds.

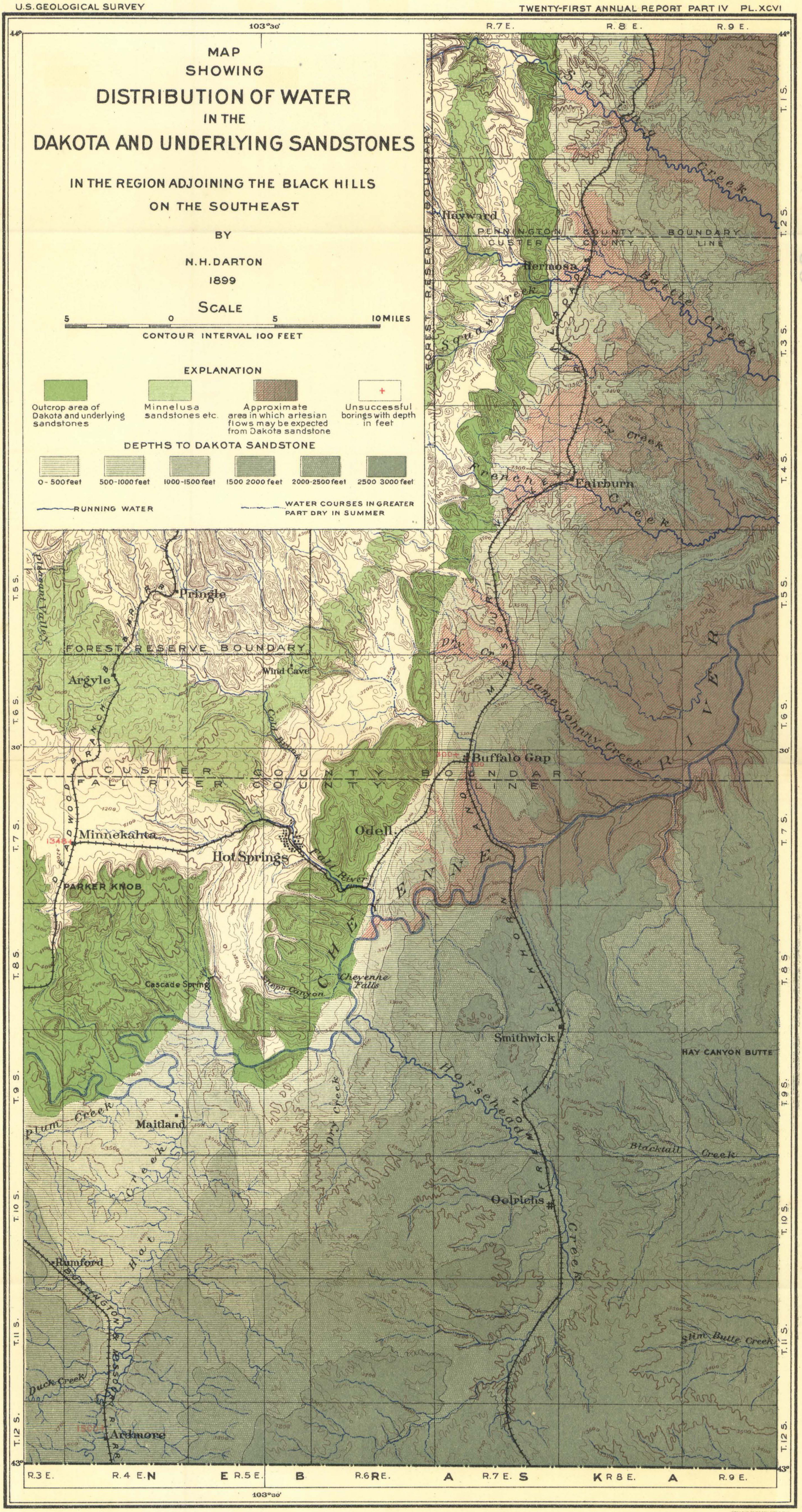
under these plains several thick sheets of water-bearing sandstones, which receive water supplies at the surface in the high lands of the

Black Hills. These sandstones are carried under ground on the general outward dip on the flanks of the hills, and owing to the relative steepness of this dip a considerable depth is soon attained. In most parts of the area the inclination of the strata diminishes away from the hills, and there is a wide area of the surrounding country under which the water-bearing beds lie at a depth that is within reach of the well-borer. As the region is semiarid, with surface waters often containing much "alkali," there is great need at most places for the underground waters. In fig. 288 are shown the principal water-bearing horizons in the Black Hills and their vicinity. These formations are all uplifted above the surface on the slopes of the Black Hills in regular succession, as described in the geologic portion of this report. They outcrop in wide zones encircling the hills, and receive a large amount of water not only from the rainfall on their surface, but from the streams which at many points sink in whole or in part in crossing the outcrops of the more permeable beds. The sinking of streams in this manner is to be observed in almost every valley leading out of the crystalline-rock area. Few of the streams carry more than a small proportion of the total original run-off of their watersheds into Cheyenne River, as much of it sinks under ground in crossing the sandstones, particularly those of the Minnelusa, Lakota, and Dakota formations. These waters pass far beneath the surface as the water-bearing beds descend on the slopes of the Black Hills uplift.

DAKOTA-LAKOTA HORIZON.

Under the plains to the east of the hills the waters lie in some places as deep as 3,000 feet, and in the case of the Dakota-Lakota horizon the water-bearing beds continue all the way under the States of South Dakota and Nebraska, outcropping on Missouri River below the mouth of Big Sioux River, where for many miles the waters escape in copious springs. Artesian wells have been sunk by the hundreds in eastern South Dakota to depths of from 400 to 1,000 feet in greater part, and yield a vast volume of waters for domestic use and even for extensive irrigation. A view of a typical well from this horizon in eastern South Dakota is given in Pl. XCIX, and the extension of the water-bearing beds from the Black Hills uplift is shown in fig. 289.

Various wells have been bored in the vicinity of the Black Hills which in most cases have yielded satisfactory supplies of water. The most notable of these are on the Burlington and Missouri River Railroad at Argentine, near Clifton, and at Jerome Siding. There are also flowing wells at Newcastle and at Belle Fourche, on the northern edge of the Black Hills, and deep wells at Edgemont, which contain water, but without sufficient pressure to flow at the surface. All of these wells and the numerous artesian wells that yield so large a volume of water in the eastern part of South Dakota obtain their sup-


MAP
SHOWING
DISTRIBUTION OF WATER
IN THE
DAKOTA AND UNDERLYING SANDSTONES
IN THE REGION ADJOINING THE BLACK HILLS
ON THE SOUTHEAST
BY
N. H. DARTON
1899
SCALE
5 0 5 10 MILES
CONTOUR INTERVAL 100 FEET
EXPLANATION
Outcrop area of Dakota and underlying sandstones
Minnelusa sandstones etc.
Approximate area in which artesian flows may be expected from Dakota sandstone
Unsuccessful borings with depth in feet
DEPTHS TO DAKOTA SANDSTONE
0-500 feet
500-1000 feet
1000-1500 feet
1500-2000 feet
2000-2500 feet
2500-3000 feet
RUNNING WATER
WATER COURSES IN GREATER PART DRY IN SUMMER
103°30'
R. 7 E.
R. 8 E.
R. 9 E.
44°
Hayward
PENNINGTON COUNTY BOUNDARY LINE
CUSTER COUNTY
Hermosa
Battle Creek
Squaw Creek
FOREST RESERVE BOUNDARY
Dry Creek
French Creek
Fairburn
Pringle
Wind Cave
Argyle
Buffalo Gap
CUSTER COUNTY BOUNDARY
FALL RIVER COUNTY LINE
Lame Johnny Creek
CHEYENNE RIVER
Minnekahta
Hot Springs
Odell
Fall River
PARKER KNOB
Cascade Spring
Cheyenne Falls
Smithwick
HAY CANYON BUTTE
Horsehead Creek
Plum Creek
Maitland
Dry Creek
Hat Creek
Blacktail Creek
Oelrichs
Rumford
BURLINGTON & MISSOURI R.R.
Slim Butte Creek
Duck Creek
Ardmore
T. 1 S.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
T. 12 S.
30'
43°
R. 3 E.
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
NEBRASKA

plies from the Dakota-Lakota horizon. This horizon is the one nearest the surface in the region adjoining the Black Hills, although, owing to the steep dip of the beds, it lies deep beneath the overlying Cretaceous shales under most localities. These shales are barren of water and in all cases have to be penetrated to reach the Dakota sandstone. In Pls. XCVI and XCVII are shown the depth to this sandstone over the entire area to which this report relates. In these plates there is also represented the area in which artesian flows may be expected, the outcrop areas of the water-bearing formations, and the location of all deep borings that have been reported. The depth to the Dakota sandstone has been ascertained by careful measurements of the thickness of the overlying formations and the determination of the structure in the region adjoining the hills. The principal guide to the structure in the wide area about Oelrichs was the occurrence of the horizon of limestone lenses in the Pierre shales, giving rise to tepee buttes.

It should be stated that the depths shown in Pls. XCVI and XCVII are to the top of the Dakota sandstone, and ordinarily it would be necessary to bore some distance farther in this sandstone before any large volume of water could be expected. The principal supplies usually occur in the upper part of the Lakota formation, which often lies 200 feet below the top of the Dakota beds. It will be noticed on the maps that the zone in which water may be obtained at depths less than 500 feet is a very narrow one for the greater part of its course and lies along the base of the hogback foothills. The belt in which the waters lie between 500 and 1,000 feet below the surface is somewhat broader and passes outside of many of the small settlements that are scattered along the railroad just outside of the hills. In the area

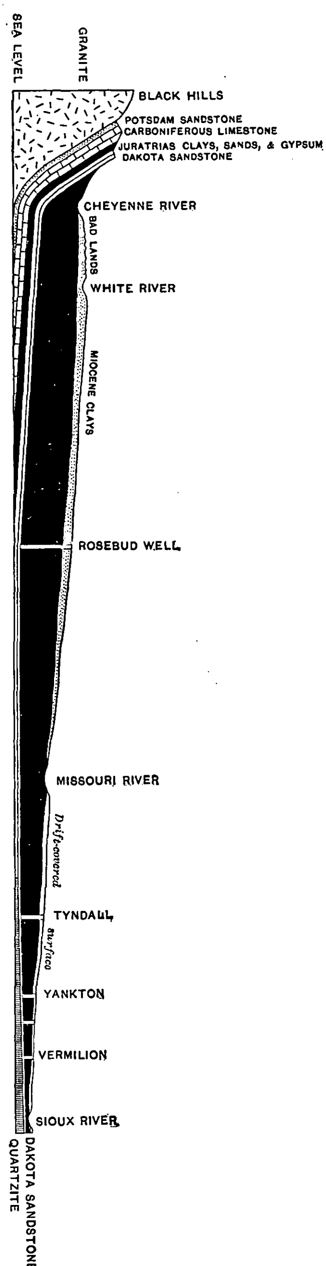


Fig. 289.—Section across South Dakota from the Black Hills to Sioux River to show the artesian conditions.

under which the water lies more than 2,500 feet below the surface it would probably not be desirable to sink a well, for it is very difficult to bore to this depth through the great mass of overlying shale. In the wide area of central Weston and Converse counties, Wyoming, the Dakota-Lakota horizon lies at great depth under the great mass

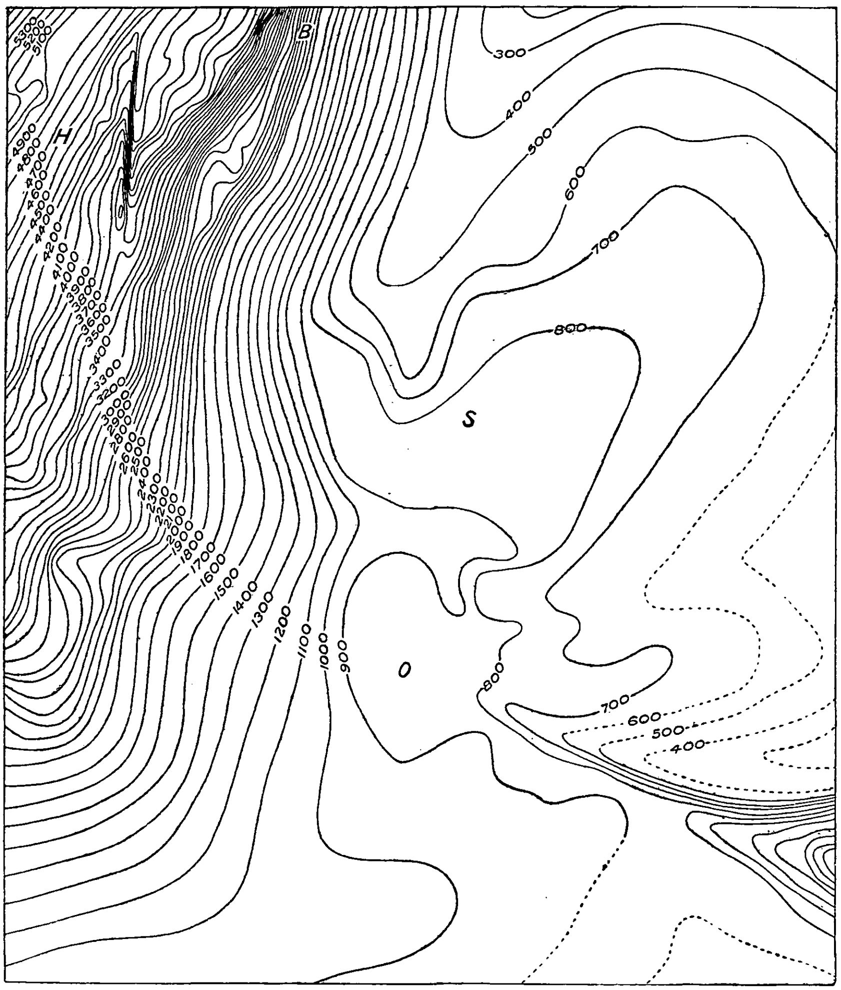
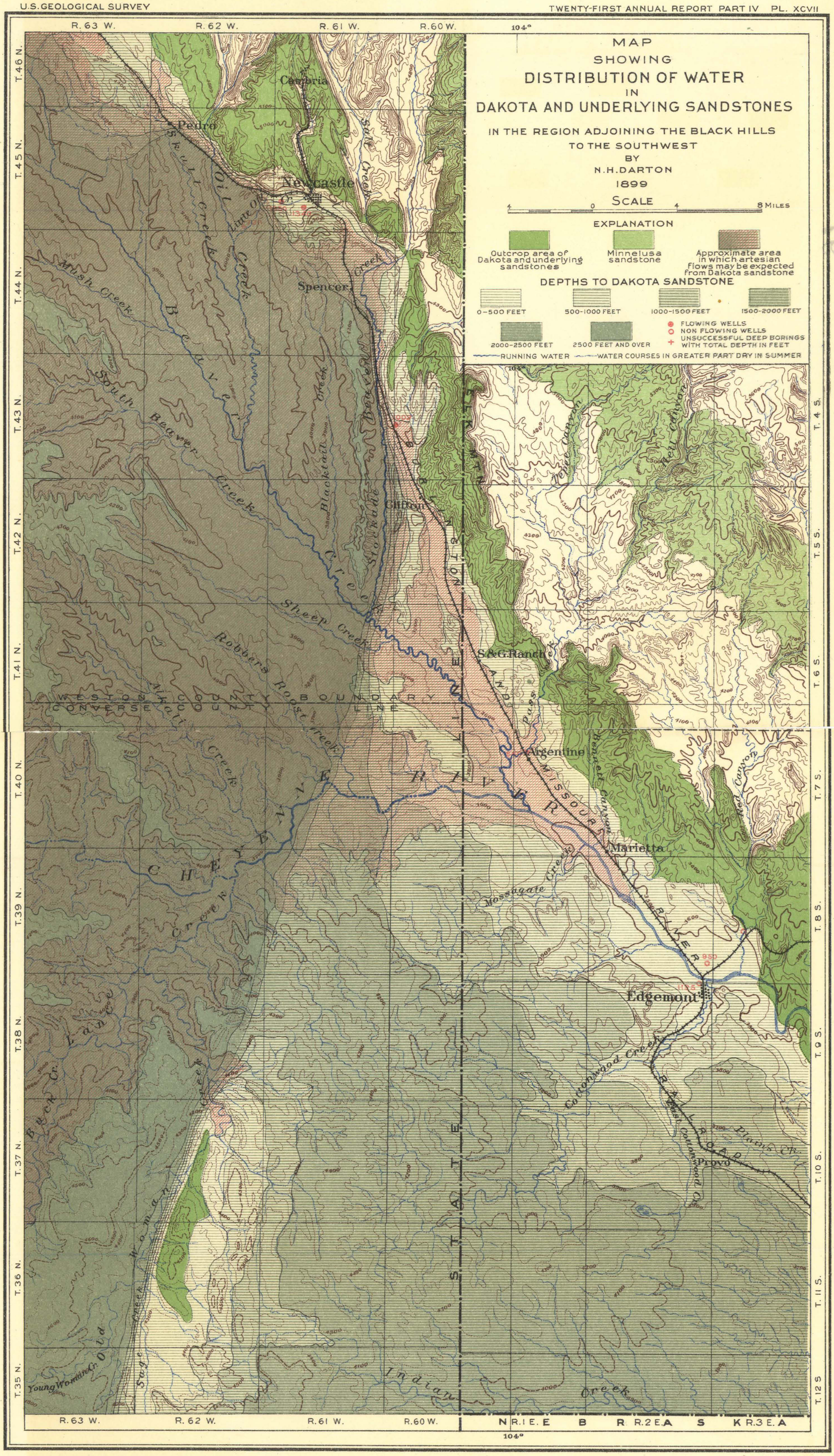


FIG. 290.—Diagram of contour of top of Dakota sandstone about Oelrichs and Hot Springs, South Dakota. O, Oelrichs; S, Smithwick; B, Buffalo Gap; H, Hot Springs.

of Laramie deposits. In that region, however, there are prospects for finding waters in the Fox Hills and the Laramie sandstone, but these would not yield surface flows in the area described in this report.

Looking at the water problem of the Northwest in a broader way, and taking the data which has been secured in the course of the last few years in the Dakotas, Nebraska, and the adjoining States, Pl. C


MAP
SHOWING
DISTRIBUTION OF WATER
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DAKOTA AND UNDERLYING SANDSTONES
IN THE REGION ADJOINING THE BLACK HILLS
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Approximate area in which artesian flows may be expected from Dakota sandstone
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0-500 FEET
500-1000 FEET
1000-1500 FEET
1500-2000 FEET
2000-2500 FEET
2500 FEET AND OVER
FLOWING WELLS
NON FLOWING WELLS
UNSUCCESSFUL DEEP BORINGS WITH TOTAL DEPTH IN FEET
RUNNING WATER
WATER COURSES IN GREATER PART DRY IN SUMMER
R. 63 W.
R. 62 W.
R. 61 W.
R. 60 W.
104°
T. 46 N.
T. 45 N.
T. 44 N.
T. 43 N.
T. 42 N.
T. 41 N.
T. 40 N.
T. 39 N.
T. 38 N.
T. 37 N.
T. 36 N.
T. 35 N.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
T. 12 S.
Cambria
Pedro
Newcastle
Spencer
Clifton
S.&G. Ranch
Argentine
Marietta
Edgemont
Provo
Salt Creek
Oil Creek
Skull Creek
Mush Creek
South Beaver Creek
Beaver Creek
Blacktail Creek
Stockade
Sheep Creek
Robbers Roost Creek
Alkali Creek
Crown Creek
Lance Creek
Buck Cr.
Young Woman Cr.
Old Woman Creek
Sage Creek
Indian Creek
Mossagate Creek
Cottonwood Creek
Plum Cr.
Pass Creek
Bennett Canyon
Red Canyon
Hell Canyon
Pedro Canyon
WESTON COUNTY BOUNDARY
CONVERSE COUNTY LINE
CHEYENNE RIVER
MISSOURI RIVER
STATE LINE
B. & M. R. R.
R. 1 E.
R. 2 E.
R. 3 E.

is offered to illustrate the factors bearing on the prospects for obtaining artesian waters from the Dakota-Lakota horizon over the entire area of the northern Great Plains region.

MINNELUSA SANDSTONE.

The Minnelusa formation is of so sandy a nature that we may expect it to contain water in sufficient volume to furnish supplies to wells in portions of the Red Valley. As it lies 1,000 feet or more below the Dakota sandstone and is several hundred feet thick itself, its waters lie too deeply buried to be available in the plains adjoining the Black Hills. The Red Valley contains but little surface water, and there are many places where a water supply from deep wells would be very serviceable. There are several large springs about the hills which appear to flow from the Minnelusa formation either directly or through crevices in the Opeche formation and the Minnekahta limestone. The most notable of these are the thermal springs at Hot Springs and Cascade, where very large volumes of water are undoubtedly derived from the Minnelusa beds, although they emerge from crevices in the Minnekahta limestone. Their temperatures indicate that they come from a considerable depth. At the Soldiers' Home at Hot Springs a well has been sunk into Minnelusa sandstone which furnishes a water supply. At Minnekahta Station a deep boring was made, apparently through the Minnekahta formation, that yielded no water. At Cambria a boring is now in progress which has penetrated through the formation without finding more than a very moderate supply of water. For part of the area at least the Minnelusa formation, although a porous sandstone at the surface, is much less permeable under ground. This is due to its being cemented into a very compact rock by carbonate of lime, which appears to so fill up its interstices that it could not contain much water. How general this condition may be under ground is not yet known.

DEADWOOD SANDSTONE.

The Pahasapa limestone is traversed by numerous open joints and caves of vast extent, but they do not appear to contain much water. It is probable that the water in the limestone is not great in volume at most, and is free to sink into the underlying Deadwood sandstone. This sandstone contains much water that would be available for wells, but in the southern Black Hills the area is very restricted in which these waters could be obtained within a reasonable limit of depth. In the sections (Pl. LXXXVIII) are shown the underground relations of the Carboniferous and Cambrian formations in the southern Black Hills. These it is thought will afford all necessary information to persons contemplating sinking wells to these lower horizons.

BORINGS.

Several wells have been bored in the region to which this report relates, some have been successful and others have failed to yield water. In most cases the unsuccessful borings were made at points where their failure might have been predicted by the geologist, but for others an explanation is difficult. As it is desirable to place on record all of the data which have been obtained regarding the borings they will be given on the following pages.

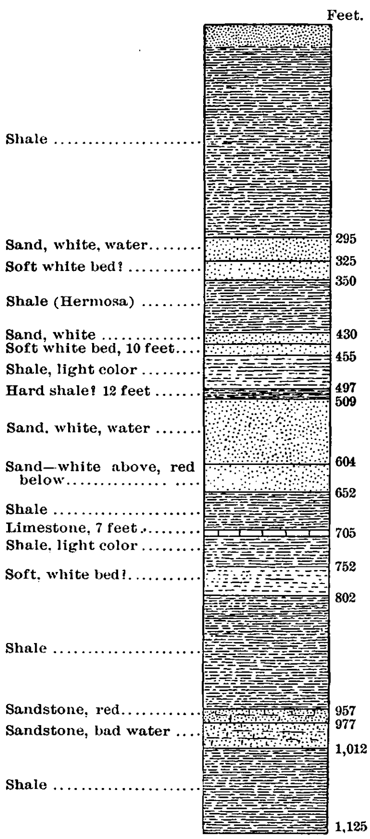


FIG. 291.—Log of deep well at Edgemont, South Dakota.

Edgemont.—In this city and its vicinity a number of wells were sunk several years ago for water from the Dakota sandstone. They nearly all obtained supplies for pumping, but owing to the low level of the outcrops of the Dakota sandstone in the vicinity the water did not have sufficient head to flow. The water did not prove satisfactory for use in locomotives, and all but the deeper well at the railroad roundhouse have been abandoned. The records of the two wells are given in figs. 291 and 293, and their location is shown in fig. 292. One of the wells at the roundhouse, of which the log is given in fig. 291, has a depth of 1,125 feet, but is now filled to the depth of 700 feet. Water of bad quality was found in the white sand at 295 feet and in the sandstone at 977 feet. Fairly good water is now obtained from the sandstone which begins at a depth of 509 feet. It rises to within 60 feet of the surface. It contains 239 grains of solid matter per gallon, of which 9.33 grains are lime. The log appears to be a fairly reliable one, indicating the Dakota sandstone from 295 to 350 feet; the Fuson formation from 350 to 430 feet; the Lakota formation from 430 to about 635 feet; possibly the Unkpapa sandstone between 635 and 652 feet; and the Sundance shales and sandstones thence to 1,125 feet, which is probably not far above the top of the red beds of the Spearfish formation. The Beulah shales may be represented between 652 and 700 feet, lying above the limestone between 705 and 712 feet, which usually occurs near the top of the Sundance formation. The well at the north end of the Y across the river from Edgemont has a depth of 960 feet, and probably ends in Sundance shales. Some water was found in the white sand at 230 feet, and in sandstones at 290 and 430 feet. At 578 feet a sandstone begins which yields a good supply of water, rising to within 30 feet of the surface. A thin sand-rock at 703 feet also yields water, but its volume is small.

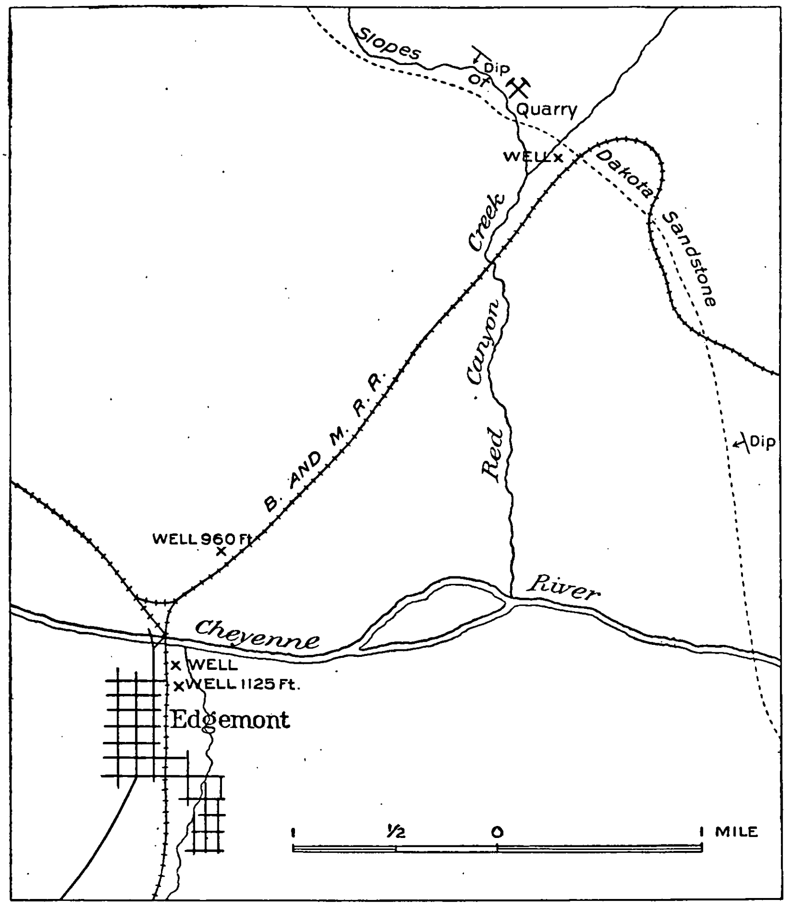


FIG. 292.—Map of Edgemont and vicinity to show the location of the deep borings.

Ardmore.—At Ardmore, on the Burlington and Missouri River Railroad, 26 miles south of Edgemont, the railroad company has made a boring to a depth of 1,500 feet without obtaining water. The hole is entirely in shale, excepting about 40 feet of white sand containing thin partings of black shale. This boring begins just about the surface of the Niobrara formation, and apparently penetrates very nearly to the Dakota sandstone, the sandstone bed reported probably being in the Graneros shales. As Ardmore is at the altitude of 3,557 feet, and the water-bearing Dakota sandstone outcrops about Edgemont are at an altitude of 3,400 feet, there is no possibility of a flow at the former place, but probably a supply of water for pumping could be obtained by deepening the boring into the Dakota sandstone. The estimated altitude to which the water would rise in such a well is about 3,450 feet.

Argentine.—This station is a water-tank siding on the Burlington and Missouri River Railroad, 17 miles northwest of Edgemont. The well is on the south side of Pass Creek, a short distance west. It is a flowing well 550 feet deep, yielding a fairly large volume of water, but of a quality not satisfactory for locomotives, as the following analysis will show:

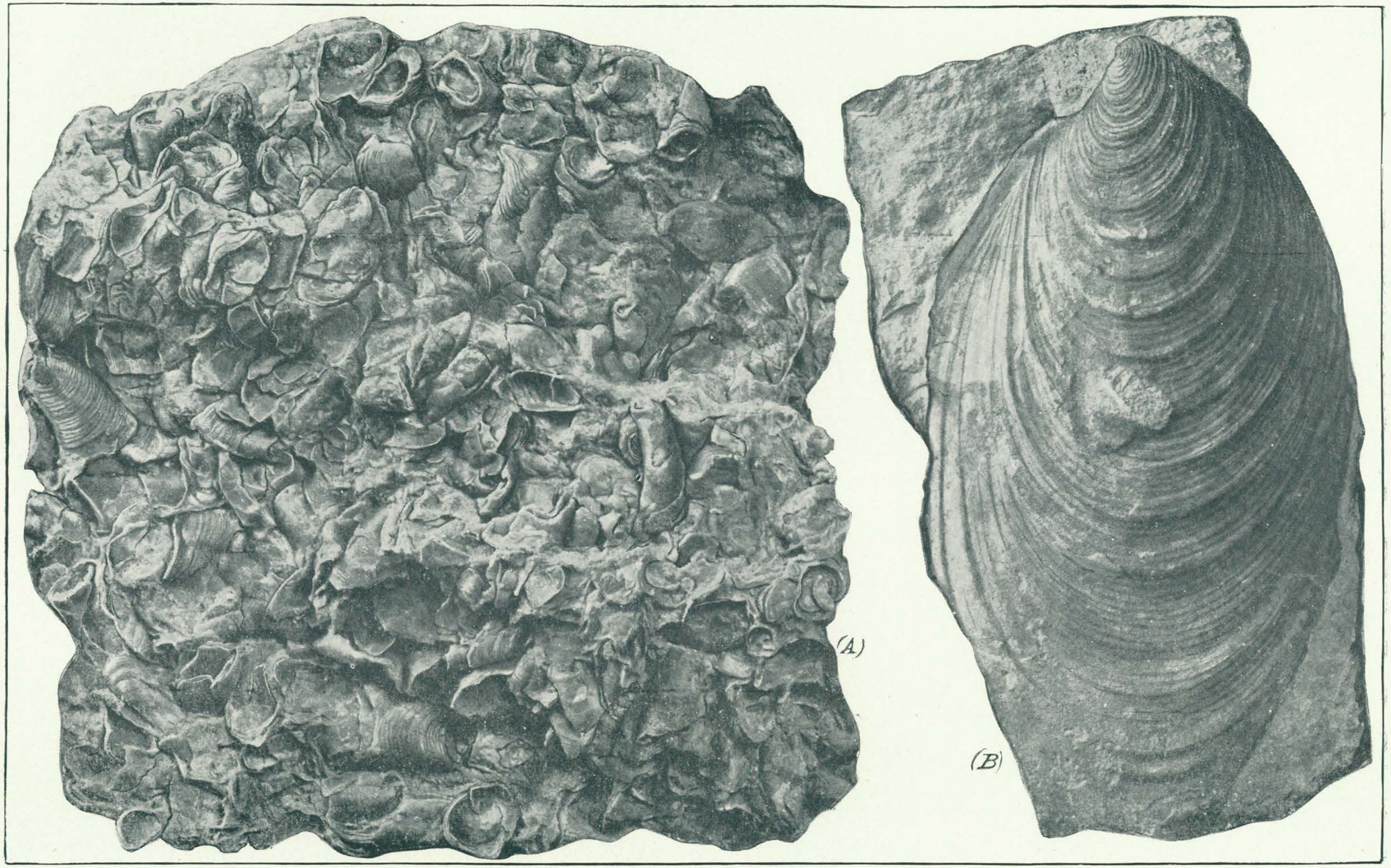
Analysis of artesian water at Argentine, South Dakota.

Constituent.	Grains per gallon.
Sodium sulphate	39.90
Potassium sulphate	0.90
Lime sulphate	4.20
Lime carbonate	6.00
Magnesia carbonate	4.00
Alumina and iron oxide	0.05
Silica	0.19
Total solids	56.60
Organic matter	0.55

This analysis was kindly furnished by the railroad company. The log of the boring was not obtainable. The well begins in Graneros shales and undoubtedly obtains its water supply from the Lakota sandstone, which outcrops in the high ridge to the east.

Clifton.—There is a flowing well 4 miles north of Clifton Siding on the Burlington and Missouri River Railroad. The log furnished by the railroad company is given in fig. 294. Flows of water are reported at 72, 210, 490, and 925 feet. The upper sandstone appears to be in the lower part of the Graneros shale, the 20-foot bed from 62 to 82 feet being the one in the small ridge just east. The Dakota sandstone probably comprises the beds lying between 200 and 290 feet. The Lakota formation is represented by heavy beds of sandstone extending down to at least 682 feet. Then come Beulah and Sundance beds, of which the limits are not recognized from the log as it is given. The 120 feet of red beds probably include the usual red member of the upper part of the Sundance formation, but as here reported doubtless include some of the adjoining beds which are not red. The water is unsatisfactory in quality and the well is abandoned.

There is another flowing well by the side of the railroad a mile and a half farther north, which yields a supply of very saline, ferruginous water. Its depth was not ascertained. At Clifton a supply of water for locomotives is pumped from a 300-foot well sunk into the Lakota sandstone, a few rods west of the Dakota sandstone ledges.



CHARACTERISTIC FOSSILS OF GREENHORN LIMESTONE AND NIOBRARA CHALK; IMPORTANT GUIDES IN WELL BORING.

(*A*) Ostrea congesta. (*B*) Inoceramus labiatus.

Newcastle.—No attempts have been made to obtain underground waters at Newcastle, but several of the oil wells have yielded promising flows of water. As these wells are described quite fully on pages 586 and 587 in connection with the oil, it is not necessary to repeat the statements.

Jerome.—There is a flowing well at this siding on the Burlington and Missouri River Railroad a few miles north of Osage Siding. Although it is just outside of the region to which the report relates, it indicates a continuation of the artesian conditions north from Newcastle in the

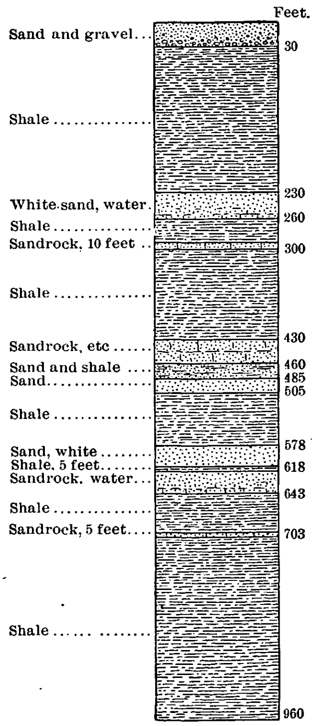


FIG. 293.—Log of deep boring at the Y near Edgemont, South Dakota.

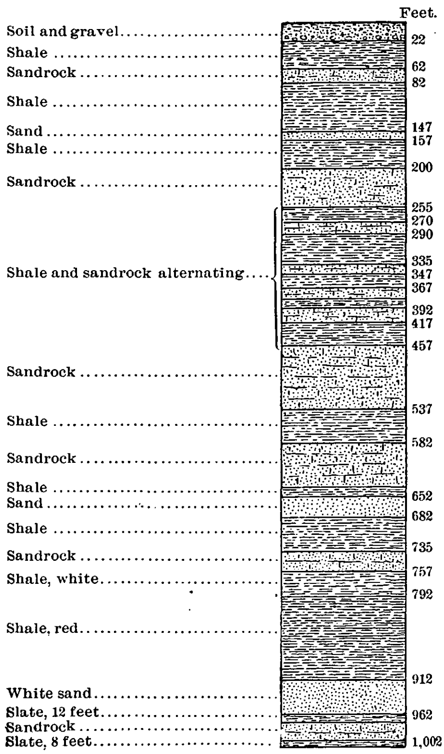


FIG. 294.—Log of artesian well at Whoopup, near Clifton Siding, Wyoming.

lowlands bordering the western slopes of the Black Hills. The depth of the Jerome well is 520 feet. It begins in Graneros shales and extends into Lakota sandstone. The railroad company has kindly furnished the following analysis:

Analysis of artesian water from Jerome, Wyoming.

Constituent.	Grains per gallon.
Sodium chloride	0.7
Sodium sulphate	29.8
Magnesia sulphate	7.0
Lime sulphate	2.3
Magnesia carbonate	0.5

Cambria.—A deep boring is now in progress at Cambria to furnish a local water supply for the town. It reached a depth 1,810 feet in the Pahasapa limestone in the early part of 1900. So far no large volume of water has been found, but there are prospects of finding a supply in the coarse Deadwood sandstone below. The experiment is an extremely important and interesting one, for it will throw light on the

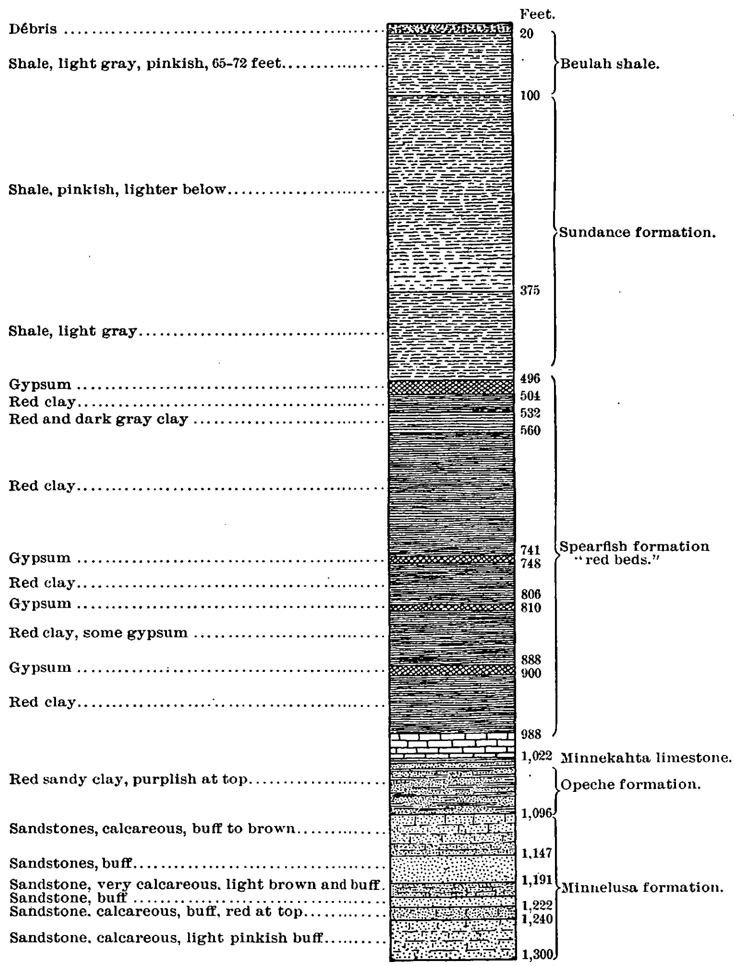


FIG. 295.—Log of deep boring at Cambria, Wyoming.

underground water conditions in all the older formations on the west slope of the Black Hills. A partial log of the boring is given in fig. 295, compiled from the set of borings admirably preserved in glass tubes by Mr. Mouck, the superintendent of the Cambria mines. The general relations are shown in section 2, Pl. CIV, which passes through Cambria. The different formations are readily recognized in the log of the Cambria boring. It begins in the Beulah shales at an altitude

ARTESIAN WELL AT WOONSOCKET, SOUTH DAKOTA.

of 5,075 feet, or about 50 feet below the coal bed. It passes through the Sundance formation and enters the Spearfish red beds at 496 feet, the first member being a bed of gypsum 8 feet thick, which caps the red beds in the exposures east of Cambria. The Minnekahta limestone occurs at a depth of 988 feet, having a thickness of 34 feet, as in the outcrops in the valley of Stockade Beaver Creek. Then come the red sandy clays of the Opeche formation, 74 feet thick, with the purplish beds at their top, and then the great mass of Minnelusa beds. They consist of sandstone with a greater or less admixture of carbonate of lime, all so fine-grained and compact as not to yield much water. The underlying Pahasapa limestone is very compact and has yielded no water.

Minnekahta.—Several years ago the Burlington and Missouri River Railroad Company made a deep boring at Minnekahta Station to obtain a water supply for locomotives. A depth of 1,348 feet is said to have been attained, but no promising amount of water was reported. The log, which is given in fig. 296, is clearly an unreliable one and very unsatisfactory for the identification of the geologic formations. No clew is given as to the location of the Minnekahta formation, which should be expected to begin at about 300 feet below the surface at Minnekahta Station. The red sands, from 743 to 908 feet, are doubtless in the Minnelusa formation. At a depth of 1,348 feet the boring should be near the granite or schist bed rock, for the thickness of the formations from the lower half of the Spearfish through the Deadwood is not much more than this in the surface exposures in the region to the north. The references to gypsum at various depths in the boring are mistakes as to the identity of the material, excepting those near the top. It is to be deeply regretted that the log is not more accurate, for it could have thrown important light on the stratigraphy.

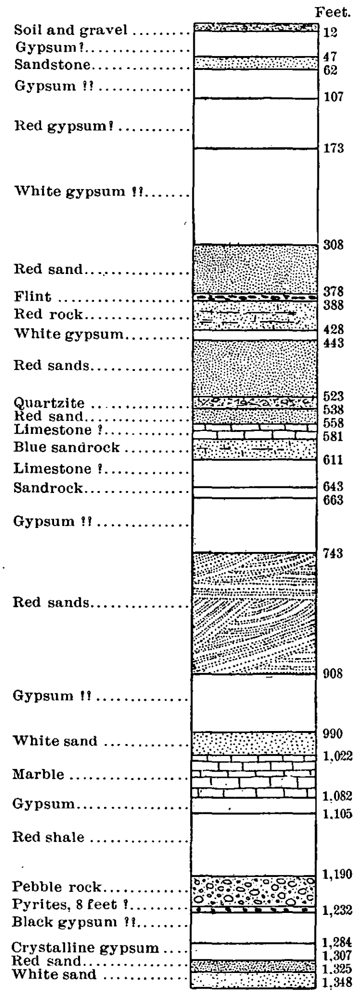


FIG. 296.—Log of deep boring at Minnekahta, South Dakota.

Buffalo Gap.—Two borings were made at this place several years ago to obtain a water supply, but they were not sunk to a depth sufficient to reach the Dakota sandstone. One was on a hill just west of the town and the other was on the principal street. The latter had a depth of 800 feet, entirely in dark shale. The boring began in the shales above the Greenhorn limestone of the Benton group and passed far down into the Graneros shales. Probably the Dakota sandstone would have been entered at a depth of about 1,100 feet.

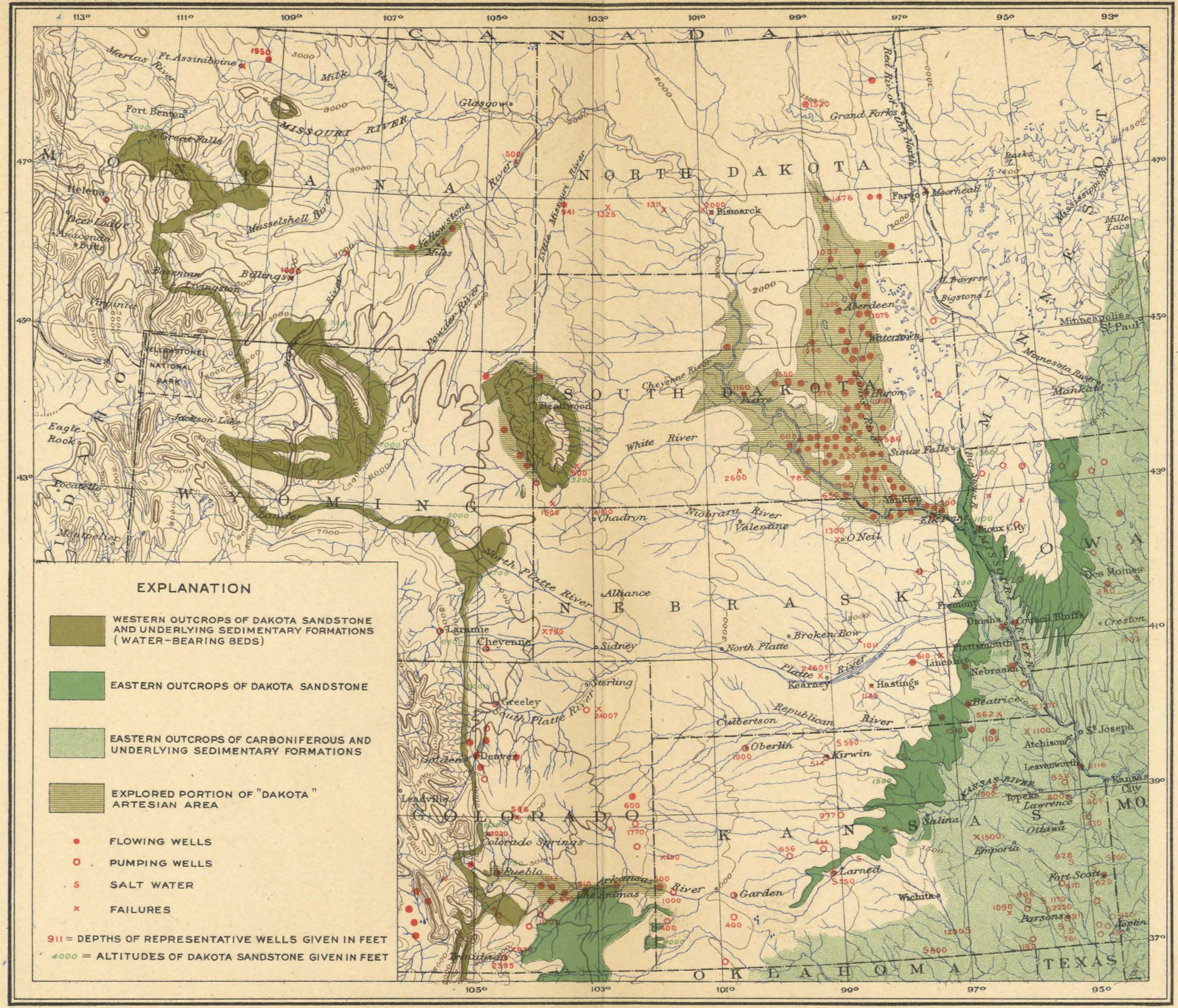
Hot Springs.—At the Soldiers' Home, a short distance west of the town, a well was sunk some time ago to a depth of 223 feet. It began just above the top of the Minnekahta limestone, and obtains a moderate water supply from the sandstones in the Minnelusa formation.

SURFACE WATERS[1] AND IRRIGATION.

On the plains adjoining the Black Hills there are usually long periods of drought during summer, so that irrigation is necessary for raising crops. In many of the valleys there are wide areas of fertile soils suitable for agriculture, and to portions of them it is practicable to carry waters for irrigation. These waters are obtainable from such of the rivers and creeks as continue to flow in midsummer. In many localities it would be practicable to pond a large part of the water from the spring rains by means of dams of greater or less size. Water could also be obtained from deep wells, and in some cases for smaller supply from shallow wells. At present the principal purposes of agriculture in the region are to raise hay, etc., for winter feed for stock, vegetables for local use, and garden truck for the small local markets. The latter is raised at several places with good profits, notably near Hot Springs, where the waters of Fall River are diverted into ditches and employed for irrigation. There is water available for a considerable extension of this industry at many points through the hills, but local markets provide for only a small consumption, and the profit is too small to pay for long-distance shipment.

Cheyenne River.—This stream enters South Dakota with a fair supply of water in midsummer, which averages from 10 to 15 second-feet at Edgemont. Along most of its course its freshet waters could be extensively impounded if they were needed, but long and very substantial dams would be required to withstand the sudden heavy flows which follow the rains. The river flows through a broad valley, usually containing low flats of good land from a quarter to a half mile wide, often in long strips well suited for agriculture. Portions of the soil are sandy, but this is the exception. The channels of the river do not change position rapidly, and the average flat is seldom widely or long overflowed during freshets. The banks vary mostly from 5 to 8 feet above the low-water level of the river. The conditions for ditch construction are usually favorable, but freshets are liable to tear out the headgates unless they are carefully constructed. A large system of irrigation from Cheyenne River was laid out above Edgemont some

[1] Gagings of the principal streams of the southern Black Hills are given on page 599.



MAP OF THE NORTHERN GREAT PLAINS REGION
SHOWING FACTORS BEARING ON PROSPECTS FOR DEEP UNDERGROUND WATERS

BY

N.H. DARTON,

Scale

100 0 100 200 MILES

CONTOUR INTERVAL 1000 FEET (ABOVE 2000 FEET)

1899.

years ago, but it was not operated extensively. It was intended to make available the wide, fertile alluvial flats extending down the south side of the river from the mouth of Stockade Beaver Creek to Edgemont. The location and course of the main channel is shown in Pl. CII, *B*.

The principal volume of water in the river at Edgemont is derived from Beaver and Stockade Beaver creeks for the greater part of the year. Above the mouth of Beaver Creek the river rarely contains running water, except for a few days during freshets. More or less water remains in pools all summer, and there is undoubtedly a moderate volume of underflow. Very little surface water is received from Lance Creek, as all of the streams in that district have water only in pools and underflow. Pass Creek, Bennett Canyon, Red Canyon, and Mossagate Creek bring no surface waters to the river except for a few days after rains. Cottonwood Creek usually flows in small volume. There appears to be considerable seepage into the river from springs in the gorge below Edgemont, for its volume steadily increases in this portion of its course. It receives water from Hat Creek, Cascade Creek, and Fall River, but a large part of the water appears to sink in the Lakota and Dakota formations about Cheyenne Falls. All along the river below Edgemont there are flats of greater or less width, which could be irrigated by water from the river with very little difficulty. A few attempts have been made to utilize the water, but they were local, transient efforts.

Fall River.—This vigorous stream is the product of springs of warm water in the gorge a short distance above Hot Springs. The principal flow is from orifices in the western part of the town, which have in all an average, nearly uniform flow of 25 second-feet. Above these springs there is a stream of small volume known as Hot Brook, fed from springs rising in the axis of the anticline 3 miles west of Hot Springs. Cold Brook, a branch of Fall River from the north, joins Fall River just above Hot Springs, but usually does not carry water at its mouth. It contains running water at various points for some miles below its head in the high hills south of Pringle. Fall River as it flows through Hot Springs is a good-sized stream of beautifully clear, tepid water, which continues down the gorge to Cheyenne River. Owing to sinkage in the porous sandstones, it diminishes somewhat in volume in passing over the Lakota formation. All running water in the vicinity of Hot Springs—Cold Brook, Hot Brook, and Fall River—is utilized to a considerable extent for irrigation. It is diverted into ditches partly supplied by water wheels. Garden truck and fruit are raised in considerable abundance and find a ready market at Hot Springs. Water power is also obtained from Fall River to supply electric light for Hot Springs. One power plant is in the town and another is at the cascades over the Dakota sandstone near Evans's quarry, 5 miles southeast of the town. The ditch at this place carries the greater bulk of the water, leaving a small amount to descend over the ledges of sandstone.

Beaver Creek.—The stream on the eastern side of the hills known as Beaver Creek rises in the schist area north of Pringle and flows through Buffalo Gap, reaching Cheyenne River 5 miles southeast of the gap. For many miles from its head, in its passage across the crystalline rock area and down a canyon in the Cambrian and Carboniferous rocks, it is a small run nearly everywhere containing a moderate amount of water. It appears to sink in the Minnelusa sandstone, but water again comes to the surface in the anticline which exposes the Minnekahta limestone at the western entrance of Buffalo Gap. From this place it flows in moderate volume continuously to the river. It is used to some extent for irrigation about Buffalo Gap, where there are several lines of ditches supplying water to large fields of alfalfa and other products.

Lame Johnny Creek.—Lame Johnny Creek heads in the higher ridges southeast of Custer, where its numerous branches are rivulets of running water. In crossing the Minnelusa formation the creek loses this water, and thence to Cheyenne River usually has water only in scattered pools. There is possibly more or less underflow.

French Creek.—This stream contains more or less water throughout its course. It is fed by springs at the foot of the limestone escarpment west of Custer, and in its passage across the crystalline rock area receives many small tributaries, some carrying small flows of water. In this region it is often bordered by narrow flats where a small amount of irrigation is practicable. It loses considerable water in passing over the sedimentary beds on the east side of the hills, and does not receive any running affluents in this part of its course. Below Fairburn it meanders through a wide valley in the bottom of which it has cut a narrow, winding trench often 15 feet in depth. In this region it has not yet been utilized for irrigation, and its volume is not sufficiently great to permit of extensive use for that purpose. The appearance of the stream at the mouth of Dry Creek is shown in Pl. CI. The appearance of the creek in the canyon in the Pahasapa limestone 10 miles west of Fairburn is shown in Pl. LXIII. Dry Creek, one of the principal branches of French Creek, often contains extensive pools of water, but rarely flows.

Battle Creek.—Battle Creek drains a portion of the elevated country about the eastern slopes of Harney Peak, receiving several large branches, of which the more important are Little Squaw, Big Squaw, Iron, and Spokane creeks. These streams all contain a moderate volume of water throughout their course, but they flow mainly in narrow channels, with the adjoining flat too small and often too rocky for agriculture. The wider portion of the valley of Squaw Creek on the Spearfish red beds contains alluvial flats of some extent in which the creek water is used for irrigation, mainly for alfalfa. In the upper portion of its course the water of Battle Creek is used for hydraulic

FRENCH CREEK NEAR ITS MOUTH, SOUTHEAST OF FAIRBURN, SOUTH DAKOTA.

mining. In crossing the sedimentary formations from Carboniferous to Dakota, Battle Creek and its branches lose considerable water. About Hermosa the valley widens, and thence toward Cheyenne River its width averages 2 miles, with fertile flats admirably suited to agriculture. The water is utilized for irrigation to some extent, but its volume is inadequate for present demands.

Spring Creek.—Spring Creek crosses the crystalline rock area and for the greater part of its course contains a moderate volume of water. There is considerable loss by underground seepage in crossing the Lakota sandstone, east of which for some distance the flow is feeble. The valley is wide east of the Black Hills, and it is utilized to some extent for dry farming. Considerable irrigation would be practicable.

Hat Creek.—The headwaters of Hat Creek rise in canyons in the north face of Pine Ridge, and are fed by numerous springs issuing from the Arikaree formation. The creek flows north for 35 miles across the shales of the Pierre and Benton formations to empty into Cheyenne River near Maitland. In this portion of its course it receives no water from the numerous side valleys, and in summer loses much by evaporation. It traverses a valley usually bordered by wide flats, which could be irrigated.

Cascade Creek.—This vigorous stream is the product of the springs at Cascade, where a large volume of water issues from the Minnekahta limestone. In Pl. CIII are shown the two largest springs at this place. The water is slightly warm, and contains a large amount of mineral matter, as is shown in the following analysis kindly furnished by the Burlington and Missouri River Railroad Company:

Analysis of water from Cascade Creek, South Dakota.

Constituent.	Grains per U. S. gallon.
Chloride of sodium	3.97
Sulphate of soda	0.29
Sulphate of lime	119.84
Carbonate of lime	34.75
Carbonate of magnesia	15.68

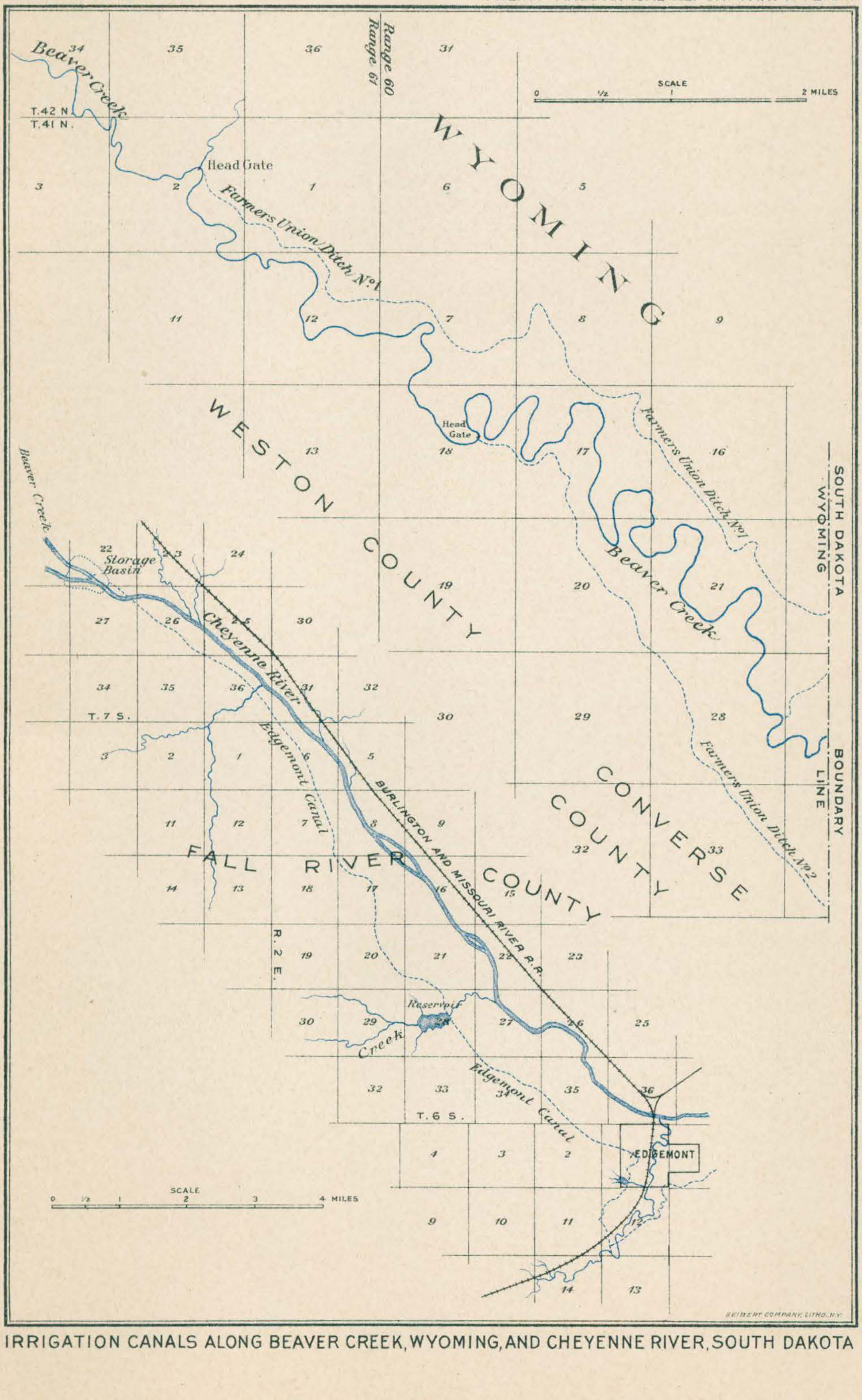
It appears not to lose any of its volume in traversing the Lakota and adjoining formations. In the flat which it crosses to reach Cheyenne River some of the water has been employed for irrigation with most gratifying results, but only a portion of its volume is utilized. The volume of the creek at its mouth was 25 second-feet on May 18, 1900.

Stockade Beaver Creek.—This fine stream rises in the ravines heading in the Minnelusa sandstone and Pahasapa limestone in the northeastern corner of Weston County, Wyoming, and carries a large volume of water to the main Beaver Creek, into which it empties in the southeastern corner of the county. It receives water from a number of springs in the Minnekahta limestone east of Newcastle, one of the most prominent of which lies a short distance west of the foot of Fanny Peak. Another source of water is Salt Creek, which brings a small volume of saline waters from the springs northeast of Cambria. Portions of the valley contain flats suitable for moderately extensive agriculture by irrigation, and several small ditches are now in operation east of Newcastle, notably one for the extensive alfalfa fields of the L A K ranch. Stockade Beaver Creek receives the drainage of the western slope of Elk Mountain and of a wide area of the western portion of the limestone plateau and slopes in the northwestern corner of Custer County and the southwestern corner of Pennington County. Two of the most extensive drainage basins empty through Redbird and Gillette canyons, but the waters of these rarely reach the main creek. Redbird Canyon has at its two head branches Antelope Spring and Preacher Spring, which yield small flows of water that sink in a short distance. This also is the case with Buck Spring and some minor seeps in the adjoining limestone area. Nearly all the springs of this series and others at the head of Stockade Beaver Creek are at the contact of the Minnelusa and Pahasapa limestone, where there are porous, water-bearing beds.

Beaver Creek.—This stream occupies the valley lying between the western slope of the Black Hills and the escarpment of Fox Hills sandstone in the southeastern portion of Weston County, Wyoming. The origin of its water is difficult to determine, but west of Newcastle it has considerable volume, which flows more or less continuously to its junction with Stockade Beaver Creek. The combined waters of the two streams flow into Cheyenne River in the northwestern corner of Fall River County, constituting the principal volume of water to Edgemont. The main Beaver Creek receives several branches that probably carry more or less water as underflow. Those heading in the Fox Hills and Laramie County to the west are dry at the surface. Oil Creek and its two branches, Skull Creek and Little Oil Creek, contain running water in the canyons north and northwest of Newcastle, but in dry weather their waters do not flow to the main Beaver Creek. The waters of Oil Creek are used for irrigation just north of the railroad, west of Newcastle. The valley of Beaver Creek is wide and contains some land that could be irrigated, but no attempts have yet been made to utilize it.

SOILS.

The soils in the southern Black Hills and adjoining regions are closely related to the underlying rocks. Excepting deposits in the larger valleys, some sand dunes, and a few local gravel areas, the soils are residuary products of the decay and disintegration of the rocks on which they lie. The larger valleys are floored by alluvial deposits of various materials washed from the higher lands and brought down by streams during freshets. All of the rocks in the region are changed more or less rapidly by surface waters, the rapidity depending on the



IRRIGATION CANALS ALONG BEAVER CREEK, WYOMING, AND CHEYENNE RIVER, SOUTH DAKOTA character of the cement which holds their particles together. Siliceous cement dissolves most slowly, and rocks in which it is present, such as quartzite and sandstones, are extremely durable and produce but a scanty soil. Calcareous cement, on the other hand, is more readily dissolved by water containing carbonic acid, and the particles which it holds together as rock crumble and form a deep soil.

Classification.—If the calcareous cement makes up but a small part of the rock, it is often leached out far below the surface, the rock retaining its form, but becoming soft and porous, as in the case of the Minnelusa sandstone. If, as on the limestone plateaus, the calcareous material forms a greater part of the rock, the insoluble portions collect on the surface as a mantle of soil, varying in thickness with the character of the limestone, being quite thin where the latter is pure, but often very thick where the rock contains much insoluble matter. Of course all soil accumulation is dependent upon erosion, for where there are slopes the erosion is often sufficient to remove the soil as rapidly as it forms, leaving bare rock surfaces. Crystalline schists and granitic rocks decompose mostly by the solution of a portion of the contained feldspar. The result is usually a mixture of clay, quartz grains, mica, and other minerals. Shales decompose less than most other formations, but readily give rise to soils by softening and washing down slopes. If they are sandy, sandy soils result, and if they are composed of relatively pure clay a very clayey soil is the product. When derived in this way from the disintegration of the underlying rock, soils are called sedentary. The character of the soils thus derived from the various geologic formations being known, their distribution may be approximately determined from the map showing the areal geology, which thus serves also as a soil map. It must be borne in mind that some of the geologic formations present alternations of beds of various materials, such, for instance, as shales and sandstones alternating with limestone. These give abrupt transitions in the character of their disintegration products with soils differing widely in composition and agricultural capabilities occurring side by side. This, however, is a less marked feature in the Black Hills region than in some other districts, for here all the formations are thick and relatively homogeneous in composition throughout. The only areas in which the boundaries between different varieties of soil do not coincide with the boundaries of the rock formations are in the river bottoms, in the sand dunes, in the areas of high level gravels described on page 545, and upon steep slopes, where soils derived from rocks higher up the slope have washed down and mingled with or covered the soils derived from the rocks below. Soils of this class are known as overplaced, and a special map of large scale would be required to show their distribution.

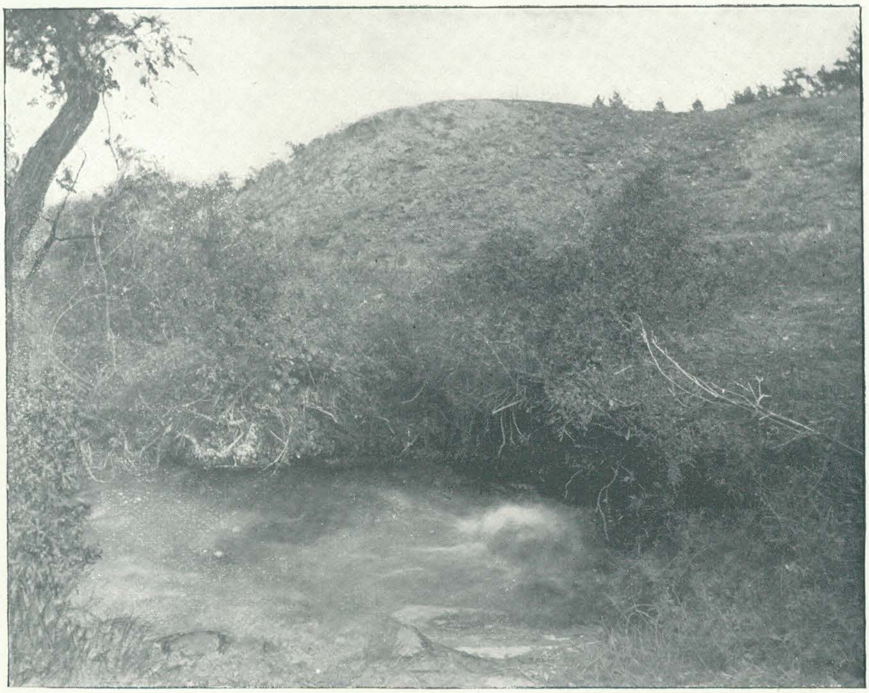
Interior region.—In the region of the schists and granites in the interior of the Black Hills there are numerous valleys between the rough, rocky ridges. These valleys are mainly parks or open glades in the forest, where the soil is deep and rich. Areas of this sort occur along the headwaters of the numerous branches of the streams which flow eastward out of the hills. Surface waters accumulate in these parks and cause deep decay of the schists, but the volume of water is not sufficiently great to carve a deep valley and carry away the soil. As the water increases in volume down the valleys, the open parks give way to deep, rocky canyons, such as those of Spring Creek, French Creek, Beaver Creek, and some of their branches. A view of a typical glade or park in the schist area is given in fig. 272. There are extensive areas of this sort about Custer, but only a relatively small proportion of the land is under cultivation. Oats and hay are the principal products, but many other crops could be raised, particularly by the aid of irrigation. Portions of the timbered area are valuable for agriculture when cleared, but such fields would be much encumbered by loose rocks and often intersected by rocky ledges.

The limestone.—On the broad limestone plateau on the western side of the hills there are extensive tracts with good soil, usually rather clayey, but containing a large proportion of plant food. There are many open parks along the heads of the small streams, and portions of the timbered area yield good farming lands when they are cleared. The sandy loams resulting from the disintegration of the Minnelusa formation are particularly favorable for agriculture. Owing to the high altitude of this plateau the seasons are short, so that only the hardier crops can be raised. Water also is so scarce that irrigation is seldom practicable. On the eastern side of the hills the high ridges of Pahasapa limestone and Minnelusa sandstones are mainly too rugged for farming, and bare, rocky ledges prevail. The Minnekahta limestone usually presents rocky slopes with very little soil.

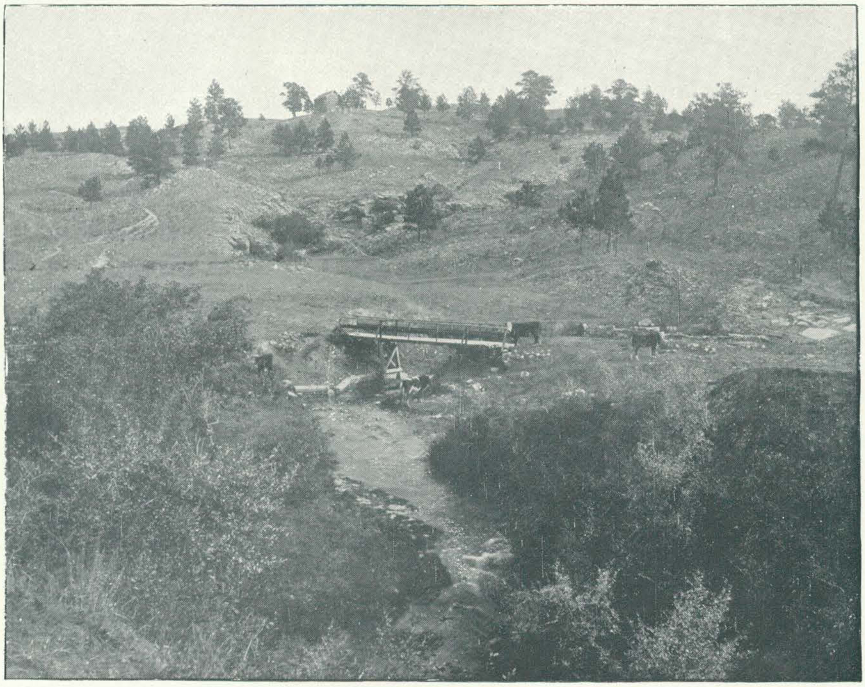
The Red Valley.—The sandy clays of the Spearfish formation give rise to a relatively barren soil, which, together with the usual absence of water in the Red Valley, has excluded farming almost altogether. Portions of the region underlain by the formation present gentle slopes and wide, level areas supporting a fair growth of grass, so that the region is one of considerable value for grazing.

The hogbacks.—The sandstone of the hogback ridges surrounding the Black Hills uplift disintegrates into a thin, sandy soil, but as the beds nearly everywhere have a steep dip down the outer slope of the ridge much of the soil washes away, and bare, rocky ledges remain. North of Newcastle, where the formations of the hogback spread out in broad, gently sloping plateaus, there are some areas which present farming capabilities. One of these is that occupied by the Mount Zion ranch, where there are several large fields under cultivation.

The Benton Valley.—The wide valley which surrounds the Black Hills is underlain by the lower shales of the Benton group. These



A. SPRING AT CASCADE SPRINGS, SOUTH DAKOTA, EMERGING FROM CREVICES IN MINNEKAHTA LIMESTONE.



B. SPRING AT CASCADE SPRINGS, SOUTH DAKOTA, EMERGING FROM CREVICES IN MINNEKAHTA LIMESTONE.

shales yield a barren soil, but they give rise to valleys which are often occupied for many miles by large streams which had deposited widely extended sheets of alluvial sands and loams, often of considerable fertility. The lower part of Beaver Creek follows a valley of this character, which extends through the southeastern corner of Weston County, Wyoming, to the vicinity of Edgemont, where it is occupied by Cheyenne River. The broad alluvial flats along this wide valley have fertile soils, and under proper irrigation would produce large crops. Hat Creek flows in a valley on the lower Benton shale, which contains some land of considerable fertility from the mouth of Plains Creek to Cheyenne River. This area has a wide extent for several miles north of the river up the valley of Cascade Creek.

The Plains.—Much of the Plains region adjoining the Black Hills is underlain by Pierre shale. This formation consists mainly of clay, and its disintegration gives rise to a stiff gumbo, which is not only very barren in itself but is acid from decomposing pyrites and too sticky for suitable working. Its area is shown on the geologic maps (Pls. LIX and LXV). It is covered with grass, which originally afforded excellent pasturage, but in some areas it has been grazed down by excessive herding. As the soil is not rich the grass grows slowly, and some time will be required for it to regain its former growth. Some areas of the Pierre shale are traversed by wide valleys with overplaced soils of considerable fertility. This is notably the case along Spring Creek, Battle Creek, French Creek, Cheyenne River south and east of Buffalo Gap, and on Beaver Creek and Stockade Beaver Creek in the lower portions of their courses. The most barren areas are on the upper portion of Beaver Creek, the slopes west of Beaver Creek, the high lands between the valleys of Old Woman Creek, Indian Creek, and Hat Creek, and the extensive areas east of Ardmore and about Oelrichs and Smithwick.

The region occupied by the Fox Hills and Laramie formations in Weston and Converse counties, Wyoming, is in greater part sandy, barren, and dry. There are some narrow strips of loamy soils derived from the sandy shales in the Laramie formation, but they are mainly on the higher land and entirely too dry for agriculture. Along the larger valleys in this region there are occasional flats of considerable width which yield an excellent growth of hay. Probably by irrigation some of these flats could be made to produce other crops if there were markets for them. The Laramie formation usually supports an excellent growth of grass for grazing, and there are wide areas of good grazing grounds remaining.

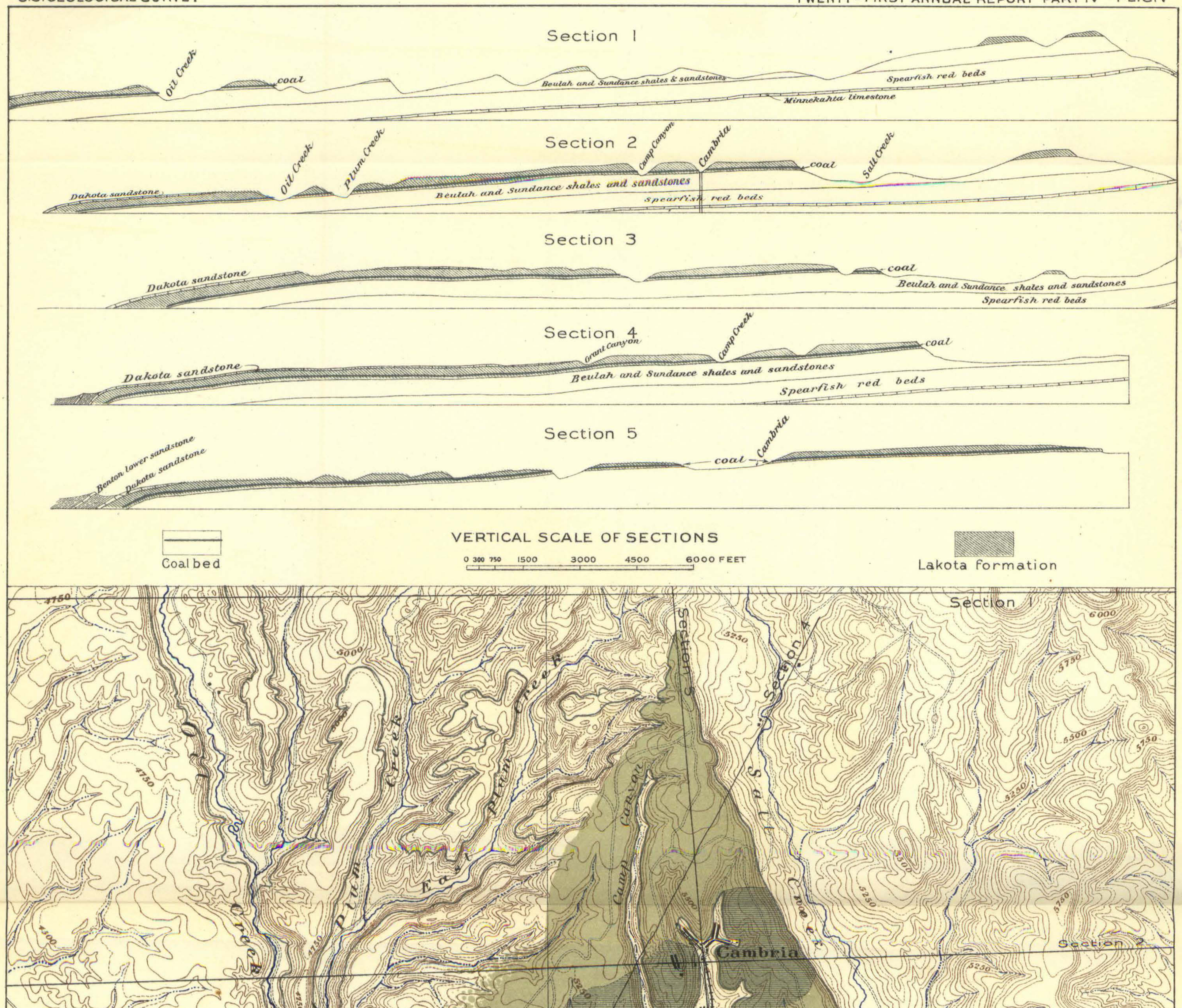
The Tertiary formations present bare slopes more or less broken into bad lands, with intervening plateau ridges of greater or less width that often have fertile soil and invariably support a rich growth of grass. The Tertiary area about Fairburn and north of Hermosa presents many small areas of fertile soils, particularly on the portions where there remain the gravel caps of the earlier Pleistocene deposition, which spread its mantle of alluvial materials over the surface of the Tertiary formations. In the regions about Hermosa and Fairburn the principal farms are either along the streams on alluvial deposits or on the tabular surfaces of the earlier Pleistocene gravel and loam. Owing to the dry climate, however, there has been difficulty in obtaining water on these higher lands, and many of the farms which were located upon them have been abandoned.

MINERAL RESOURCES.

COAL.

Coal is the principal mineral resource in the sedimentary formations of the Black Hills. Its occurrence is confined mainly to the Lakota formation, where it is characteristic of one horizon over a considerable area. The Carboniferous formations which are the coal measures in the Mississippi Valley and eastward do not contain beds of coal in the Black Hills region. Along the eastern side of the Black Hills the Lakota formation shows no trace of coal. The first deposits begin near Edgemont, and continue at intervals along the western side of the hills and around the northern foothills to the Hay Creek coal field. In much of the area the beds are too thin or impure to be of economic value, but in the vicinity of Cambria, north of Newcastle, they attain a thickness of 7 feet or more and furnish coal of excellent quality. Coal has been mined at Cambria for the last decade, and during this time nearly 4,000,000 tons have been produced, with an average shipping value of about $1.50 per ton. The product in 1889 was over a half million tons, valued at over $800,000. A portion of the product is converted into coke, which is shipped to smelting works in the northern Black Hills.

The mines are at Cambria, 6½ miles north of Newcastle, where a settlement of about 500 inhabitants owes its existence and sustenance to the mining and coking operations. It is connected with Newcastle by a branch line from the Burlington and Missouri River Railroad. The distribution of coal and the structural relations of this region are shown by the map and sections (Pl. CIV). It will be seen that the coal underlies all of the plateau on the west side of Salt Creek, but the horizon has been cut through by Little Oil Creek, Oil Creek, Plum Creek, and their branches. To the south and west it dips beneath the surface, and passes deeply beneath a thick mass of overlying sandstone and shale. The structure is shown in the cross sections. The coal in this area varies greatly in thickness and purity, but as shown on the map (Pl. CIV) there is a large area in which the thickness is 5 feet or more, attaining in places over 7 feet. In the adjoining areas the thickness rapidly diminishes and the coal becomes extremely impure,



TOPOGRAPHY BY W. H. HERRON

MAP AND SECTIONS OF THE CAMBRIA COAL FIELD NEAR NEWCASTLE, WYOMING

BY
N. H. DARTON
1899

HORIZONTAL SCALE
0 2 MILES
Contour interval 50 feet

EXPLANATION

Coal outcrop

Approximate area of coal known to be over 5 feet thick

Area of workings to end of 1899

Area in which coal horizon is more than 400 feet below the surface in greater part giving place to dark carbonaceous shales. The course of the principal basin of purer, thicker coal trends northeast and southwest, with its center passing through Cambria. To the northeast it has been entirely eroded away by the valley of Salt Creek, and, although some Lakota sandstone remains on the high ridges east of that valley, it is the bed lying beneath the coal horizon. To the southwest the coal slopes gently downward, lying from 250 to 325 feet below the surface of the table, to the Mount Zion ranch, beyond which the sudden increase in dip carries it rapidly below the surface, as shown in section 4 of Pl. CIV. In the canyon a few rods southwest of Mount Zion ranch, the following section was measured:

Section near Mount Zion ranch, Wyoming.

	Feet.
Bony coal	½
Hard sandstone	3
Good coal	4
Sandstone with coaly streaks	½–1½
Coal	2

This section is 150 feet below the top of the table. The overlying formation is sandstone and conglomerate. Underneath there are 40 feet of very light-colored massive sandstones, in part cross bedded, lying on Beulah shales. A mile northeast of this locality two shafts were sunk in which the coal was found at depths of 312 and 324 feet, exhibiting a thickness of from 5½ to 6½ feet. A mile farther northeast are the mines of which the present workings occupy the area indicated on the map. In the mines the thickness of the coal averages from 6 to 7 feet over a wide area. In Camp Canyon, northwest of Cambria, a trial pit exhibited the following section:

Section in Camp Canyon, Wyoming.

	Feet.
Coal	2½–3
Shale and bone	1½
Coal	6

There are three mines, known as Jumbo, lying east of Cambria; Antelope No. 1, between Cambria and Camp Canyon; and Antelope No. 2, between Camp Canyon and Grant Canyon. The two Antelope mines are connected by a continuous main shaft leading out to a breaker on the west side of the valley at Cambria, while the Jumbo mine is worked from the main drift opening on the east side of that valley. The dip is gentle to the southwestward, so that the drainage of the mines is easily effected, the workings being 50 to 60 feet above the valleys which here cut across the coal horizon.

A coal bed averaging 6 feet in thickness contains about 3,000,000 tons of coal per square mile, but of course there is considerable loss in working. There are now in the Cambria coal field about 10 square miles underlain by coal that would average 5 feet or more in thickness, lying above the general country level. On this estimate the field has a productive capacity of 30,000,000 tons. How far under ground the coal bed may extend to the southwest of the Dakota sandstone ridge is not known, but owing to the steep pitch of the beds it lies too deep for profitable working. North of Cambria the coal appears at intervals, apparently in detached basins. The most promising developments are on Skull Creek, near its forks, where 6 or 7 feet of coal are exposed in recent drifts. In Elk Mountain the Lakota formation exhibits the coal horizon at many points, but the contained coal bed is thin and impure. So far as observed here the deposit usually consists of carbonaceous shale with occasional thin coaly lenses. South of Pass Creek the coal beds are thicker, and there are several deposits which promise to have some little value. In the canyon 4 miles north-northeast of Marietta Station there has been considerable prospecting for coal, but the material exposed is mainly a sandstone with thin coaly layers and black shale intercalations. In the gorge of Cheyenne River below Edgemont the coal beds have been opened at various points. On the south bank of the river 3 miles below the town a drift has been run in on a thin bed of coal in the basal portion of the Dakota sandstone 50 feet below the top ledges of the formation, in which a thickness of 3 feet of coal of fairly good quality is exposed. Beginning at the second bend of the river, 5 miles southeast of Edgemont, where the stream is flowing nearly due south, there are a number of coal openings in the bluffs on the east bank. From 1 to 3 feet of variable coal is exhibited in the first series of prospect pits. In the bend where the river turns east-northeast again there is a mine which has been worked to a small extent, exhibiting 4 feet of coal lying in a basin which is seen thinning out to the east. There are two tunnels about 75 to 100 feet in length along which the coal varies in thickness from 4 to 5 feet. It lies between massive, light-colored, fine-grained sandstones about 40 feet above the base of the Lakota formation. The bed dips very gently to the southeast. Small showings of coal occur in the deep canyons northeast of this locality, but the beds are very thin and impure. Apparently this is at the southeastern margin of the area in which the conditions were favorable for coal accumulations at the time of the deposition of the Lakota formation.

GYPSUM.

The Spearfish red beds carry deposits of gypsum—a hydrous sulphate of lime—throughout their extent, and often the mineral occurs in very thick beds. These are relatively pure, and if nearer to good markets the deposits would be of great value. The only commercial operations so far have been at Hot Springs, but they are discontinued for the present owing to the expense of taking the product to market. A view of the works is shown in Pl. CVI, *B*. The gypsum is calcined

COAL MINE OPENING AT MOUNT ZION RANCH, NORTHWEST OF NEWCASTLE, WYOMING.

at a red heat, to drive off the chemically combined water, and is then ground and packed in barrels. The product is plaster of paris.

The gypsum deposits attain great thickness in the vicinity of Hot Springs. In the valley of Cold Brook, three-quarters of a mile northwest of the station and a short distance north of the works above mentioned, is an exposure shown in Pl. CVI, *A*. The section there exhibited is shown in detail in the following figure:

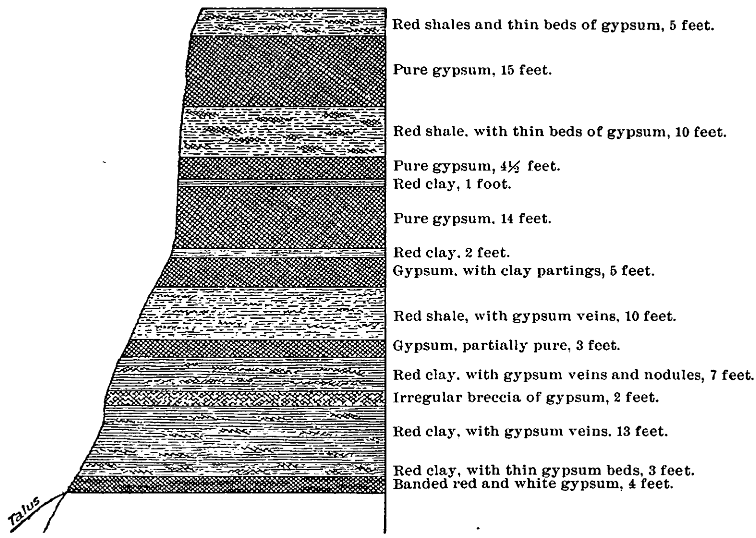


FIG. 297.—Section of Spearfish red beds containing gypsum deposits, on Cold Brook, three-fourths of a mile northwest of Hot Springs, South Dakota.

This deposit is an unusually extensive one, but nearly everywhere throughout the outcrop area of the red beds there are workable beds of gypsum from 5 to 15 feet thick. Further details of their distribution are given on pages 517 and 518.

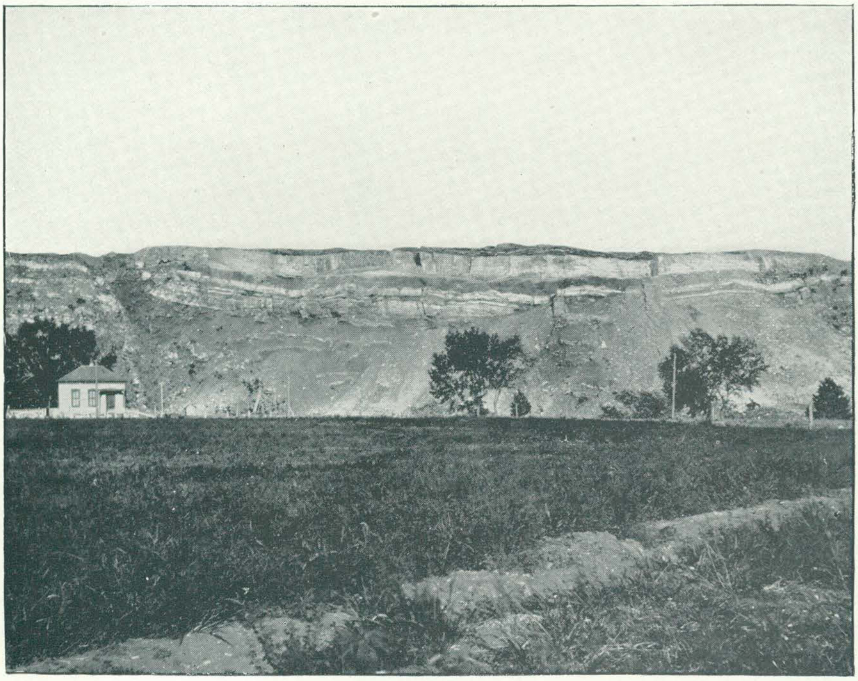
The following is an analysis of a typical gypsum from south of Hot Springs. It was made by Mr. Steiger in the laboratory of the United States Geological Survey.

Analysis of gypsum from south of Hot Springs, South Dakota.

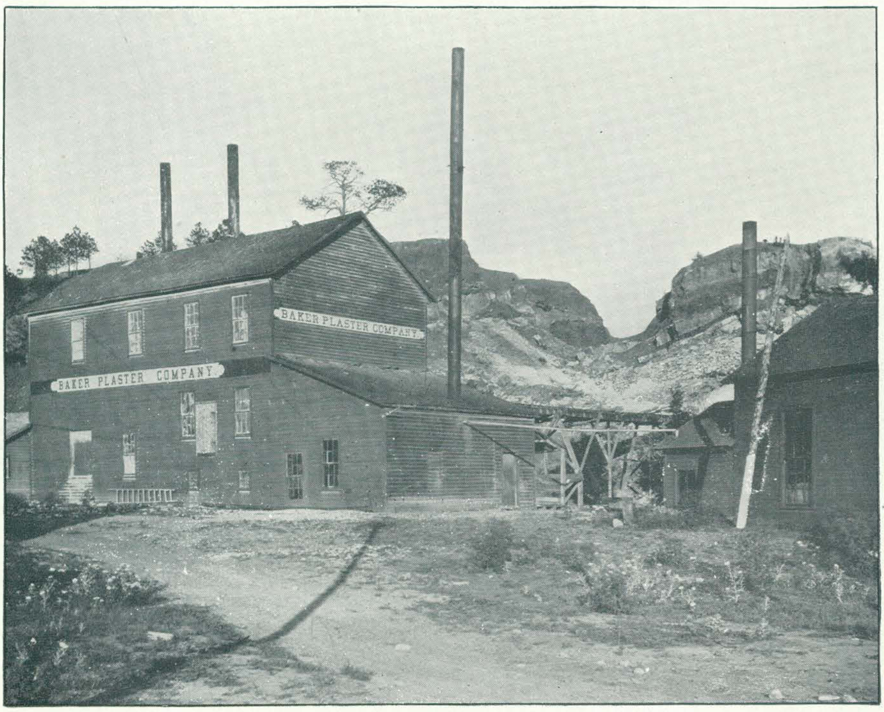
Constituent.	Per cent.
Lime	32.44
Magnesia	0.33
Alumina	0.12
Silica	0.10
SO_3	45.45
CO_2	0.85
Water	20.80
Total	100.09

PETROLEUM.

In the vicinity of the town of Newcastle explorations to develop an oil field have been in progress for several years. Small supplies of excellent petroleum have been obtained from borings and from two oil springs. The oil is very heavy, and even in its crude state is a high-grade lubricant. The oil occurs in a sandstone in the lower portion of the Graneros formation, which is extensively developed in the vicinity of Newcastle. It lies between 250 and 275 feet above the Dakota sandstone, from which it is separated by the basal black shales of the formation. The Graneros sandstone here varies in thickness from 10 to 30 feet in greater part, and its surface outcrops give rise to ridges of considerable prominence. The first line of ridges lying west-northwest of Newcastle owe their prominence to the locally increased thickness and hardness of this sandstone. Where the rock has been exposed to the weather it is hard, moderately fine-grained, light-gray sandstone in massive beds. As it passes below the surface it is softer in texture, buff or brown in color, and usually strongly charged with petroleum. At two localities the oil oozes out of the sandstone and collects in springs, which for many years have yielded a small supply of oil for local use. One of these springs is 2¼ miles due west of Newcastle, just north of the railroad, and the other is 2 miles farther northwest and slightly farther north of the railroad. At these points the oil-bearing sandstone passes beneath the surface in small draws, and the escaping oil accumulates in the loose materials adjacent. Cisterns have been constructed in such manner as to catch the oil, and a few gallons per week are obtained which find ready sale as a lubricant. Several attempts have been made to develop the oil sand in its extension under ground by means of wells in the region west and southwest of Newcastle, but so far these operations have not yielded a large supply of oil. In most cases the oil horizon has been passed through and the boring uselessly extended far into the underlying shales and sandstones. As the sandstone appears to contain considerable oil in the vicinity of the oil springs, and as it underlies a wide area about Newcastle, it is difficult to understand why the wells have not given more encouraging results. From the statements made by the promoters of the enterprise, it seems probable that the oil sand was not always recognized in the boring operations, and at any rate was not adequately tested. The oil is very viscid and should hardly be expected to flow from wells at any point in the area, but possibly by dynamiting and pumping a supply can be obtained. In Pl. CVII are shown the relations of the oil-bearing sandstone and associated formations and the location of wells which have been bored. In the sections may be seen the conditions under which the oil sand passes under ground and the thickness and nature of the overlying materials. These formations are



A. GYPSUM LAYERS ON SPEARFISH RED BEDS ALONG COLD BROOK, 1 MILE ABOVE HOT SPRINGS, SOUTH DAKOTA.



B. GYPSUM WORKS NEAR HOT SPRINGS, SOUTH DAKOTA.

relatively uniform in thickness and invariably lie in regular sequence. In surface exposures they are all distinctive in appearance, particularly the bed of Greenhorn limestone and the thin sandstone layer 300 feet above. The distinctive fossils of the Greenhorn limestone and of the Niobrara chalk, which lies 700 feet above, are shown in Pl. XCVIII. In sections 1 and 2 may be seen the manner in which the formations dip steeply beneath the surface in the vicinity of the railroad, so that to the southeastward the oil sand soon lies under 2,500 feet or more of shales. Approaching Newcastle, as shown in sections 3 and 4, the dips diminish rapidly and there is a basin of considerable size in which the formations are spread out widely. The deepest boring in the region, the one shown in section 3, has a depth of 1,950 feet. It passed through the oil sand at a depth of about 100 feet and then penetrated the shales, Dakota and Lakota sandstones, and underlying shales and red beds. From the Lakota sandstone it obtained a flow of water which is still running over the mouth of the well. Only a small amount of oil was observed. The well a half mile southwest of Newcastle, with a depth of 1,340 feet, penetrated the oil sand at a somewhat greater depth than the first well, and oil brought up by water from the underlying sandstones is still flowing out of the casing. The 420-foot well, a short distance northwest of the 1,340-foot well, is said to have just reached the top of the oil sand, where a promising showing of oil was observed. The 720-foot well, 3½ miles southwest of Newcastle, as shown in section 2, was entirely in shale and failed to reach the oil-bearing sandstone by about 2,000 feet. It is greatly to be regretted that this boring was not continued sufficiently deep to test the contents of the oil sand where it is deeply buried and so far from surface outcrop as to permit the accumulation of considerable head if there is any oil present. In the vicinity of section 1 two deep borings have been made and another one is now in progress in the steep-dipping beds near the outcrop of the sandstone. The results so far obtained have not been successful, although the borings are midway between the two oil springs described on a preceding page. It can not be claimed that the Newcastle oil field presents promise of being a bonanza, but it is believed that the capabilities of the oil-bearing sand have not been adequately tested and the prospects are sufficiently good to warrant further exploration. The oil sand horizon extends southward nearly to Clifton and is over 30 feet thick near the L A K ranch. To the north it thins out near Skull Creek. Whether it contains oil away from the immediate vicinity of Newcastle remains to be ascertained by borings.

GRINDSTONE.

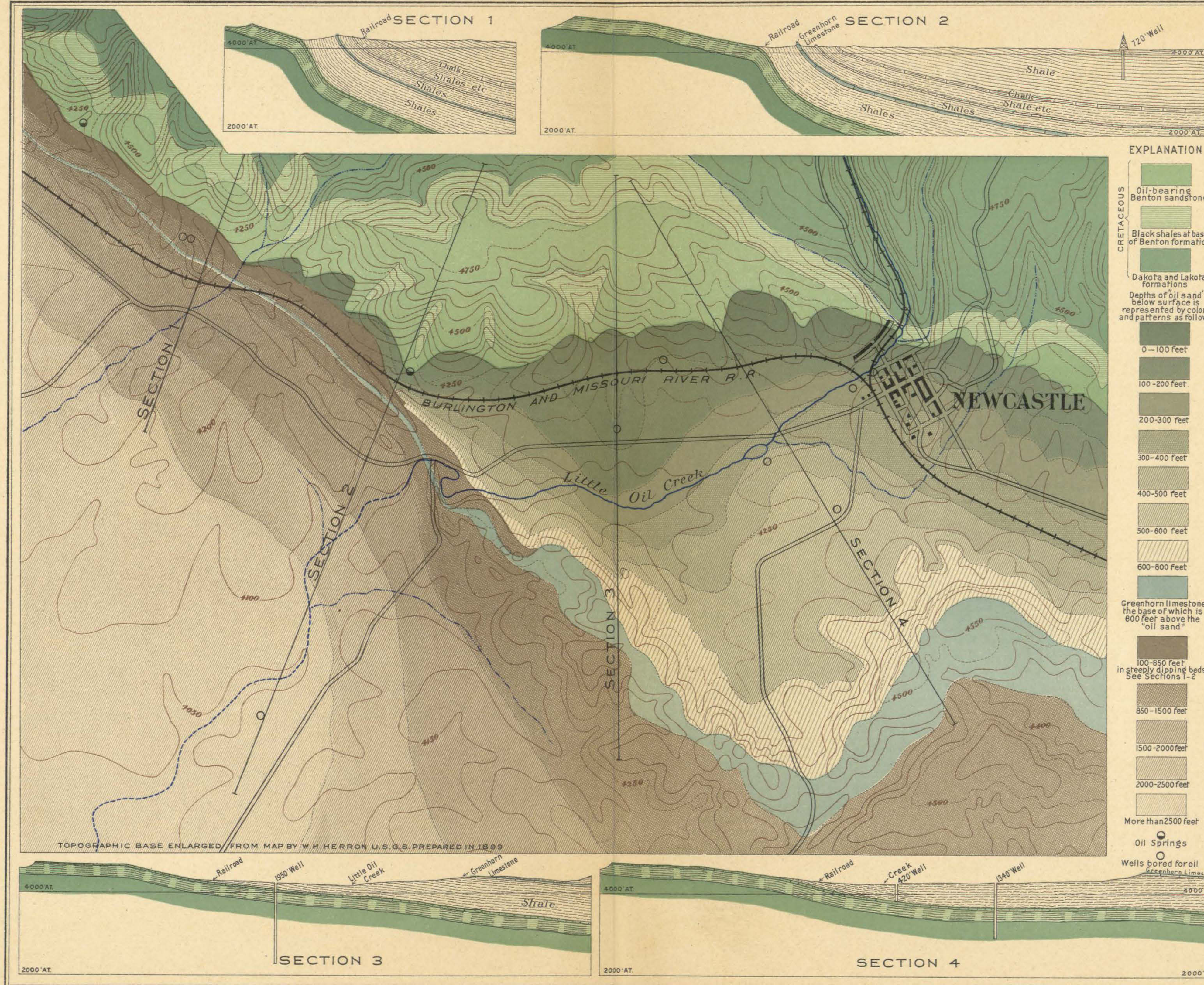
Three and a half miles north-northeast of Edgemont the Dakota sandstone has been quarried to some extent for grindstones. The product has not been large so far, and at present the quarry is not in operation, but the stone is claimed to be obtainable in large supply and to be of excellent quality. The conditions for working are most favorable, as the beds are in a high bank on the north side of Red Canyon, with plenty of room for the disposal of waste, perfect drainage, and no great amount of stripping. The dip is to the southwest at a low angle.

HONESTONE.

Portions of the Dakota sandstone at the Edgemont quarry are of fine, uniform grain, suitable for giving the finest edge to tools. Shipments have been made, and the materials have been received with greatest favor by tool finishers and cutters. It is said to be entirely satisfactory for sharpening razors.

FULLERS' EARTH.

A large portion of the Chadron formation—the basal member of the White River group—consists of fullers' earth, using the term more in a mineralogic than in an economic sense. The deposit consists of hydrous silicate of alumina with a small variable admixture of other components. It is amorphous and spongy in texture. Much of it has the property of decolorizing oils, etc., and when this property is highly developed the material is economically a fullers' earth and of considerable value. It differs from ordinary clay in its texture, which is spongy rather than plastic, and the water in its composition appears to be combined in a relatively definite ratio. Its economic value depends entirely upon its physical constitution, and can only be determined by practical tests. It is a material greatly in demand for clarifying oils, lard, etc. At present the greater part of the supply used in this country is imported from England, but there are mines of considerable extent in Florida. In the Chadron formation adjoining the Black Hills there are thousands of square miles of deposits having the chemical and physical properties of fullers' earth, but it is not known what proportion of the material is available for commercial use. Mining operations were begun at a point 3 miles southwest of Argyle and on the east side of the hills 3 miles south of Fairburn, but the first shipment failed to yield satisfactory results in the factory tests. It is claimed by owners of the Argyle property that their trial shipment was not selected with sufficient care to exclude extensive admixture with the more sandy associated beds, and the failure at Fairburn appears to be due to a similar hasty shipment without careful selection of the best material. As tests of the small samples were satisfactory, the miners supposed that the earth was all serviceable and did not discriminate in making a bulk shipment. It is desirable that further trial should be made of these earths on a larger scale and that the shippers should be guided by careful sampling and testing, so as to be able to select only the very best material obtainable.



MAP AND SECTIONS SHOWING RELATIONS OF "OIL SAND" IN THE VICINITY OF NEWCASTLE, WYOMING

BY

N. H. DARTON

HORIZONTAL AND VERTICAL SCALE

1000 500 0 ½ 1 MILE

FEET

CONTOUR INTERVAL 50 FEET

1899

Proper powdering and drying are also to be considered. The fullers' earth deposits extend from the high slopes of the hills west of Fairburn and Hermosa far eastward into the Bad Lands, as shown on the geologic maps (Pls. LIX and LXV) and explained in the description of the geology of the Chadron formation on page 543. The deposit southwest of Argyle covers an area of at least 1,000 acres. The tests made of small samples of these earths from Argyle and from the beds a mile northeast of Fairburn have given excellent results with cottonseed oil, and, as they present all the characteristics of genuine commercial fullers' earth, they deserve to be carefully developed.

The following are analyses of some of the fullers' earth deposits, taken from a paper by Heinrich Ries:[1]

Analyses of fullers' earth from South Dakota.

Constituent.	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
Silica	68.23	60.16	56.18
Alumina	14.93	10.38	23.23
Ferrous oxide	3.15	14.87	*a* 1.26
Lime	2.93	4.96	5.88
Magnesia	0.87	1.71	3.29
Loss on ignition	6.20	7.20	*b* 11.45
Total	96.31	99.28	101.29

	IV.	V.	VI.
	Per cent.	*Per cent.*	*Per cent.*
Silica	55.45	57.00	58.72
Alumina	18.58	17.37	16.90
Ferrous oxide	3.82	2.63	4.00
Lime	3.40	3.00	4.06
Magnesia	3.50	3.03	2.56
Loss on ignition	8.80	9.50	8.10
Volatile	5.35	5.85	....
Alkali	....	....	2.11
Moisture	....	....	2.30
Total	98.90	98.38	98.45

a Fe_2O_3. *b* H_2O.

Analyses I to V were made by Professor Flinterman, of the South Dakota School of Mines, at Rapid, and VI by Mr. E. J. Riederer. No. I is from William Bodemer's pit north of Fairburn; II and III are from M. Palmiter, Fairburn; IV and V from D. Henault, Custer (from the Argyle mines), and VI from southeast of Fairburn.

[1] The fullers' earth of South Dakota: Trans. Am. Inst. Min. Eng., 1897.

BUILDING STONE.

Several of the sedimentary formations in the Black Hills region would afford large supplies of building stones, but so far they have had but little more than local use. The red and banded sandstones of the Unkpapa formation have been worked to some extent in the canyons in the hog-back range between Buffalo Gap and Hot Springs and furnish a stone of beautiful color, even texture, and a fair degree of durability. It is soft, but when properly selected does not crumble on exposure. Buildings in Hot Springs, Buffalo Gap, and other places have been erected of the stone, but it has not yet found an extensive market. The massive sandstone of the Dakota formation has been quarried for several years at Evans's quarry on Fall River, 5 miles east of Hot Springs. The stone varies from gray and buff to a very attractive pinkish tint. It is easy to work, but is much harder than Unkpapa sandstone. Several of the hotels and other buildings at Hot Springs have been built of this rock. The quarrying operations are on a small scale, but they are still in progress and recently work has been begun on the same ledge at the mouth of Odell Canyon, 3 miles to the north. A small amount of limestone was quarried at Limestone Butte, near Oelrichs, for building in the vicinity. Much of the Lakota sandstone could be employed for construction and there are numerous beds of limestone in the Pahasapa formation which would furnish desirable building stone. The local demand for stone in the Black Hills is not large and it is generally claimed that the expense of shipment is too great at present to enable any but the most attractive materials to compete with the present supplies in distant markets.

LIMESTONE.

Under this heading it may be desirable to call attention to the vast quantities of limestone in the Black Hills which are available as flux in metallurgical processes. The Pahasapa limestone is well suited to this use throughout its extent, as are also the Minnekahta, Minnewaste, and White River limestones. An analysis of a typical sample of Minnekahta limestone from near Cascade Springs is given on page 515.

LITHOGRAPHIC STONE.

West of Custer, on the limestone plateau, there are beds in the Pahasapa limestone which present promise of being suitable for lithographic stone. The texture appears to be right, and it is stated that a slab of moderate size has proved satisfactory in practical tests. Large stones can be obtained, but until they are produced and tested the availability of the deposits for this purpose must remain uncertain.

VOLCANIC ASH.

The volcanic-ash deposits in the White River formations have economic value as polishing powder. It is the material that is used in some of the abrasive soaps and in its raw state as a polishing powder. The deposits in this region so far have not been worked. The thick bed at the fullers' earth mines southwest of Argyle would furnish a large amount of ash of excellent quality. The grains are small, uniform in size, and have sharp, cutting edges. The deposit is 3 feet thick and probably retains approximately this thickness for a few acres at least. The deposit southeast of Oelrichs is too small in extent to be worked for shipment, but it is a particularly sharp-edged ash, and consequently very powerful as an abrasive.

SALT.

The salt springs at the head of Salt Creek issue in large volume from the red beds of the Spearfish formation, giving rise to a creek that flows for many miles and finally empties into Stockade Beaver Creek. For a number of years the waters have been evaporated for the purpose of obtaining salt for local use. It is possible, however, that the output could be increased and a moderate amount of salt of good quality obtained for shipment. An analysis of the brine, made in the laboratory of the Geological Survey by Mr. Steiger, gave the following results in parts per hundred:

Analysis of brine from salt from Salt Creek, Wyoming.

Constituent.	Per cent.
Lime	0.20
Magnesia	0.04
Soda	2.73
SO_3	0.36
Chlorine	3.15
Bromine	None.
Iodine	None.
	6.48
Less O=Cl	0.71
	5.77

This is equal to a little more than 5 per cent of sodium chloride or common salt. The flow from the spring is about a gallon per second, which is equivalent to a production of about 35,000 pounds of salt every twenty-four hours.

CLIMATE.

The Black Hills have a climate much more attractive than that of the adjoining plains. The extremes of temperature are less, both diurnally and annually, and there is a more abundant precipitation. The weather is dry and hot in summer, moderately moist in late spring, and cold, with moderate snowfall, in winter. The climatic features vary

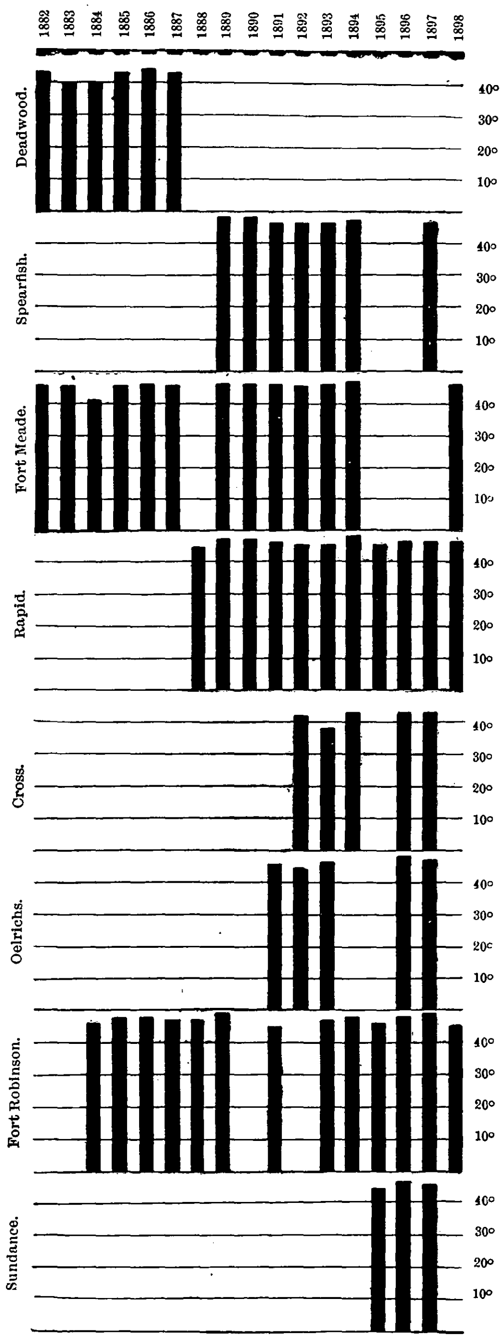


FIG. 298.—Diagram of mean annual temperature in the Black Hills and adjoining regions.

from year to year, and show much local variation from point to point,

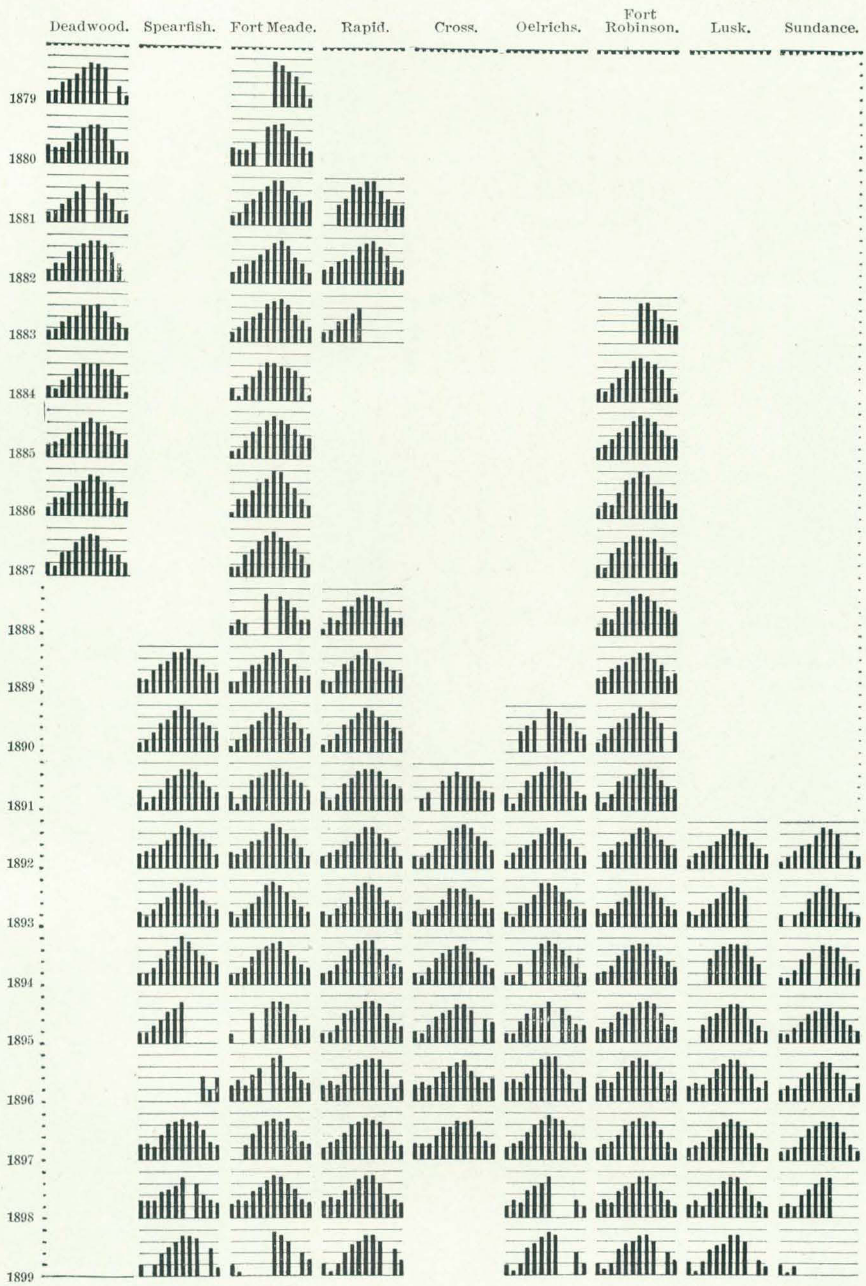


DIAGRAM OF TEMPERATURES IN THE BLACK HILLS AND ADJOINING REGIONS, 1879–1899.

By months, January to December. Space between two parallel lines represents 20 degrees.

particularly in rainfall. There is more snow in the Black Hills than on the adjoining plains, and, owing to more shade and shelter from sun and wind, it remains longer on the ground. Records of the weather at various points in the hills and their vicinity have been kept for many years. From these records have been compiled the diagrams constituting Pls. CVIII and CIX and figs. 298 and 299. Much information up to the end of the year 1891 was obtained from the report by Lieut. John P. Finley, on Certain Climatic Features of the Two Dakotas.[1] Pl. CVIII and fig. 298 illustrate the local and annual variations in temperature from month to month at points in or near the Black Hills. The prominent feature shown is a gradual rise of temperature in the spring to a maximum in July and August, as in most places on the same latitude. These two months often have an average of 70°, generally being a little more on the plains and somewhat less in the woods and on the high lands. Ordinarily July is hotter than August. The range in temperature in the twenty-four hours in summer is great, the heat often rising to considerably above 100° in midday and decreasing to below 60° at night. In the autumn there is a gradual decline in temperature for the first two months and then usually a rapid diminution to uniformly low temperature, which prevails throughout December and January. The average winter temperature is usually between 20° and 25°, but it varies more or less. As shown in fig. 298, the mean annual temperature varies considerably both by locality and from year to year. It is considerably lower in the northern part of the Black Hills, probably owing entirely to the difference of latitude.

The Black Hills exhibit a higher average temperature in winter and a lower average in summer as compared with the adjoining plains. The explanation that has been offered for this is that the region is protected by heavy forests from the high and dry cold winds which sweep across the plains.

The normal monthly temperatures for typical northerly Black Hills stations up to the end of 1891 were as follows:

Normal monthly temperatures in the Black Hills.

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Deadwood	21	23	32	40	50	60	65	65	54	44	33	23
Fort Meade	18	21	31	44	54	65	71	70	59	48	33	24
Rapid	20	22	33	46	53	64	71	71	61	48	34	31

The number of days in which the maximum temperature equaled or exceeded 90° were: Fort Meade averaged about 2 days in June, 7 days in July, 7 days in August, 1 day in September; at Deadwood the average is less than 1 day in June, 2 days in July, and 1 day in August.

[1] Published by United States Weather Bureau, 204 pages, 163 plates, 4°, Washington, 1893.

Precipitation in and about the hills is extremely variable, much of the variation being local. There is a rainy season in the spring, which in some years attains its culmination in May and in others in June.

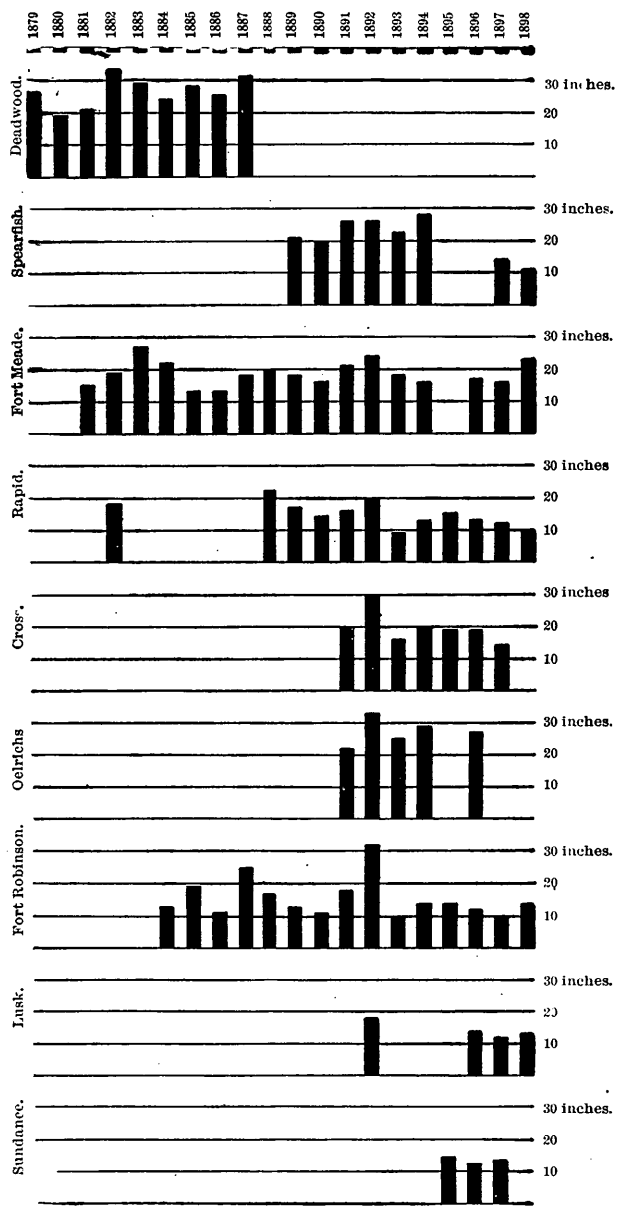


FIG. 299.—Diagram of total precipitation in the Black Hills and adjoining regions.

It is usually followed by a period of drought in July and generally with numerous scattered showers in August and September. Snow is

DIAGRAM OF RAINFALL IN THE BLACK HILLS AND ADJOINING REGIONS, 1878-1899.

By months, January to December. Space between two parallel lines represents 2 inches.

usually expected early in October, but the first snows are light and do not lie long on the ground. The midsummer precipitation in the Black Hills is not large in volume, but there is scarcely a day without light local showers at one point or another. They usually fall out of small clouds moving in narrow zones, and are a very small factor in agriculture. The rain often falls from one stratum of air and is absorbed again in another before reaching the ground. The idea that the climate of the region is changing—a theory which many people hold—is not borne out by the meteorological records. The great variation from month to month and from place to place seems to recur through recent seasons with the same range and averages as is shown in the earlier records. The average number of rainy days in which the precipitation equaled or exceeded 0.01 inch are as follows:

Rainy days on which precipitation equaled or exceeded 0.01 inch.

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Deadwood	11	11	12	14	14	13	10	11	7	8	6	5
Rapid	5	9	11	9	12	13	9	10	4	7	6	5

The average number of clear days per month, or those in which less than one-third of the sky was obscured by clouds, are as follows:

Average number of clear days per month.

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Deadwood	12	9	10	8	9	11	15	16	18	15	14	11
Rapid	13	6	6	10	6	6	9	9	14	11	14	13

At Deadwood the mean annual precipitation from 1878 to 1887 was 28.4 inches. At Rapid from 1881 to 1891 it was 18.46 inches. The following excessive precipitation has been recorded:

Excessive precipitation at points in the Black Hills, South Dakota.

RAPID.

May 1–31, 1883	10 inches.
June 7, 1888	0.27 inch in 12 minutes.
August 10, 1890	1.17 inches in 1 hour and 6 minutes.
July 5, 1891	1.33 inches in 43 hours.

DEADWOOD.

July 27, 1872	1.16 inches in 45 minutes.
August 8, 1875	1.7 inches in 1 hour and 5 minutes.
April 16, 1877	2.52 inches.
April 17, 1878	3.20 inches.

Excessive precipitation at points in the Black Hills, South Dakota—Continued.

DEADWOOD—continued.

April 21–22, 1879	2.86 inches.
April 22–23, 1886	3.32 inches.
May 2, 1874	4.55 inches.
May 7–8, 1882	3.33 inches.
May 17–18, 1883	2.77 inches.
May 18–19, 1888	2.62 inches.
June 9–10, 1874	2.51 inches.
June 23–24, 1883	3.34 inches.
October 15–16, 1879	3. 47 inches.

FORT MEADE.

July 1, 1888	1.40 inches in 1 hour.
July 11, 1889	1.40 inches in 35 minutes.
June 4–5, 1890	3.8 inches.

SPEARFISH.

June 14, 1891	3 inches in 2 hours and 40 minutes.

The average quarterly precipitation for three points in the Black Hills is as follows:

Average quarterly precipitation at Deadwood, Fort Meade, and Rapid, South Dakota.

Month.	Deadwood.	Fort Meade.	Rapid.
	Inches.	*Inches.*	*Inches.*
January, February, March	4. 45	2. 42	2. 44
April, May, June	13. 55	9. 61	10. 24
July, August, September	6. 13	4. 92	4. 46
October, November, December	4. 35	1. 62	1. 30

This apportioned between the dry season or winter, comprising January, February, November, and December, and the wet season, from March to October, inclusive, is as follows:

Average precipitation during wet and dry seasons at Deadwood, Fort Meade, and Rapid, South Dakota.

Locality.	Dry season.	Wet season.
	Inches.	*Inches.*
Deadwood	5. 23	25. 25
Fort Meade	2. 30	16. 27
Rapid	2. 07	16. 37

MAP SHOWING DISTRIBUTION OF FORESTS IN THE BLACK HILLS

COMPILED MAINLY FROM REPORT BY H.S. GRAVES WITH LATER INFORMATION FOR AREAS OUTSIDE OF THE RESERVE

SCALE

5 0 5 10 MILES

HEAVY TIMBER
2000–10000 FEET B.M. PER ACRE

LIGHT TIMBER
UNDER 2000 FEET B.M. PER ACRE

SCATTERING TIMBER

The average monthly precipitation, deduced from observations to the end of 1891, is as follows:

Average monthly rainfall at Deadwood, Fort Meade, and Rapid, South Dakota.

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Deadwood.....	1.25	1.21	1.99	5.17	4.65	3.73	2.84	2.23	1.06	1.58	1.26	1.51	28.48
Fort Meade....	0.73	0.63	1.07	2.38	4.02	3.22	2.40	1.96	0.56	0.68	0.48	0.46	18.59
Rapid	0.45	0.83	1.16	2.03	4.30	3.91	2.14	1.59	0.74	0.51	0.35	0.45	18.46

TIMBER.

The Black Hills owe their name to their dark appearance when viewed from a distance, due to the extensive forests of pine by which they are covered. The forests occupy all of the higher land, but vary greatly in density. The principal tree is *Pinus ponderosa* Lawson, or yellow pine. Large areas are densely timbered, but there are numerous open parks in the woods, and lumbering and forest fires have made deep invasions in them at some points. The principal forest growth lies within the encircling rim of Minnekahta limestone. The Red Valley is destitute of trees, but there are scattered pines on the ridges of the hogback range and in places along the Graneros shales. The principal area of timber has been made a reservation by Presidential proclamation, in order that the cutting of timber might be controlled and more thorough vigilance exercised in preventing devastation by fire. The timbered area and the boundary of the forest reserve are shown in Pl. CX, which has been compiled from a description of the reserve by Mr. H. S. Graves, forester,[1] with later data for some outlying areas. On this map an attempt has been made to classify the timber as heavy, thin, and scattering, but it has been done in a somewhat arbitrary manner and necessarily with considerable generalization, on account of the small scale of the map. Besides the yellow pine there occurs in the hills a greater or less quantity of the following species:

Trees occurring in the Black Hills, South Dakota.

Spruce (*Picea canadensis* Mill.).
Aspen (*Populus tremuloides* Michx.).
White birch (*Betula papyrifera* Marsh).
Bur oak (*Quercus macrocarpa* Michx.).
Box elder (*Acer negundo* Linn.).
White elm (*Ulmus americana* Linn.).
Ironwood (*Ostrya virginiana* (Mill.) Koch).
Cottonwood (*Populus deltoides* Marsh).
Cottonwood (*P. angustifolia* James).
Red cedar (*Juniperus virginiana* Linn.).

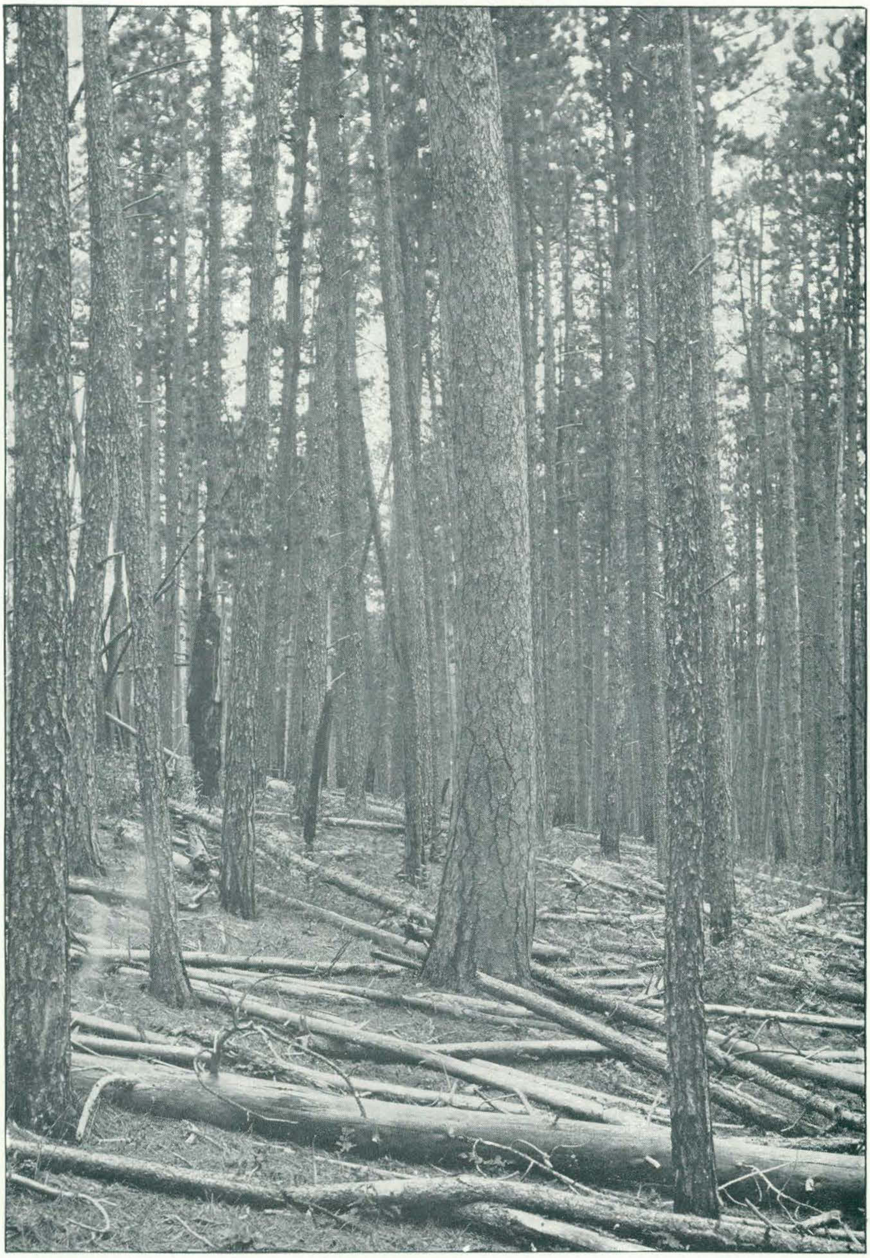
The larger pine timber attains a height of 100 feet, but it is estimated by Mr. Graves to average not over 80 feet, with an average diameter of about 20 inches. Timber of this kind is found "on the divide west

[1] The Black Hills Forest Reserve, by Henry S. Graves: Nineteenth Ann. Rept. U. S. Geol. Survey, Part V, pp. 67-164, Pls. XIX-XXXVI, and maps.

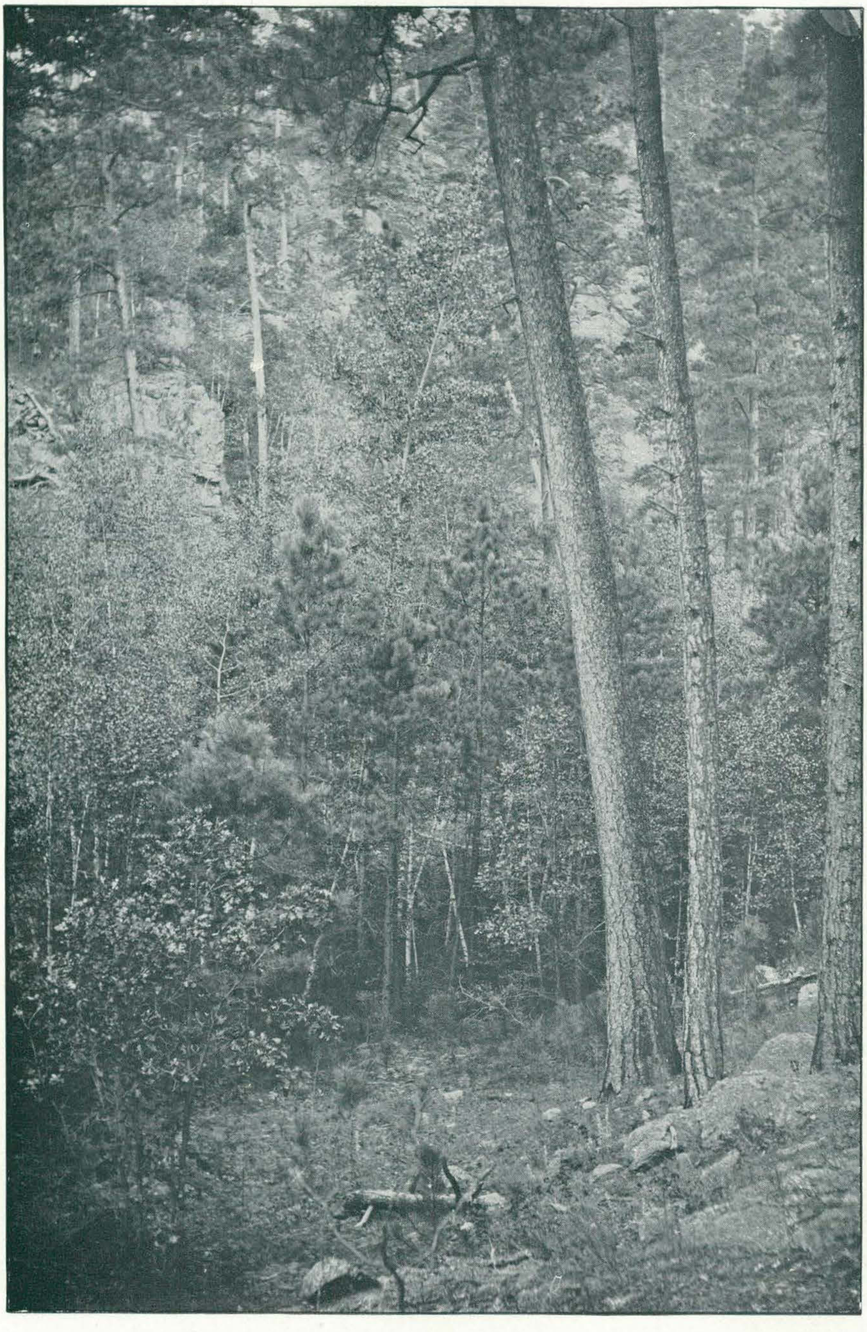
of Spearfish Canyon, on South Box Elder Creek, at the head of Spring Creek, on Soldier, Cold Springs, and Sand creeks, and elsewhere in small amounts. It has an average yield of 4,000 to 8,000 board feet per acre." The second class of original timber is that which covers the greater portion of the Black Hills. "It has about the same development in diameter, but it is not so tall as the first class. It averages about 65 feet in height" and is less dense. "The third class of timber is found on ridges and steep slopes and is both smaller and shorter than the first two classes. The diameter averages 14 to 17 inches."

The spruce grows in the highest valleys and mainly on the northern slopes, where the coolest and most moist conditions are found. It occupies considerable bodies on the high limestone plateau, notably about the head of Castle Creek. It is scattered along some of the higher ravines which head against Harney Peak. It often attains a height of 100 feet and a dimeter of nearly 3 feet, but it averages much less than this. Aspen is scattered over the hills, especially where there have been forest fires, and the white birch occurs in similar manner.

The parks occurring along the higher ridges of the Black Hills are usually found in the heads of valleys where the declivity is small and there is a large accumulation of decomposed rock detritus. Young pines are often found in these parks, especially around their edges, but they do not grow to any great height, apparently on account of the lack of the firm rootage which is essential to the growth of the pine. The existence and perpetuation of the parks is not due to fires, as has been suggested, but to the depth of the decomposed material which is too soft to afford proper conditions for the growth of the roots of the tree. In the lower portions of the valley the streams have sufficient volume to clear out the decomposing rock, so that most canyons through the hills are well wooded. This is also thought to be the principal reason for the absence of the pine in the Red Valley and the plains adjoining the Black Hills. The characteristic feature in the occurrence of the pine is its growth where there are rocky ledges to give suitable attachment for its roots.



A DENSE FOREST OF POLES 8 TO 10 INCHES IN DIAMETER, WITH ONE OF THE MOTHER TREES IN THE CENTER, REYNOLDS GULCH, SOUTH DAKOTA.



A CHARACTERISTIC FOREST IN A DEEP, NARROW RAVINE AT AN ELEVATION OF ABOUT 4,000 FEET.

Stream gaging by John T. Stewart in 1900.

Stream.	Location.	May.	June.
		Second-feet.	*Second-feet.*
Cheyenne River	Edgemont	14	.5
Do	do	10	.3
Do	Above Cascade Creek	12	.7
Do	Below Beaver Creek, southeast of Buffalo Gap.	47	49
Do	Above Fall River	39	.19
Stockade Beaver Creek.	2 miles above LAK ranch	11	12
Do	Mouth	9.4	3.5
Salt Creek	East of Newcastle	.2	.2
Big Oil Creek	Burlington and Missouri River Railroad bridge.	.2	.03
Little Oil Creek	Newcastle	.05	.02
Cascade Creek	Mouth	25	20
Fall River	do	33	25
Do	Below Hot Springs	25	29
Iron Creek	Glendale	3.8	1.6
Beaver Creek	3 miles northwest of Buffalo Gap.	12	15
Do	7 miles southeast of Buffalo Gap.	1.2	6
Battle Creek	Keystone	3	2.3
Do	Hermosa	9	2.3
French Creek	10 miles northeast of Fairburn.	13	5
Do	At Fairburn	3.3	.2
Spring Creek	Fremont, Elkhorn and Missouri Valley Railroad bridge.	.4	.1
Do	North of Rockerville	6.5	.7
Squaw Creek	Otis	8	2.8

THE HIGH PLAINS AND THEIR UTILIZATION

BY

WILLARD D. JOHNSON

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ILLUSTRATIONS.

THE HIGH PLAINS AND THEIR UTILIZATION.

By Willard D. Johnson.

CHAPTER I.

INTRODUCTION.

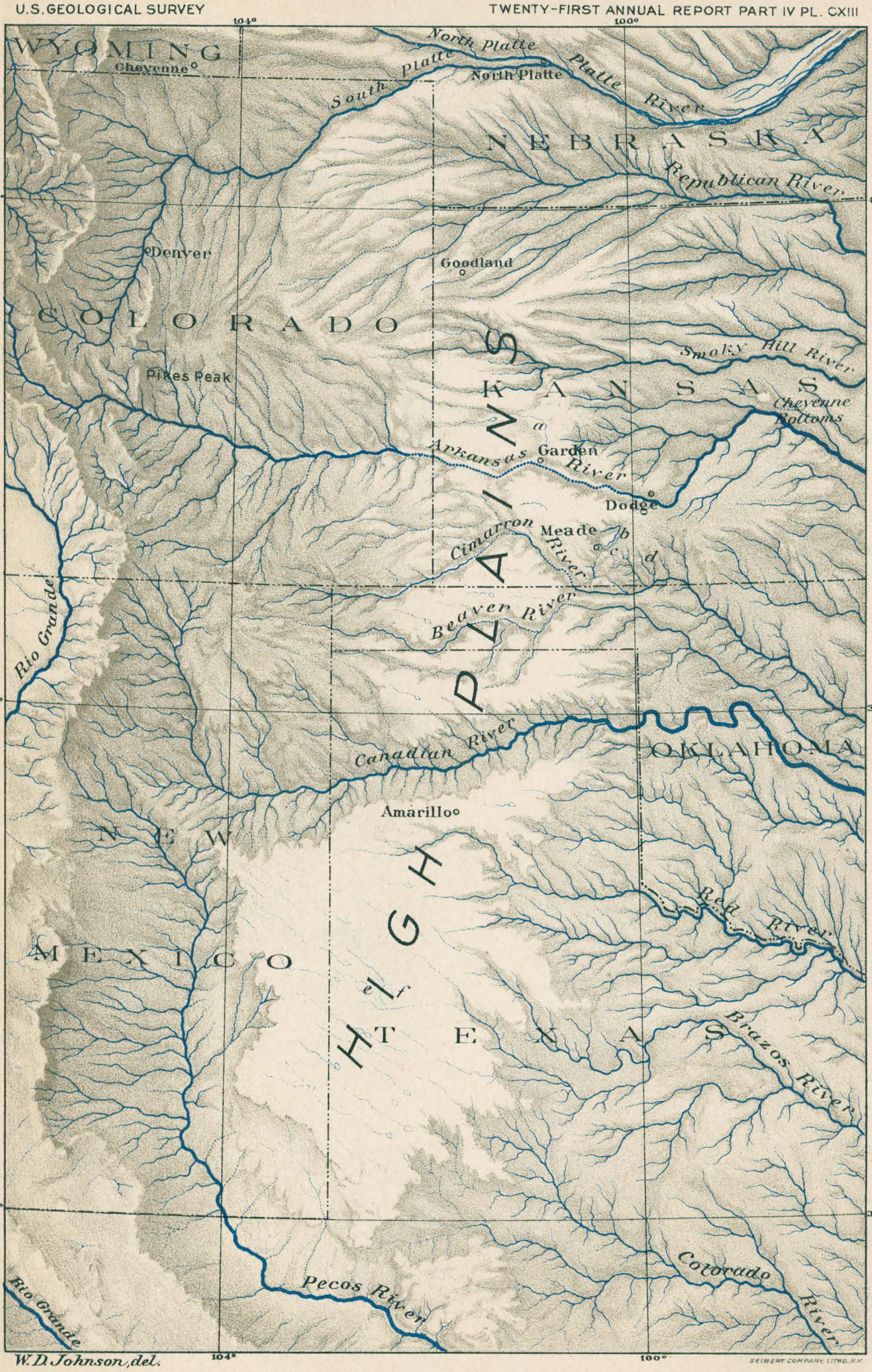
THE GREAT PLAINS AND THE ARID REGION.

The Arid Region, as its limits are now determined, comprises a smaller and much more irregular area than the featureless, "unexplored" region of the early maps known as the Great American Desert. This contraction of boundaries, by the recognition of relatively humid tracts, has in fact gone so far that the name Arid Lands, as implying rather a grouping of detached parts, is coming into use instead.

Originally the desert was assumed to have its beginning in the treeless expanse of the Great Plains, including the whole. We now witness the spectacle of the highest type of agricultural development extended over a belt of States wholly within that early boundary. So much of the Plains had been mistakenly regarded as arid. Yet the development was slow and uncertain. Gradually also, beginning at a somewhat later date, reclamation on a small scale, by irrigation, was undertaken in the unmistakably arid region at the western limit of the Plains, under the spur of the mining development near by, in the mountains. And here, too, natural fertility was demonstrated.

Altogether, however, no great inroad, comparatively, had thus far been made upon this immense body of open land, nor any deliberate effort toward its fullest utilization. The public lands elsewhere had not yet become exhausted. It remained undetermined how far encroachment might profitably be carried without artificial aid. Finally, realizing that exhaustion of public land in the recognized humid areas was close at hand, immigrants rapidly invaded and in a short time covered with settlement the entire intervening space, westward to the zone of irrigation. It was at the worst a drought belt; and the experiment was tried on a scale, and with a reckless elaborateness, that promised heavy disaster in case of failure.

Failure in fact followed, and disaster, with almost complete depopulation, has resulted. Especially was this the case with the High Plains, which presented the maximum inducement of fertile soil and unbroken smoothness of surface.



W. D. Johnson, del.

SEIBERT COMPANY, LITHO. N.Y.

THE HIGH PLAINS

Scale of miles: 0 50 100 150 200

POSITION AND DISTINCTIVE CHARACTER OF THE HIGH PLAINS.

A TOPOGRAPHIC UNIT.

The High Plains approximately correspond to what is sometimes called, merely for convenience of subdivision, the Central Plains region. They lie in irregular belt form about midway across the long eastward slope of the Great Plains. They have fairly definite boundaries, however, and are in fact a natural subdivision of the Great Plains area.

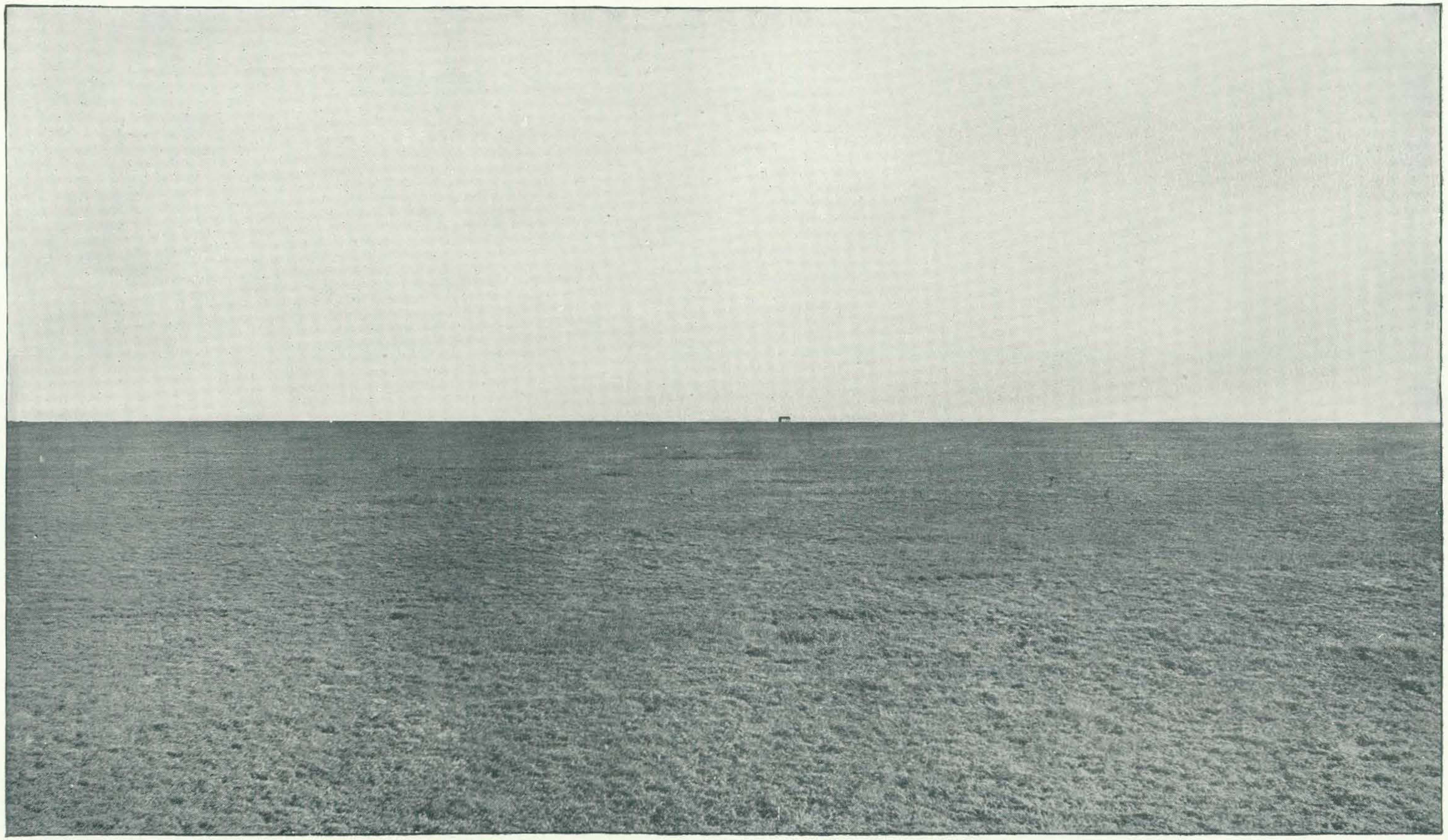
The Great Plains as a whole constitute a geographic unit. Their extent is so great that they are properly to be regarded as one of the primary divisions of the continent. In that broad sense they are a plain. But topographically they present, in the main, an erosion surface—a surface of degradation—with topographic diversity. That is, in detail they have not, in the main, the character of a plain.

The High Plains are the exception. They have practically no drainage, the local precipitation being disposed of by absorption. Comparatively, therefore, their surface has the general effect of a dead level. Indeed, by way of distinction, they are to some extent locally known as "The Flats" (Pl. CXIV). Of the Great Plains area they are a natural subdivision by topographic difference. In this sense they are a topographic unit.

At the same time they are upland or plateau flats. And they are upland flats of survival; differential erosion of an original vastly extended plane surface has left here a fragment, or a close assemblage of fragments, in relief. The relief is not considerable. It is, however, sufficient to be dominating. But the High Plains—locally so called to some extent also—are individual more because of the conspicuous contrast of surface character they present. They are virtually unscored by erosion; though but a fractional part of the whole slope, they are yet absolutely of great size, and the traveler upon them immediately recognizes that they constitute the Plains proper. They alone have strictly the character which that term implies.

A CLIMATAL UNIT.

The Great Plains area, furthermore, may be regarded as naturally subdivided into belts by climatic difference also. In its westward rise of thousands of feet it passes through climatic gradations from humid to arid. Although, necessarily, along a uniformly rising slope, the passage is gradual, so that any subdivision must be arbitrary, it may at least be said that midway, across a considerable breadth, the climate is semiarid or subhumid. Indeed, the vague Central Plains region is sometimes called the Subhumid Belt. Agreeing generally in position with the topographic subdivision of the High Plains is this subdivision by climatic difference. The boundaries of the topographic belt, to a considerable extent, have been given sharp definition by marginal



THE FLAT UPLANDS.

recession—a work of head-stream sapping and encroachment from the eroded area (see fig. 300)—and the topographic belt in consequence lies somewhat contracted within the limits of the climatic belt; but substantially there is agreement in position. Cause and effect here may appear to be far apart, but it is not difficult to trace their connection. The High Plains are equally the subhumid plains.

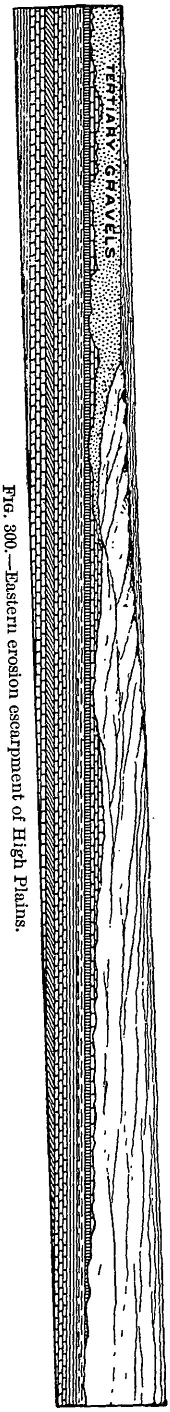


Fig. 300.—Eastern erosion escarpment of High Plains.

THE PROBLEM OF UTILIZATION.

Despite the persistent attempt at settlement already made and its utter and disastrous failure, the High Plains continue to be the most alluring body of unoccupied land in the United States, and they will remain such until the problem of the best means for their utilization shall have been worked out. For not only are they flat and fertile, but their variable annual precipitation, though occasionally falling to the minimum of a truly arid climate, rises to humidity at intervals of about a decade, and may even so continue for two or three consecutive seasons.

It should be recognized at the outset, however, that for agriculture to be profitable in the long run, the subhumid country, like the arid, requires the artificial application of water, though in less degree; and that if the required additional supply is not to be had, the subhumid country in effect is arid also.

It is the purpose in this paper to show that the High Plains, except in insignificant degree, are nonirrigable, either from streams, flowing or stored, or from underground sources, and that therefore, for general agriculture, they are irreclaimable; but that, on the other hand, water from under ground is obtainable in sufficient amount for reclamation of the entire area to other uses; that such reclamation has in fact already begun, and is in process of gradual but sure development; and that it will be universally profitable.

The problem will be found to be essentially one of well making and of the proper location of wells. It is important, therefore, first fully to understand the structure and texture of the ground, to such depths as it may be water yielding; for, given a ground-water supply, upon these factors the "flow," or yield, of wells will wholly depend.

CHAPTER II.

ORIGIN AND STRUCTURE.

Along their eastern front the Rocky Mountains rise from the Plains abruptly, as if from a broadly sloping pedestal. This feature of a far-spread foot slope, made up of their own waste products, is a characteristic of desert mountains. The ranges of the Great Basin region of Utah and Nevada, for example, all have the inclined débris plain as an invariable topographic accompaniment. With such wide sweeping slopes on either hand the desert range has the appearance of being perched upon a base appreciably above the general level. In end view the pedestal effect is conspicuous.

The Great Plains are of such vast dimensions, it is only in imagination that they can be regarded as a foot slope of the Rocky Mountains. However, in the sense that, superficially, ranging down to several hundred feet in depth, they have been built to a smooth surface by mountain waste, stream-spread to great distances, they have this character. At the base of the mountains the Plains mass has a thickness, to sea level, of several thousand feet. It is made up in the main of marine-rock sheets with a general inclination eastward, due to broad regional tilting, in which plains and mountains have shared together.

But the present surface grade of the Plains is not that of the original tilting. The surface has undergone a series of transformations. These have all been accomplished by the eastward-flowing streams from the mountains. In a first stage the mountain streams, traversing the Plains, cut into their smooth structural slope and produced a topography of parallel broad valleys and ridges. In a second stage they ceased to cut, depositing instead, and refilling the valleys they had excavated, even burying the intervening ridges, to a smooth upper surface. The original surface was a product of deformation, the second of a destructive process of stream erosion, the third a product of stream deposit and construction, involving the spreading of a waste sheet to great distances and a uniform level, and to a depth over the greater valleys often of several hundred feet. In the final and present stage, virtually the same streams have returned to the earlier destructive habit, and erosion has in large part carried away the high-level plain of stream construction. About midway of the long slope, in a north-south irregular belt, large uneroded fragments of the smooth constructional plain remain. As we have seen above, these fragments constitute the High Plains.

THE DÉBRIS APRON.

The foot slope of the desert range is a wash plain of mountain waste, burying its foot, in fact. In humid lands the waste from mountain degradation does not accumulate in this manner, but is carried through to the sea. Its accumulation in arid lands, at an appreciable grade, is an effect of imperfect and early arrested drainage. An apron of débris rising high upon either flank, therefore, is characteristic of desert mountains.

A BUILT PRODUCT OF DRY-CLIMATE DRAINAGE.

A mountainous tract in an arid region is, relatively, a humid tract. Its streams may not have the perennial character of streams in a humid climate, but they run strong, and they carry through—i. e., they do not fail appreciably in volume and deposit their load. But beyond the mountain boundaries they deposit, because the climate there is dry. They sustain losses only and are not replenished.

The stream upon the desert proper is dwindled, and finally brought to an end, depositing the whole of the load which it carries in suspension, and a part of that in solution, because of excessive evaporation into the dry air on the one hand, and because, on the other, of absorption into the dry ground. The stream in humid lands runs upon ground already saturated by the local rainfall; it runs also, normally, below the general level, cutting into it and receiving a contribution from the ground water. The desert stream, on the contrary, normally runs and spreads upon the surface, which either it has itself built up or is engaged in building up; and by seepage loss it contributes to the ground water.

All streams are variable in flow, and with respect to their really effective work in erosion, they are periodic. Effective work is done during flood periods only. During the period of light flow, comparatively of long duration, there would be accomplished a considerable measure of work except for the fact that flood flow leaves the stream bed paved with large material, too heavy for the stream in its feeble stages to handle. The stream upon the desert differs from that of humid lands in that commonly its periods of strong flow alternate with periods of no flow at all.

Arid lands are dry not because their atmosphere in equal degree is devoid of moisture, but because the conditions are not favorable for the precipitation of such moisture as it has. Not infrequently, indeed, the heavy rainfall of humid lands is delivered from air which has reached them across an extensive arid tract. The mountainous areas of an arid region are relatively humid areas because they present, locally, conditions favorable for precipitation. In order to pass over them moving air is forced to rise; in rising it is both expanded and cooled, and expansion and cooling alike diminish its moisture-carrying capacity. Only the nonmountainous expanses of an arid region, then, constitute the desert proper.

The desert proper is without streams, except such as extend into it from locally humid areas—its mountains—and which, after comparatively brief extension, become "lost" upon it by absorption and evaporation. In exceptional cases rivers, such as the Nile or the Colorado, having their rise entirely without its limits, may traverse a desert, and be perennial across it; but the drainage which is normal comes from included elevated tracts, locally humid, is widely variable in volume of flow, and is peculiarly subject to heavy floods.

Streams having this habit of violent flow, following long periods of rest, though they may have brief duration, will yet reach the desert plain heavily loaded; for the processes of rock disintegration will not have been wholly suspended in their headwater region, and the material for loading will be ready at hand. Furthermore, in its upper region of tributary contribution the growing stream will add to its load by erosion of its bed; but upon the dry plain, without tributaries, and rapidly dwindled by absorption and evaporation, it will build, rather, by unloading. Thus, normally, in a dry climate, streams from a mountain range spread aprons of débris against its base, seemingly lifting the range above the general desert level upon a broadly spread pedestal.

Such streams in their mountain headwaters act separately and individually, carving systems of mountain canyons, but upon the plain without, if issuing close together, they may act jointly, extending a uniform slope of mountain waste. The débris apron is the correlative of the fan-form groups of headwater canyons.

This pedestal-building work of mountain streams in an arid region finds its equivalent in humid lands in foothill sculpture. Arid mountains normally are without foothills, at least as erosion effects; and where originally they do occur, in time they become buried in the process of creation of normal foot-slope profiles.

ANALOGY WITH HUMID-CLIMATE CONSTRUCTIONS.

The débris apron is related in manner of construction to the delta of the humid-lands river as well as to the backward-spread bottom land above the delta. It is more nearly of a kind with the plain which, in a climate of perennial drainage, streams in parallel series form along a coast, advancing the coast line, and which in reality is the product of coalescence of individual stream deltas and delta plains.

But these constructions are terminal phenomena of through streams, which extend to base-level at still water and there develop scattering flow, because primarily slope has become almost insensible. They are practically flats at the foot of a long grade. The débris apron, on the other hand, is a deposit of the intermediate course. The typical arid-lands, or desert, stream does not carry clear through—does not reach to any ultimate base-level. It comes to an end while yet upon a relatively steep grade. For this reason the slope of desert waste material constitutes a topographic feature of appreciable relief and is characteristic and conspicuous in desert scenery as a symmetrically spreading pedestal complementary to the desert range.

A COMPOSITE; THE ALLUVIAL FAN ITS UNIT.

As a topographic individual the débris apron strictly is a composite, just as the coastal plain is a composite. The alluvial cone or alluvial fan, radially spread from the mouth of a canyon, is its unit, as the delta is the unit of the coastal plain. The débris apron is formed by coalescence of alluvial fans in series along a mountain front. The alluvial fan, then, is the desert counterpart of the delta.

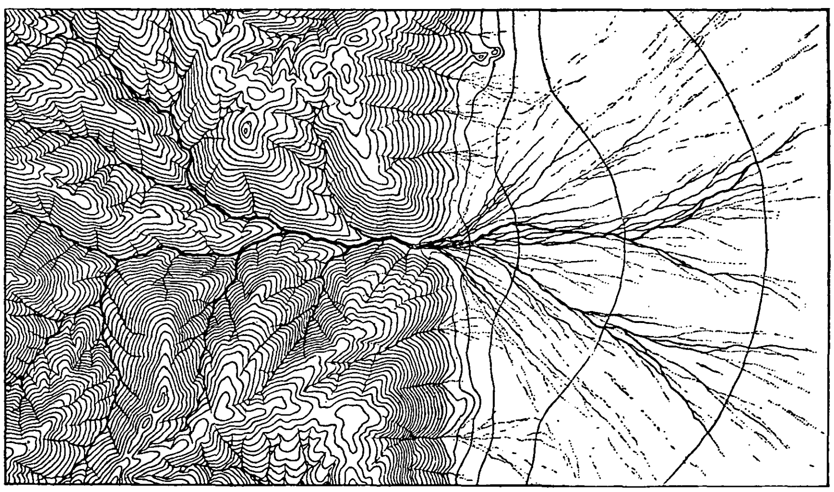


FIG. 301.—Tributary and distributary regions of a fan-building stream.

The terminal fan-form construction (tidal interference in the one case aside) is normal to all streams, whether perennial or intermittent. It is a phenomenon of their final and rapid unloading following upon rapid failure of flow, the deposited load in turn reacting upon flow to impede and subdivide it and to deflect it in many divergent courses. In the case of the perennial stream, which goes through to base-level and still water, radial spreading occurs only as a termination to a course of concentrated flow, relatively long. Such a system has its upper region of branching tributaries and its lower region of branching distributaries, with trunk-stream connection, while the stream from the desert range commonly has its tributary region directly united to its distributary region, in hourglass form, at the mouth of a mountain canyon. Alluvial fan building, like delta building, follows upon failure of flow, but with the difference that in arid lands flow fails, not because grade finally has become lost and flattened out at base-level, but because the stream itself has become enfeebled and finally brought to an end through ground absorption.

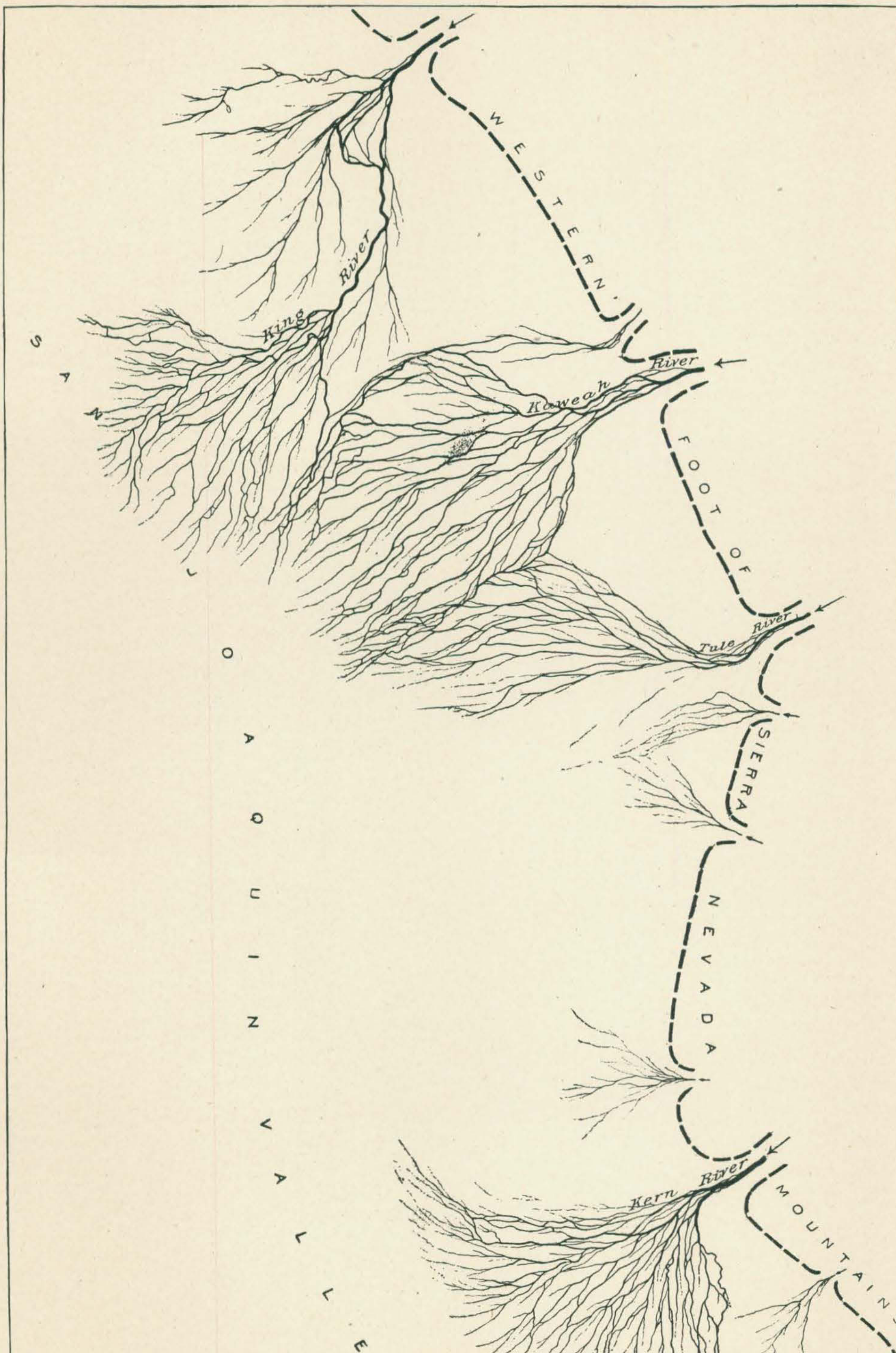
HIGH GRADES THE RESULT PRIMARILY OF STREAM ABSORPTION.

The perennial stream maintains the ground over which it runs in a condition of saturation. In arid lands the ground water of saturation sinks, between the periods of flow of the intermittent stream, and has first to be replenished. The ground water thus robs the desert stream. In transportation of load, stream velocity is the prime factor, but stream volume is a secondary factor and may at times assume primary importance. The delta is built at standing-water level because velocity is brought to an end there on a bed without grade, but on the comparatively steep grade of the desert alluvial fan the load in transportation—relatively heavy because desert degradation is easy—becomes an overload, not because, primarily, velocity is diminished, but because volume is diminished. The intermittent stream finds its end, not at base-level, in the sea, but at an early stage on the way to it in the ground.

As between the desert range and its foot slope, then, the former is the region of relative humidity (because of its relatively high altitude), of stream development through concentrating flow, of degradation, and of loading; the latter, of stream dwindling and failure through ground absorption, of unloading, and of distributed flow. For a given volume of issuing stream the heavier the load the greater will be the tendency to spread, and therefore the steeper the grade, since spreading promotes stream failure by bringing the water into wider contact with the dry and porous ground. Desert streams from unclothed mountain flanks are, as a rule, heavily loaded.

The débris apron will have its own independent precipitation and its drainage of local origin; and this local drainage originating upon it unloaded will tend in turn to degrade it to some lower inclination and to distribute its material farther on. Through recurring local reenforcement of transmission from local precipitation the waste from desert mountains must eventually reach the sea. But in proportion as the run-off from the mountains, reaching out upon the desert, is more vigorous in its scattering transportation and unloading than the drainage of local origin is in picking up again, the waste plain will grow rather than diminish. In short, the slope is maintained at its high grade against a tendency to reduce it, and it must be because it is rapidly built that it has topographic prominence.

This high grade of the apron of deposit is not due, necessarily, to small size of its shaping streams. The streams of humid lands, small and large alike, build flats. Nor is it due to low velocity of flow, for



MAP OF DISTRIBUTARY FANS OF KING, KAWEAH, AND KERN RIVERS, CALIFORNIA.

the stream we are here considering is of mountain origin, and leaves its canyon with a high velocity, which would tend rather to produce a gentle and long grade. It is due to the facts that, being intermittent, the stream issues from its gathering ground overloaded, in the first place; and that, issuing upon porous ground not already saturated, it is rapidly dwindled and made to disappear by ground absorption.

SHEET FLOW AND LACED DRAINAGE.

Since the drainage of a desert range does not flow off from it as a sheet, but rather at points of concentrated discharge spaced along the range front, as a parallel system of streams from canyons, it must thereafter, in order to construct a débris apron, take on something of the nature of sheet flow, by the spreading out of each individual stream, and, at an early stage, by the union of these individual stream fans.

As a matter of observation, actual sheet flow does take place for some distance out from the canyon mouth during periods of maximum discharge. Yet, though the bed of the spreading stream is fairly smooth, there is discernible within the spreading sheet a tendency to flow in currents because the bed is not absolutely smooth. At the same time it will be apparent that the growth of each thread of current, though rapid, is but momentary, and that concentration is here again the next moment followed by spreading, after the manner of the stream as a whole; and as current growth necessarily entails channel cutting, there will take place also increase of the already heavy load, overloading, and deposit.

Against this deposit the channel scar, through backward building, becomes in large part healed. Ahead of it, on the other hand, in consequence of the relief from overload, channel flow is resumed. However, because of the spreading and thinning, it is not resumed as a single channel, but as several minor ones—again after the manner of the stream as a whole. The general tendency would be thus rapidly toward a closer semblance of true sheet flow—that is, toward a closer approach to balance between the opposite tendencies of scour and of building, by rendering oscillations across the mean minute—if it were not that each branching current comes more and more into union with like branchings from currents on either side. In so doing a new, continuing series of threads of swift motion is established—though of somewhat lessened vigor—each approximately central to a preceding pair.

In other words, flow becomes laced. That is, briefly, there is developed within the sheet a net of currents. As no single thread maintains a fixed position, but in the alternation of backward refilling with channel cutting is continually crowded aside, one way and another, the net will be a shifting one, in time working over all parts of the surface. Thus, because the meshes of the net are flooded across, there may be the semblance of sheet flow for a brief space out from the canyon mouth; but, even within the sheet, effective work will be done by currents interlacing.

Development will not be symmetrical; some threads will gain at the expense of others; but as thinning progresses, this structure, as a persistent one, becomes plainly revealed. The meshes, which are greatly lengthened in the direction of slope, widen at the same time in that direction, with the radial spread of the network, and sheet flow ultimately thins so far as to open to a mere skeleton of lacing currents.

In this open form there is greater extension. Here again, however, inequality of volume among the various threads of current continues and increases, though to the marked advantage of but a few, ground absorption rapidly bringing to an end the enfeebled many, and developing gaps. In consequence, the extreme limit of outward extension is reached by individual streams only, wide apart and still divergent, and commonly with one or more far outrunning the others, until they, too, become absorbed. During the period of full flow the front, thus shredded out, will hold approximately its position, the loose ends, however, not only widely separated, but each shifting laterally, one way and another. At the outer margin of the fan there is rarely to be seen more than a single feeble and failing current, halting and dodging upon its own deposits.

In spite of the fact that the stream early loses the symmetrical fan form of extension, it nevertheless spreads symmetrically its fan of débris, to the farthest reach of its divergent, wandering threads. During any single period of flow of the intermittent stream, these threaded currents wander over a fraction merely of the total surface. They do not distribute uniformly their addition to it. In successive periods, however, successive sets of stream threads wander repeatedly over the whole, and as each patchwork addition is in fact but slight, construction is carried forward with substantial uniformity. In effect, also, considering the successive different courses together, laced flow may be regarded as coextensive with the débris fan.

Recognition of this process of building is important as bearing upon questions of ground structure, in their relation to well making and to the delivery or "flow" of wells. For every stream has a line of swiftest motion, relatively quite narrow, along which its coarsest material is deposited, and broadly bordering which, on either hand, it deposits finer material, so that a débris slope, built up by a virtual net of shifting streams, will have a structure reflecting such a process. It will be a structure, not of bedded sheets, as the alternate occurrence of coarse and fine material in well sections would seem locally to indicate, but of interlaced gravel courses penetrating a mass of fine material.

As a rule, however, it is on a small scale only—by a minor stream from a minor canyon—that the perfect alluvial fan is formed and left isolated. The conditions are exceptional which favor spread to a distance uninterrupted, even upon an unbroken plain. The desert range discharges its drainage from canyons in a spaced series of streams along its front, and commonly, therefore, there is union of the resulting series of débris fans at an early stage in their expansion. Indeed, there is a faint topography in confirmation of what we here theoretically suppose: Close to the range foot the débris slope is undulated along a line parallel thereto; individual fans or cones rise perceptibly to each point of discharge. Somewhat farther out there is undulation, merely broader and fainter; and eventually, so far as the eye can discern, union becomes complete. The streams, in short, build together an inclined plane, rather than each independently an alluvial fan.

Strictly speaking, then, there is no such thing as sheet flow. Where for a space there is semblance of it, the fundamental condition, as shown, is one of intimately lacing threads of current; and while the débris apron itself is in effect a sheet of waste, built up by additions practically sheet form, so that its surface rises uniformly, it is in fact an interwoven mass rather than either a homogeneous or a bedded one. The degrading stream persists upon a line once taken; but the aggrading stream shifts from course to course, abandoning considerable lengths at a time. And fan building is accomplished not by a net of streams working simultaneously over the whole area, but by a few threads of stream continual shifting, producing a net of stream courses in final plan.

THE GRADED SLOPE.

It is apparent that débris aprons may be accumulations of notable depth. The waste of humid lands goes into the sea and accumulates heavily there only; but arid lands are always deeply cumbered with their own degradation products. The region of through streams has the sea for its base-level of deposit, while the region of incomplete drainage has virtually no base-level at all. Its débris accumulations, however, though in deep masses, are not disordered; they are disposed in graded slopes.

Though the absence of a complete cover of protecting vegetation especially favors degradation, and though (the intervals of quiescence not considered) the wear of desert mountains is in fact rapid, so that they are strikingly pinnacled and sharp, nevertheless, under normal conditions the great body of an arid region will have the appearance of being exempt from even the touch of erosive agency. Its characteristic profiles are long and sweeping; indeed, they are delicately modeled curves.

DEGRADATION AND AGGRADATION.

And yet, in arid as in humid lands the agencies of degradation are everywhere in some degree operative. It is only because in arid lands, on the waste plains, their work normally is feeble in comparison with that of the building agencies that seemingly they are inactive. In humid lands all above base-level is a region of degradation. The effect of drainage in humid lands (conditions remaining stable) is always to take away; never more than lightly and temporarily to add. The waste plains of arid lands, on the other hand, are regions of aggradation. Their mountains are exceptions; it is from the very vigorous wear of these elevated regions that the waste plains are spread, but in arid lands normally—that is, where conditions have long been stable—the mountainous tracts areally will be inconsiderable. The desert range, because high and irregular in outline, where all other lines are symmetrical, is conspicuous; but ordinarily, in cross profile, it is no more than a knob between far sweeping débris slopes. Without mountains, the desert, like the land of perennial drainage, would be everywhere a region of degradation; the rate of degradation merely would be slow.

It should be noted that, while obviously the ultimate effect of the uninterrupted operation of these processes must be reduction of the mountains, complete reduction over large areas is perhaps never attained; for the period required is very long—longer than that of mountain making, and losses are compensated by renewed deformation and uplift.

THE GRADED SLOPE A BALANCED PRODUCT.

Neglecting the slight effect upon waste plains of their local precipitation, the mountain streams which become extended and spread over them tend at the same time both to sculpture their surfaces faintly and to build them up. The long grade is therefore a balanced product. Its symmetrical, faintly curved profile is really an expression of delicate equilibrium attained and established between opposing tendencies—an equilibrium easily disturbed, yet constantly maintained.

This dual process has been termed "gradation." The slope, in profile, will always, with an aggrading stream, be symmetrical—always, indeed, slightly curved; but its average grade, or the average inclination of the curving plain at which its two antagonistic shaping forces are brought into balance, may range from steep and short to gentle and far extended. Thus, essentially, the slope is one of equilibrium. It has been better called a "graded slope." It is, in fact, by cutting and filling, or, in other words, by grading, that the forces which shape it come into equilibrium.

GRADATION A CONTINUING PROCESS.

Strictly, the graded slope, properly to be so called, should be a finished construction. It should be a slope upon which the stream would run without variation either of velocity or of load and without either scouring or building up its bed. By deposit, however, the slope continually grows (up to a certain maximum limit of mountain waste and yield), and at the same time it continually alters its inclination. There is slow departure from equilibrium, and there is closely following readjustment toward recovery of it.

But these modifications and readjustments do not take place at the same rate at all points of the grade. Essentially they are effects of terminal unloading and building propagated backward along the grade, and this propagation proceeds at a slowing rate. In consequence, the profile is curved. With perennial streams—i. e., streams which extend to base-level—this curvature is concave, flattening with terminal building and lengthening. With the periodic desert stream of variable extension, as with the perennial stream, concavity of profile is normal and follows essentially upon terminal unloading. But with the play, or variation in position along the grade, of the stream end such curvature may, in fact, become either accentuated or flattened, or even for a space reversed.

In any event, curvature will be barely perceptible; but that there is curvature at all, however slight, and that it is persistent, shows gradation to be both a process responsive to slight influences and a continuing process.

RELATIVE STABILITY OF GRADED SLOPE.

Under stable conditions—i. e., with unchanging climate and freedom from earth movement—the graded slope passes through these transformations with a slowness comparable to that of mountain wear. Deprived of the greater part of its load, the same stream would at once attack its former slope of equilibrium, and rapidly, though at a progressively slowing rate, lower it. On the other hand, its load largely increased, the stream would rapidly build up the slope. In either case, however, it would come to a stand at a new grade of equilibrium, at some new level, lower or higher, answering to the changed conditions. Contrasted with this promptness of response to abnormal influences, the rate of transformation through which the graded slope itself normally passes is a secular one. It keeps pace with the slow growth of the débris mass following upon mountain lowering, and imposes upon it merely the condition of symmetrical development. That, however, the processes involved in gradation, which raise or lower the stream bed to equilibrium of grade, are themselves essentially rapid is apparent from the swiftness of the alternate cuttings and refillings, of small amount, in which first one and then the other of the two opposing forces gains or loses the advantage.

As at the surface of a river, the material moves on, while the level of the plain is maintained virtually undisturbed; and, as with the river, if the rate of supply of this material be increased or diminished, the surface of the plain will be correspondingly elevated or depressed—graded up to a higher position or graded down to a lower one. If the disturbance of equilibrium be abrupt, the raising or lowering of the surface to the new position will be accomplished swiftly.

THE GRADATION PLANE.

The term "graded slope" applies to the stream bed in longitudinal profile only. It applies equally to that of the perennial through stream of humid lands, which by channel cutting persists along a definite line, and to that of the intermittent desert stream of shifting habit. But the bed of the humid-lands stream has such insignificant width that it does not in itself constitute an important topographic form. Nevertheless, the entire surface in humid lands, since all of it is drained, may be regarded as made up of an infinite number of drainage courses. The minuter ones are not definitely marked, since with them, as with desert drainage, flow is intermittent, and, when it does occur, amounts to overflow; but the larger ones are fixed in their courses along gullies, ravines, and valleys of their own making. On desert plains, equally, the entire surface is properly to be regarded as a stream-bed surface, but here, over large unit areas, it is virtually the bed of a single stream. The bed of the desert stream, then, is not a graded profile merely, but a plane of gradation, and constitutes a topographic form which is, in fact, the dominant and characteristic feature of desert landscapes.

THE DÉBRIS APRON A PLEXUS OF GRADED STREAM BEDS IDENTICAL IN PROFILE.

In short, not to complicate the statement with details at every point, a series of streams from a mountain range, which in humid lands would persist upon independent courses and excavate valleys, may in arid lands unite by broad branching and interlacing flow and build up the original surface to a smooth and far-extended apron of débris. This débris apron, having the profile of a graded stream bed along all lines in the direction of its slope, will be a gradation plane, sensitive as a whole to any disturbance, by outside influences, of the equilibrium between its opposite grading forces, just as the single profile is sensitive.

DISTURBING INFLUENCES.

While, then, it is understood that the plain of graded stream beds holds a constant level—or a level that, normally, is departed from only by slow, secular growth—it is yet important to recognize that it does so only so long as the conditions upon which its growth has depended remain constant. The gradation level represents merely a balance attained between agencies or groups of agencies, either of which, if this balance were greatly disturbed by outside influences, would swiftly and radically transform the entire surface. It has been intimated that waste-plain development in an arid region has a cycle, the inception of which is mountain birth, through the operation of agencies which need not here be considered, and its close the completion of mountain destruction and leveling, through the operation of the familiar agencies of erosion. At the same time it was pointed out that desert topography bears record, as a rule, of the frequent interruption of these long gradation cycles by earth movement resulting in deformation, with the result always that gradation levels are disturbed and that regradation is set up toward new levels; and in the passage from any such established level, or, strictly speaking, inclined plane of equilibrium, toward a new one, there will be a topography of changing type marking stages in the transition. If, for example, deformation has been of such character that the new plane of equilibrium, or adjustment, is lowered relatively to the old one, the forces of degradation alone will effect the change. The transformation will have two stages, marked by distinctly different topographic types. In the simple and typical case of the mountain range and its débris plain, the streams which formerly upon issuing from the range spread toward one another, and in so doing built the plain, as in effect a single broad stream bed, will now continue across it in fairly direct, individual courses, steadily cutting downward, and creating in time a parallel series of V-form valleys or canyons. This is the first stage. The canyons will widen at top, retaining sharp edges, but at bottom they will continue to have the width only of the stream itself, until in downward cutting, at a slowing rate, the newly imposed level, or gradation plane, is reached. Here deepening will come to an end, as if upon a rock floor, though the material still continue to be the loose material of a débris accumulation. Here will begin the second stage, with appearance of the new gradation plane, by widening of the valleys at bottom as well as at top, and the development of valley "bottoms."

With the maturing of effects under these new conditions a striking contrast is presented from those of the earlier stage. In the first there is a single plain, sharply dissected merely; but in the second there are two plains, the one of widening valley bottoms, the other of isolated, subdivided, and dwindling plateau surfaces. In the widening of valley bottoms, to the ultimate union of them all in a continuous new plain at the lower level, with complete removal of the interstream plateaus, each stream is none the less occupied in degradation because it has ceased to cut downward. There is return to the earlier habit of wandering, subdivision, and fan-like spreading, but, in proportion as the valley walls interfere with this tendency to spread and extend the new plain, they are cut into horizontally and are undermined, the displaced material being added to the "load" of the stream. Degradation of this type has been well styled "planation."

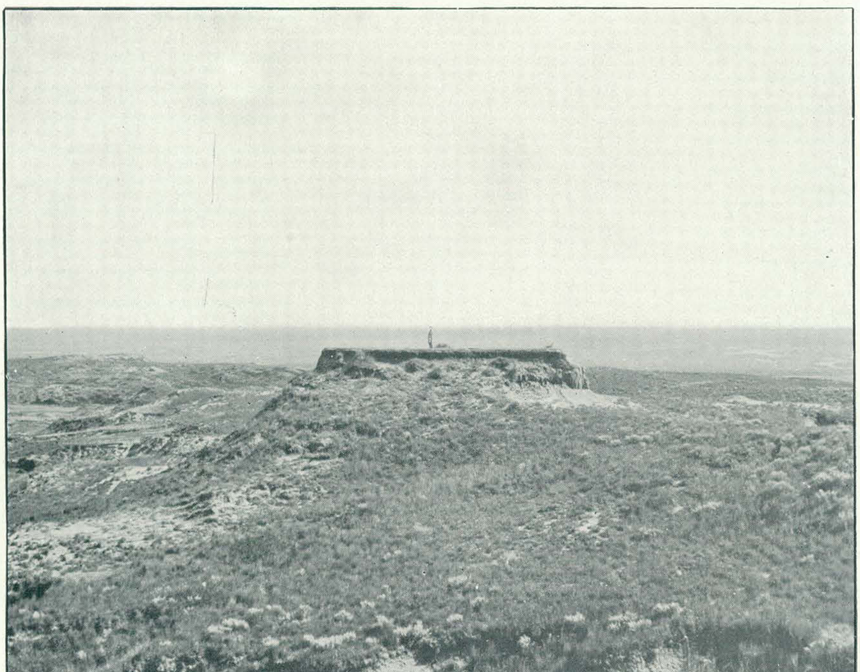
When deformation is of such character that a surface which had been brought to grade becomes depressed below grade, readjustment will be by building—by development, first, of alluvial cones or fans, and eventually, through the coalescing growth of these, of a new gradation surface at the new and relatively higher level. But readjustment by dissection and planation to a lowered plane of equilibrium produces topographic forms that are very different.

Desert cycles of mountain reduction and plain building have great duration, because stream work in a region of light humidity is discontinuous. Desert streams are vigorous in work, but their periods of activity are relatively brief. The desert is so called because the condition of dry stream courses and of stream inactivity is the normal one. During these long, dry periods, furthermore, the wind, acting upon a ground surface unprotected or but feebly protected by vegetation, produces effects which, on the whole, hamper the systematic work of gradation. Certain characteristics of the structure and texture of desert-plain accumulations, as revealed in canyon sections, seem to point to this agency as at times accomplishing notable results.

Since desert cycles are of long duration, desert surfaces commonly bear record of repeated interference with these cycles. While profiles prevailingly are smooth and sweeping to great distances, yet not infrequently the slopes will be found to be characterized in detail by a topography of readjustment. They will exhibit multitudes of residual fragments marking earlier and abandoned planes of equilibrium, perhaps of several such planes in series, with slight vertical intervals.

It is characteristic of deserts not only that their plains are large, but that their streams are few. As shown, the plains of the desert constitute the desert proper; the mountainous tracts are not only relatively humid, but small in area; and such streams as the plains have, whenever there is flow at all, are mainly traversing streams—the surplus run-off from the mountains. There is a rainfall of some amount upon the desert proper, but the intervals between rains are much longer than in the mountains. Under stable conditions the influence only of the traversing mountain drainage is perceptible upon the débris plain; but if some disturbing influence, such as local uplift, interfere

A. ABRUPT SIDE SLOPE OF VALLEY ABOVE GRADE.



B. GENTLE SIDE SLOPE OF VALLEY AT GRADE.

with the spreading and depositing habit of the traversing streams and cause them to erode instead, and to flow in single lines, in valleys, then the interstream areas—upland flats—will be left wholly to the influence of the local precipitation. This local precipitation may or may not develop drainage and accomplish some measure of degradation of its own. The ground is dry and commonly of a more open texture than in humid lands. On the other hand, desert rainfall is usually heavy during its brief period; but because the period is brief there may be complete absorption and no run-off whatever, if there happens to be fairly close-set vegetation to act as a cover.

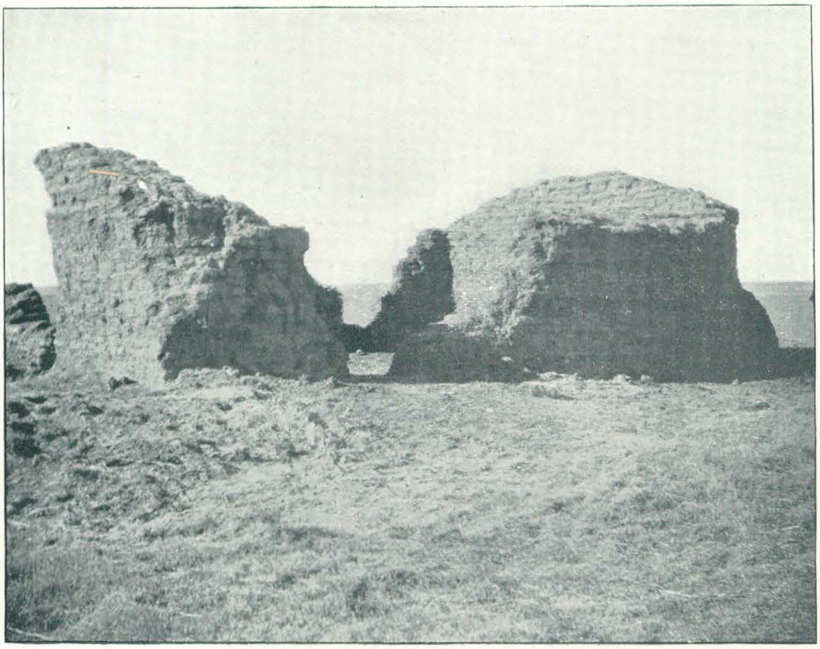
There are degrees of aridity, and there are corresponding differences in the character of desert vegetation. But there is not a like gradation in the erosive effect of the local precipitation upon desert plateau surfaces. Either they are more or less intricately cut up or they are left virtually in the large, unmodified tables blocked out by the mountain streams. Either there will be a considerable degree of erosion or there will be none at all, according as desert conditions are severe or only semiarid. It follows that semiarid or "subhumid" tracts in arid lands, where they bear record of interruption and reversal of gradation cycles, will have a distinctive topography, commonly in light relief, of broad alluvial plateaus. Obviously these plateaus, thus held above grade against a precipitation greater than that which is sufficient for the intricate sculpturing of more arid tracts, have a precarious hold on existence. Their surfaces are protected because they have slight grade. They could not be thus protected on the sharp slopes of matured drainage lines. Hence, if drainage were to be once initiated, degradation would be swift. "Bad lands," which commonly occur in regions not extremely arid, possibly have origin in such delayed degradation, set up finally by temporary shifting of climate to severely arid conditions, as by a protracted series of droughts, killing vegetation.

Thus the vegetal cover may be a conserving factor of much importance in arid regions. The most effective covering, outside of regions of tropical vegetation, is sod. On deserts proper, grass, where it grows at all, grows only in tufts. Nor is there continuous sod even in humid lands, where the ground is overshadowed in greater or less degree by larger growths. But in subhumid lands, upon plains, sod is universal. Thus the subhumid belt of the Great Plains—i. e., the High Plains—is referred to in the adjoining arid and humid belts, to the west and the east, respectively, as the "short-grass country." In the appearance of its covering it is in marked contrast with the "bunch-grass country" to the westward. The short-grass country might, in fact, appropriately be termed the "sod belt." This character of a sod belt is strikingly brought out in the contrast presented in the nature of materials used in house building by the pioneer, here and to both the east and west in the humid and arid belts of the plains, respectively. In the short-grass country the pioneer builds with sod, because there are no trees. In the humid belt he has the choice between sod and logs, and he builds with logs. The humid plains are not timbered, but trees line the streams. They would line streams in the subhumid region also, but that region is virtually without streams. To the westward, in the arid belt, however, there is neither sod nor timber, and there the almost universal building material is, of necessity, "adobe" or sun-dried mud.

There are then, two possible disturbing influences which may result in transformation of the gradation plane—deformation and change of climate. When the disturbance is of such character as to result in degradation, whether by reason of deformation or of climatic change, there are two factors which, on the other hand, make for preservation of the plain, at least against its local precipitation, viz, absorption by the porous and dry ground and evaporation, the vegetal cover, by retarding flow, aiding both. Where the vegetal cover is sod it retards flow completely, not only because the grass blades entangle the water already fallen, until absorption and evaporation can dispose of it, but because blades and roots together resist the impact of rain drops. It is because, in humid lands, the heavy and long-continued rain, by mere repetition of blows, gets at the soil directly, that the rill is established, concentrated flow made possible, and drainage initiated.

THE HIGH PLAINS PLATEAUS REMNANTS OF AN OLD DÉBRIS APRON.

The High Plains in several respects are notable topographic forms. They are gravel plains unscored by drainage, yet standing in relief. The Arid Region affords many examples of gravel-plain plateaus, but on a small scale. These of the Great Plains slope are remarkable by reason of their extraordinary dimensions. The common understanding of a plateau is that, structurally, it is a rock-sheet platform, owing its form and its survival to this horizontal structure and the resistant character of its material. The High Plains, on the contrary, are of soft material, unconsolidated, or but very partially and lightly consolidated. There are such plains, built under water and subsequently uplifted, which have a structure representing the extreme of evenness in the grading of materials. Also there are soft plains of glacial origin, representing in their mass the other extreme of no orderly structure whatever. But the High Plains exhibit, in the main, in their sections, both artificial and natural, unmistakable evidence that they were built upon dry land by streams. They are remnants of an old débris apron. Their surfaces are residual patches of a former vastly extended gradation plane. That this is so—that the deep silt, sand, and gravel accumulation is of fluvial origin—unmistakably appears upon detailed examination of its composition and structure.



A.

B.

SOD HOUSES OF THE SUBHUMID PLAINS.

SOURCE OF THE MATERIAL.

The gravel is disposed in courses, always, so far as they are traceable, closely following the direction of slope of the Plains. It is far traveled—i. e., is well rounded, and of material which, in long transportation, would most successfully resist both mechanical wear and chemical decomposition. In this respect the gravel of plain-building streams, well away from the source of derivation, differs from shore gravel. The latter, while made up largely of resistant material, well rounded, is nevertheless to some extent graded, including always fragments freshly derived. Again, in the mid-slope region as well as close to the mountains, the Plains gravel is seemingly identical in composition with the harder crystalline rocks of the eastern Rocky Mountain front.[1] It contains pebbles of volcanic rocks eastward of the range foot, in southern Colorado.[2] Pebbles of basalt occur at all levels in canyon sections across the High Plains to the eastward of the basalt areas in northeastern New Mexico. In short, the source of the material was the Rocky Mountains; the agency in its transportation running water—i. e., streams from the mountains—and these, extending into a desert climate, had the desert habit of branching and lacing flow, and built up the desert surface with their burden of débris from the mountains to a delicately adjusted slope of equilibrium.

THE GREAT PLAINS A STRUCTURAL SLOPE SUPERFICIALLY MODIFIED BY STREAMS.

But the Great Plains, as we have seen, are only superficially a débris slope. They are not, for example, like the slope which flanks the Sierra Nevada along its whole western base, forming in breadth most of the Great Valley of California, an accumulation of mountain wash from top to bottom. Except superficially, they are a structural slope of marine-rock sheets uplifted, with generally uniform eastward inclination. They are merely mantled by débris. The traversing streams from the mountains, as the alluvial covering attests, have found the structural surface, however, below "grade," and have at some time brought it up to grade, or have striven to do so, by building upon it. But while the buried rock sheets are virtually uniform in their eastward inclination, wherever the bed-rock surface is exposed by degradation it is apparent that previous to burial they had been eroded. The covered surface had a topography of considerable diversity and relief.

While, then, the Great Plains are to be regarded as in the main a structural slope merely modified by streams, they are yet superfi-

[1] Physical properties of the Tertiary, by Erasmus Haworth: Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 253.

[2] The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 576.

cially, and to the depth of their alluvial veneer, a débris apron of the Rocky Mountains. Absolutely, from the point of view of the well maker, the depth of the veneer is often very considerable. It is least close to the mountains,[1] but midway, upon the High Plains flats, it sometimes reaches a thickness above the old valleys of the bed-rock topography of 500 feet.

THREE GRADATION STAGES RECORDED.

In the buried topography of the floor, in the smooth surface of the High Plains, and in the topography of the erosion at present in progress, there are recorded three stages of gradation by the mountain streams—virtually the same streams as at present, since, however devious their courses without the mountains, they must have issued, throughout the entire period, from practically the same series of canyon openings along the mountain front.

Prior, then, to the stage during which these streams covered the Plains heavily with their deposits the slope must have been considerable. The present streams have in places cut through the cover into the old topographic surface, and are there showing a disposition toward planation—i. e., are subdividing in their flow and widening their bottoms. It would seem, therefore, that the eastward inclination during the earlier cutting was probably not materially different from that at present. If it differed at all, probably it was greater, since there is no indication that the earlier streams had anywhere reached down to grade. Hence, to assume that between the early erosion and the present erosion burial of the early surface was accomplished in any other manner than by stream building is to assume a radical deformation in that interval, and yet with a return at its close to substantially the original condition.

But it is not necessary to assume instability of the structural slope. It is not necessary, in order to account for change in behavior of the traversing streams, to appeal to deformation. A sufficient cause may be looked for in change of climate. There is record of erosion, with reversal to deposition and rebuilding, and reversal again finally to erosion, and there is reason for believing that this series of interruptions of the gradation cycle was an effect of climatic oscillation rather than of earth movement.

SURVIVAL WITHIN THE MID-SLOPE BELT A CLIMATIC EFFECT.

As pointed out, the uneroded fragments of the old surface fall within the boundaries of the subhumid belt. Their preservation in this region of considerable precipitation, in contrast with the erosion in both the arid belt to the westward and the humid belt to the eastward, is ascribed to a graduation across the Plains in the character of the

[1] The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 576.

vegetation corresponding to the gradual failure of humidity, which in the subhumid belt has developed a universal, close-knit sod. Sod appears to be a most effective covering, while bunch grass, or grass of the same variety or varieties, growing in tufts, affords virtually no protection at all.

Thus the High Plains, of unconsolidated material, above grade, and exposed to a considerable precipitation, are held by their sod. The tufted growths of bunch grass and light "brush" of the arid zone fail almost completely in protection because they do not constitute a continuous cover; and sod, on the other hand, is completely effective, not because it resists the erosive work of well-developed drainage, for that it can not do, but because it prevents the initiation of drainage. It is effective against the first faint beginnings. The great plateau surfaces of the High Plains have to show no systems of drainage, because, presumably, from the commencement of the present erosion stage they have been sod covered, as at present. In other words, the High Plains have endured as alluvial plateaus since Tertiary time, or at least since the opening of the Pleistocene.

While degradation is at a standstill upon the plateau surfaces the topographic belt which they constitute has, however, been appreciably narrowed within the corresponding climatic belt by marginal recession. The limiting bluff, especially that facing eastward, is carried backward by sapping on the part of small streams, or feeble beginnings of streams, originating in springs and "seeps" at the bluff foot. These springs are points of escape, or drainage off, of the upland ground water, which in turn has its origin in the upland precipitation. In this indirect way, by marginal attack, a small percentage of the local precipitation of the plateau areas slowly accomplishes a small degree of degradation. The narrowing of the plateau belt proper within the subhumid belt and the sharp delimitation of the plateau areas along their western edges are due to this action.

But these plateaus, none the less, are essentially ephemeral forms; vegetation is not of sufficiently vigorous growth to hold upon arroyo slopes after the arroyos are once established. As soon as the sod is cut through, the flat plain almost immediately vanishes and a bad-land topography of unclothed dirt slopes is quickly developed. In humid lands vegetation in a measure preserves slopes, in spite of the heavier precipitation, because the vegetation itself is heavier, and a characteristic topography results.

GEOLOGIC DATE OF THE BUILDING.

The date of the building of the great débris sheet, so far as included fossil remains would seem to determine it, might range anywhere from middle Tertiary to early Pleistocene.[1] However, the beginning

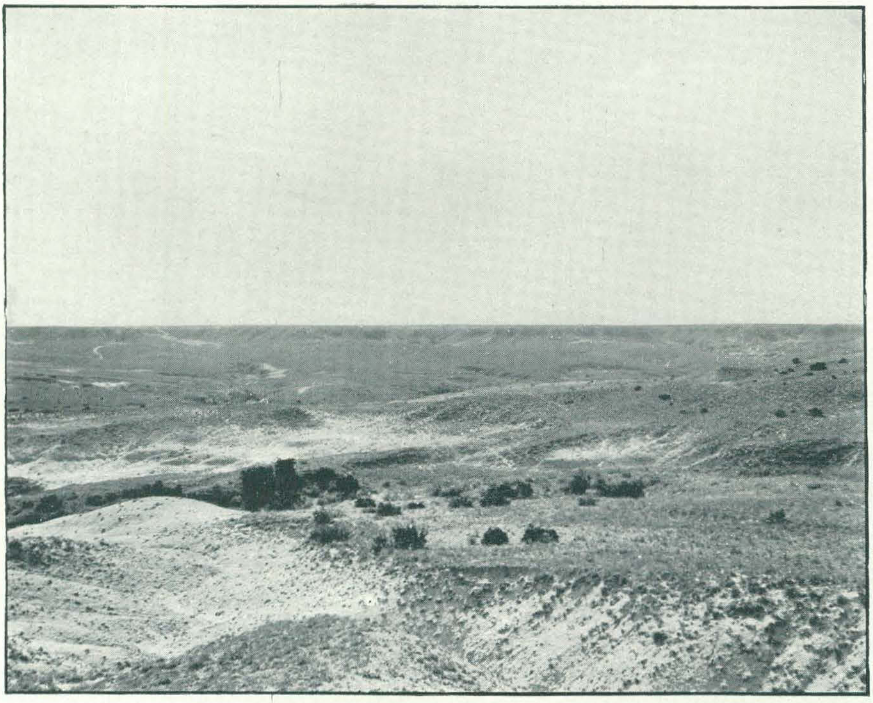
[1] Physical properties of the Tertiary, by Erasmus Haworth: Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 280.

of the final and present degradation stage, during which the smoothness of the Great Plains has been in large part destroyed and their surface lowered, with exception of the sod-covered plateaus of the central zone, doubtless dates from the opening of that period of climatic oscillations in the Pleistocene which, in the Great Basin region of Utah and Nevada, gave rise to repeated floodings of large areas and the creation of lakes. Indeed, it is not unlikely that the grading of certain of the minor plateau surfaces of the High Plains, which stand appreciably below the general level, is to be correlated with the several returns in the Great Basin to severe desert conditions during this period, which also are plainly recorded among the old lake evidences.

This alternate flooding and drying out of areas of interior drainage in the Arid Region to the westward is apparently to be regarded as the desert equivalent of the alternate occurrence and fading away of continental glaciation to the northward and of local mountain glaciation in the Sierra Nevada and the Rocky Mountains in even latitudes. In other words, there was in the Arid Region during the Glacial period no accumulation of snow resulting in glaciation except upon a few of the higher mountain summits, but there were large accumulations of water in the western part of that region wherever opportunity for accumulation was afforded. That is, wherever in the Arid Region there was failure of outlet seaward, there was ponding or the development of inland water bodies; not continuously, however, as the record shows, but in a succession of relatively humid epochs.

It does not necessarily follow that these were epochs of increased precipitation. The change may have been one of temperature only, lessening evaporation. Probably in some degree there were both decrease of evaporation and increase of precipitation; but in either case there would be, in effect, a more humid climate, and the streams upon the delicately graded plain eastward of the Rocky Mountains would become correspondingly invigorated. Lessened evaporation alone would result in their invigoration equally with direct increase of volume by increased precipitation, for they would be taken up less rapidly by the porous ground. They would therefore carry their load farther and equilibrium would be disturbed in favor of degradation. They would be affected in the same way by direct increase of volume at their headwaters; that is, by change of climate toward greater humidity the gradation plane would be lowered and degradation of the old plane would result. It is therefore to be inferred that while the interior basins to the westward (in the Great Basin region) were being flooded the sloping plains to the eastward (the Great Plains) were being channeled by streams of increased vigor.

The erosion might, of course, have been brought about by deformation alone, increasing the eastward inclination of the Plains and thereby giving to their streams greater velocity. But not only would



A. EASTWARD-FACING ESCARPMENT OF HIGH PLAINS.

B. COARSE GRAVEL AT FOOT OF ESCARPMENT.

the explanation by climatic change be adequate; the Pleistocene lakes of the Great Basin afford evidence that such climatic change or changes actually took place. Furthermore, from this same lake record the inference is strong that there was freedom from earth movement meantime. For example, these inland water bodies (several of them approaching in dimensions those of the Great Lakes) as a rule did not overflow their basins, from which it appears that no actual reversal of climate occurred, but only a mitigation of desert conditions. Failing of outlet, they fluctuated in level, with numerous pauses, responsive to the fluctuating climate. As a rule these pauses, corresponding to intervals of climatic stability, were brief, but at certain levels they had great duration, as evidenced by a notable shore topography of embankments and cliffs remaining to the present day. And yet nowhere in this system of far-reaching shore lines, covering in their time record probably the whole of the Pleistocene, is there material departure from parallelism, indicating earth movement.

The destruction of the old surface, of which the High Plains are a belt of great fragmentary survivals merely, began, then, with the opening of the Pleistocene. That the spreading of the mass occurred at an earlier period than this appears from the abundance of included Tertiary fossils. The fact that there are Pleistocene fossils also is intelligible on the assumption that during the return to arid conditions in the Pleistocene, evidenced by the drying away of lakes in the Great Basin, and probably corresponding to the "interglacial epochs," there was resumption of stream building and refilling of valleys. It is improbable, however, that all of the damage was ever wholly repaired.

Hence, with a few small exceptions at slightly lower levels, the High Plains are Tertiary in the date of their building. They were blocked out in plateau fragments in the Pleistocene; but it would seem there can be little question that their alluvial surfaces are survivals, without sensible change, from as long ago as the beginning of the Pleistocene.

To summarize, then, the Pleistocene is defined as beginning with the first continental ice invasion. Here certainly was marked climatic change. The Great Basin ranges, the Sierra Nevada, and the Rocky Mountains responded to it. They bear record of oscillating glaciation. The basin deserts are marked with the shore lines of lakes of fluctuating level, and here and there the record by glacial moraines is interwoven with that by lake shores. In other words, there was increased stream flow from the glaciated mountains draining into the basin deserts. At the same time there must have been increased stream flow from the glaciated mountains draining across the eastern plain. This plain shows evidence of extensive stream dissection of an originally smooth surface; and as it can hardly be doubted that mountain glaciation throughout the Arid Region was synchronous with the general glaciation of the northeastern humid region, it follows that the beginning of the Pleistocene found the Great Plains slope a smooth surface of soft material.

STREAM DEPOSITS *v.* STILL-WATER DEPOSITS.

This mantle upon the eroded marine-rock sheets is sometimes referred to as the Plains Tertiaries; sometimes, also, as the Tertiary "gravels." In the former of these two designations there is implied subdivision into subformations, or successive widely extended individual beds. Origin by deposit in still water is assumed. But there are no such beds—at least of original structure. There is suggestion of them in the so-called "mortar beds;" but, as will be shown later, these mark cementation levels merely, recording fluctuations of the ground-water plane corresponding to pauses and reversals during the general degradation. In the latter designation—of "gravels" for the mass as a whole—there is recognition merely, on the part of those who have observed the fact, that there is mingled with the heavy accumulations of silt and sand a notable quantity of coarse material.

Until quite recently, however, there has been no serious consideration of the possibility that the Tertiary mantle might have had origin in stream building. There has been no attempt to account for the presence of large gravel in wide distribution. The whole accumulation has been regarded as made up of lake deposits. It is in the main, to be sure, of fine material, as indeed any far-spread fluviatile accumulation necessarily is; but it has been wrongly assumed to have the regular bedding of lake deposits—even of lakes of shifting shore lines; and until recently there has been no recognition, except so far as implied in the term "gravels" applied to the whole mass, that the occurrence everywhere in some degree of coarse material at least renders the general explanation of origin by deposit, in still water, complex and difficult.

The latest statements of the lake-deposit explanation, in which that view was presented without qualification, appeared in 1895. In a paper on Semi-Arid Kansas,[1] Professor Williston describes, first, an uplift, followed by erosion, during which the floor topography was given shape; second, a reverse movement, resulting in "a series of extensive fresh water lakes extending from Dakota to Texas," in which deposits of débris from the Rocky Mountains were laid down; and, finally, uplift again, with erosion of the lake floors, "leaving on the uplands an immense area of remarkably flat lands with a gentle inclination toward the east." And Professor Hay, in a discussion of the water resources of northwestern Kansas and adjacent territory,[2] indicates a belief not only that the deeper accumulations, well out from the moun-

[1] Univ. Kansas Quart., Vol. III, No. 4, 1895, pp. 213–214.
[2] Sixteenth Ann. Rept. U.S. Geol. Survey, Part II, 1895, p. 569.

tains, are lacustrine, but refers to indications even "that the Tertiary lakes extended into the mountain valleys."

As already pointed out, the trend of the buried ridges and valleys is fairly in accord with the run of the present streams. Hence, on the assumption that burial was accomplished in standing water, there must have been either regional subsidence to a general level or repeated and shifting local deformation; and, whatever the nature of this disturbance of grade from an inclination giving something like 1,000 feet of rise in 100 miles down to a level condition, there must have been recovery from it at the close to virtually the original grade, as seen in the Plains at present. In short, the vertical movements appealed to must have been of vast magnitude, and widely extended.

The evidences directly exclude marine origin; they only indirectly indicate origin in lakes, and they do not exclude stream building. It is because such deep accumulations, far distant from any field of erosion, have heretofore been taken as necessarily indicating still-water deposit, that they were assumed to be lacustrine. They could not be marine, since the included fossil remains are of land animals.

Determination of the question should be possible from detailed examination of the structure of the mass, especially of the distribution and arrangement of its coarse material. The importance of the existence of gravel—even the fact of its existence—at all levels has not been generally recognized.

WIDE DISTRIBUTION OF THE GRAVEL.

Where there is no erosion of the surface there is no gravel at the surface. The eroded areas of the Plains Tertiary here and there show superficial gravel; the High Plains surfaces do not. They have a hard "adobe" soil—except where, over comparatively small areas widely separated, it is covered by drifting sand. But well sections, canyon sections, and the shallow beginnings of erosion at the plateau edges occasionally show gravel close to the surface. All sections, artificial and natural, whether near to the mountains or far out, show a no less frequent occurrence of it at one level than another. Nor is there observable any graded variation in the size of the gravel, up or down, in section. There is gradual diminution in size from the mountains outward, but the rate of this diminution seems to be the same at all levels.

SIZE OF GRAVEL IN THE HIGH PLAINS BELT.

The maximum size of gravel in the High Plains belt is that of cobbles. Material so coarse as this is quite uncommon; yet from northern Kansas to the southern limits of the Staked Plains of Texas the writer has occasionally found beds of cobbles, and no more frequently at one level than another, though seldom, as we have seen, any coarse material actually at the surface, upon the uneroded uplands. Individuals of larger size—bowlders—are here and there to be found. As a rule these are not thoroughly rounded; they are of the nature of erratics, and probably have been transported either by river ice or in uprooted trees, and they may be of the softer rocks, such as sandstone, while invariably the gravel in beds is hard.

But though bowlders and beds of cobbles are rare, in sections of the High Plains, smaller material, which would still be regarded as coarse gravel, is comparatively abundant.

THE GRAVEL COURSES.

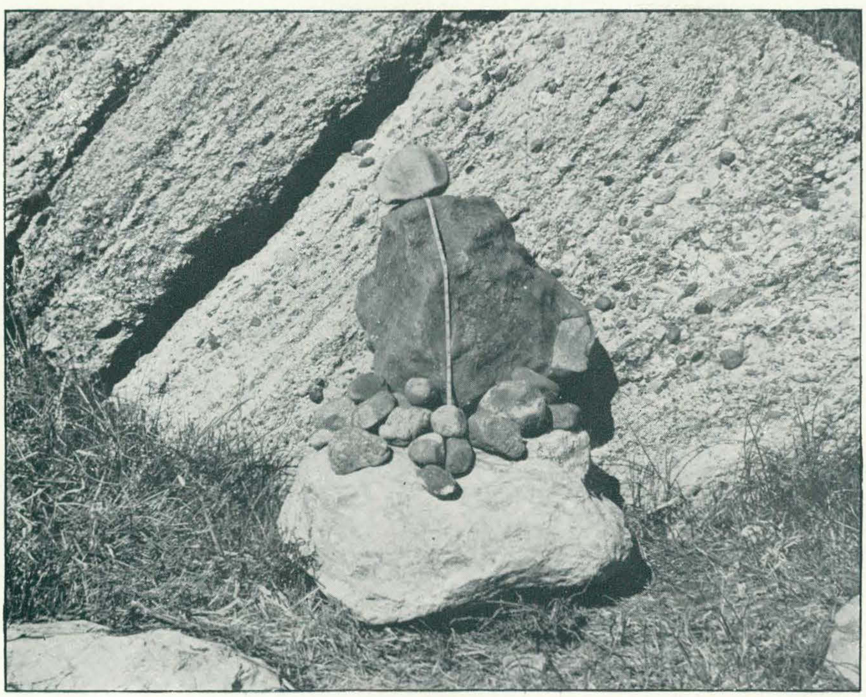
At several localities within the High Plains belt, where natural sections are afforded, the writer has been able fairly well to determine the outlines of gravel beds, and invariably these have been found to be greatly elongated in the direction of the slope of the Plains, or approximately in that direction. Also, they are prevailingly cross bedded. In short, they plainly mark the channel courses of eastward-flowing streams. The valley or broad canyon of the Canadian—a mountain stream limiting the Staked Plains on the north—has several short tributary canyons, affording north-south sections. In the walls of these tributary canyons it is apparent that the beds are cut across, while along the side walls of the main valley they are exposed longitudinally, for in the latter case they are relatively very long.

Immediately to the eastward of the High Plains, in the eroded area of the Tertiary, such exposures often are numerous. The gravel courses can then be made out somewhat definitely. In some instances they are thus closely traceable, with their branchings, for several miles. Where the erosion is not of the bad-lands type—that is, where divides are broad and slopes gentle—differential washing will sometimes result in a superficial accumulation of gravel, so that wagon wheels grind upon it as though running upon macadamized roads. These superficial gravel areas also are spaced apart, in north-south order, as belts extending eastward; and they will each be found to cover, not a continuous bed of gravel of equal breadth, but a net of gravel courses, with the meshes drawn out long in east-west direction. Pl. CXVIII, *B*, illustrates the character of the ground surface over a belt several miles in width, beginning at the foot of the uplands at the head of Pease River, Texas, and extending eastward fully a dozen miles. In the much broader areas of fine material, between the belts of surface gravel, well sections and canyon sections often here and there develop gravel beds again at various depths.

SAND BEDS AND "CLAY."

Of the sand, as of the gravel, it may be said that it is disposed in beds with eastward elongation, only the sand beds are deeper and broader. The gravel courses are interwoven through them.

A. SURFACE GRAVEL IN ARROYO ON STAKED PLAINS.



B. COARSE GRAVEL IN "MORTAR BED."

Yet gravel and sand together constitute much the smaller part of the total bulk of the Tertiary accumulation. Very fine material (the barren "clay" of the well maker) constitutes the body of the mass, through which the coarser materials are extended in layers at varying intervals and of varying thickness. The well maker should understand this complex structure, and should recognize that, while the occasionally embedded masses of coarse material, from which alone water is obtainable in appreciable quantity, are not continuous geological "formations," they are nevertheless not mere "pockets," but have extension in a constant direction and often may be easily followed with lines of wells.

LARGE GRAVEL NEAR SURFACE NOT OPPOSED TO HYPOTHESIS OF STREAM BUILDING.

It might at first sight appear that in the building up of a plain to a graded slope of stream equilibrium throughout there would be gradual diminution in the velocity of stream flow as the rate of building lessened and the slope of equilibrium was approached, because grade would be gradually lessened also. But grade would be lessened only in a narrow zone at the beginning of the slope; over the remainder it would be increased.

Every stream has its upper region of erosion and its lower region of building. In longitudinal profile normally it is concave, concavity

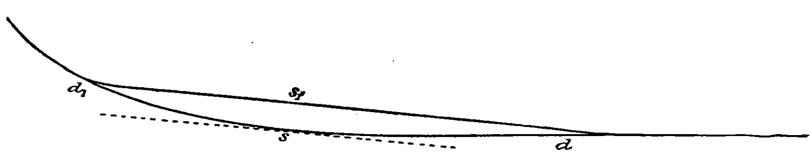


FIG. 302.—Flattened grade profile of stream, after change from degradation to aggradation.

being pronounced toward the head and slight toward the foot; that is, there is flattening in the region of unloading. Hence, if, without earth movement lessening declivity, but as a climatic effect solely, a stream have its point of change from degradation to building shifted backward, the portion of the profile thus affected will have its concavity flattened by filling in, as in fig. 302. Yet, though flattened—i. e., changed from a hollowed profile to a straight one—the new profile, through the greater portion of its length, will have a steeper inclination than the old one had. If, for example, in the figure, the point where deposit begins (or where ultimately it will begin under completely readjusted conditions) be shifted back from d to d_1, the new slope will have less inclination than the old one down to a point s_1; but below that point it will have greater inclination. Also, the new perfected slope will not be reached by accumulations beginning at d_1 and gradually extending outward, with diminishing grade, as in fig. 303, but by accumulations beginning at *d* and gradually extending backward with increasing grade to d_1, as in fig. 304. A graded slope is finally reached and building comes to an end, not because the stream has failed in transporting power and runs clear, but because with declivity and velocity of flow increased to a point where the constant supply of mountain débris ceases to be an overload, it no longer deposits, or at least it alternately deposits and picks up again equal amounts.

As already shown, cessation of work is not absolute. The apparent stability is relative only. There is lengthening at the foot, and slow backward building; and there is slow lowering at the upper end in the

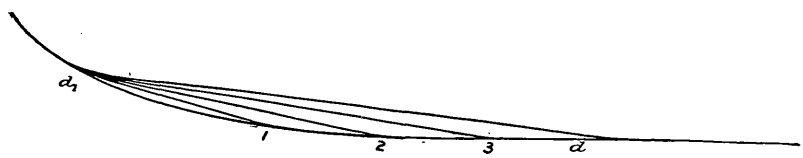


FIG. 303.—Successive grade profiles in the building of an aggradation plane. An incorrect representation.

region of erosion. But in the middle course, along the slope in the main, and, of the Great Plains slope, that portion in which the plateau fragments of its old surface are situated, there is attained virtual stability of position in comparison with the previous rapidity of building from the abandoned grade of equilibrium up to the new one.

Thus building results from stream feebleness, or from imperfect transportation of load; and it ceases when, with continual increase of declivity, the stream finally has become equal to full transportation. Hence, at any given distance out upon the rising plain, there will not necessarily be, as might at first sight appear, gradual decrease in the

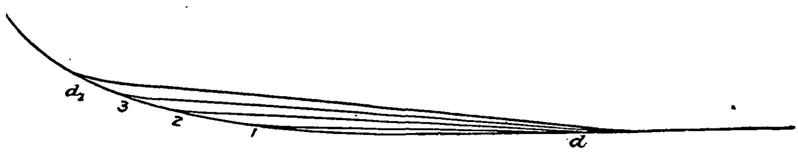


FIG. 304.—Successive grade profiles in the building of an aggradation plane. A correct representation.

size of material carried and deposited. It would seem rather that there should be increase, and that the last addition to an aggradation plain would exhibit the coarsest material. There is another factor to be taken account of here, however. With the rise of the surface, and its increasing inclination at the same time, as shown in fig. 304, there is retreat upstream of the point at which subdivision of flow begins, so that while velocity of flow is increased, volume of flow, with each individual channel, is notably diminished. This is a quantitative factor and can not be evaluated. Until it became extreme the effect of shallowing would be slight, while the effect of increase of velocity would at once be marked. At least it is not against the hypothesis of origin by stream building that the mass shows equally coarse material at all levels.

INCREASE DOWNWARD IN THE SIZE OF BEDS OF COARSE MATERIAL.

It is generally held by well makers that the heaviest beds of coarse material lie near the bottom. This is the view also of Professor Hay, only he goes so far as to divide the mass into two distinct formations—a lower one, the "Tertiary grit," made up largely of coarse material, and an upper one, the "Plains marl," containing no coarse material.[1] He says of the thickness of the marl that it "varies from a few feet to 200," leaving to the grit a much greater average thickness, and sometimes the thickness nearly of the whole.

To the southward, in the High Plains belt, as a rule there is deeper erosion on the part of the eastward-flowing streams than to the northward. The Cimarron, the Beaver, and the Canadian rivers, as well as several lesser streams to the eastward, which have extended canyons into the Staked Plains by headwater recession, have cut through the Tertiary into the floor for greater or less distances—the Canadian across the full width of the belt—exposing complete sections. There are also a few exposures of like character in northwestern Kansas. From examination of these sections, here and there where they are clearly displayed, it appears to be a fact, as the well makers maintain, that there is increase in the size of beds downward. While the beds do not carry larger material at the lower levels, they are thicker and broader there and are more easily traceable. At the same time, however, they are farther apart. It does not appear, therefore, that there is appreciable difference in the total quantity of gravel from level to level; the net of interlacing courses merely is finer and closer above, heavier and more open below. If there is, in fact, as extended field observation seems to indicate, any general law of thickening of beds downward, there are occasional important exceptions to it. At horizontally wide intervals thick beds occur in the upper levels.

Decrease in the size of channel courses, in rising order, together with increase in their number, as with these gravel beds, should follow in the building of an aggradation plain as a consequence of the progressive shifting backward of the point at which stream subdivision begins. But not only is the dry-climate stream periodic in flow, it varies greatly in volume as well, and, like all streams, at long intervals it is subject to exceptional floods. In the case of a plain of rising grade, the effect of the exceptional flood will be correspondingly to advance again the point at which subdivision begins, and to erode for itself upon the plain a broad and shallow trench. That is, there will

[1] Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, pp. 569-570.

be concentration and trunk flow for the moment, but concentration will be imposed upon the normal flow for a time thereafter, until the trench is refilled. Thus, also, the occasional east-west belts of relatively heavy interlaced beds, above referred to as occurring in the upper levels, exposed by erosion, are explainable on the hypothesis of origin of the whole accumulation by progressive stream building. Furthermore, they at least are stream courses unmistakably. Therefore the supposition of lacustrine origin for the bulk of fine material which they penetrate becomes a violent one, since it is necessary to assume repeated deformations, back and forth, from a horizontal position of the plain, affording opportunity for the thick silt accumulations, to a sloping one affording opportunity for stream work

STRUCTURE IN THE FINER MATERIALS.

But the bulk of fine material which the gravel courses penetrate is not wholly structureless. The gravel courses illustrate, in a conspicuous way, a type of structure which is often to be detected in the heavier sand beds also, and which seems to be characteristic especially of the innumerable minor streaks of sand.

Well makers insist on the frequent occurrence, within the limits of the High Plains belt, of deep and widely extended masses of clay. These are to them barren grounds. Under the general term "clay," however, they include indifferently all fine material, even clean sand, if very fine and interbedded thinly; and this fine sand, where the clay masses are exposed in section, will commonly be found to be disposed, not in broadly spread sheets, but in innumerable disconnected streaks, long also in direction of the general slope, like the gravel courses. No account is taken of these, since their water-bearing capacity is insignificant. They carry (below the water plane) unimportant "veins" of water only. With the first settlement of a neighborhood, and the beginning of well sinking, it will sometimes happen that there will be outlined an extensive barren tract, or clay mass. As within its limits the number of wells increases, however, and especially as the depth of sinking increases, as a rule gravel will be encountered here and there at varying depths. Nevertheless, broad and thick sheets of clay do occur, and such accumulations must be deposits from virtually quiet water.

An elongated clay mass is described by Prof. Erasmus Haworth as occurring near Garden, Kansas, close to the surface, and extended in an east-west direction.[1]

Such an oblong lenticular mass lies to the north of Garden, along the north part of the Arkansas River Valley. Here, for a distance of 4 to 6 miles along the river, is a narrow strip lying just back of the river valley proper, beneath which the clay

[1] Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 274.

exists from 75 to 100 feet in thickness. Many attempts have been made to obtain water in this particular area by different citizens, each of whom has usually abandoned his well because it was known that only a short distance either north or south water could be found in the sand beds at comparatively shallow depths, while if drilling was continued in the clay area a depth of 100 feet or more would have to be passed before water could be reached. The clay beds by no means are confined to such lenticular masses, but frequently appear as thin masses of clay spread out between layers of sand or gravel.

The writer made especially careful examination of this particular clay mass, by means of trial well borings, to determine its dimensions. While from the well maker's point of view there is barren ground of about the area and depth given by Professor Haworth, it is made up of a closely assembled group of elongated clay beds separated by thin sand beds and occasionally by fine gravel. In a single instance only was pure clay for any great depth encountered, and this depth was 46 feet. At many points upon the High Plains, however, deep borings have encountered clay through the full thickness of the Tertiary, interrupted at wide intervals only by thin sheets of sand. Often in such cases other wells in east-west order for several miles will get much the same disappointing results for considerable depths, while, on the other hand, at relatively short distances in north-south order gravel in thick beds may be found both near the surface and alternating rapidly with sand and clay to the bottom.

The clay bodies, especially considering their lenticular, east-west form and arrangement, are not opposed to the hypothesis of stream origin for the entire mass. Fluvial building, as may be observed in the case of all great rivers which have extensive flood plains—notably, for example, in arid lands, the Colorado below the junction of the Gila—proceeds over broad areas mainly by silt deposit, with sand in diverging and subdividing bands, while gravel is to be discovered only in freshly uncovered channels or occasionally interbedded in their banks.

In short, the Tertiary mantle of the Great Plains slope has the character of river deposits everywhere—i. e., in the main, a mass of silt, penetrated with sand and gravel in linear arrangement, but in lines slightly divergent and crossing—and the coarse material is of so frequent occurrence that the whole loose accumulation is sometimes referred to as the Tertiary "gravels."

CEMENTATION.

The mantle is not absolutely loose and unconsolidated. As a whole it is feebly cemented, mainly with carbonate of lime. The cementation is slight, however, not because lime in this form is present only in small quantity—it is, in fact, abundant—but because, as a rule, it binds feebly.

Of the nature and occurrence of this cement Professor Haworth says, speaking of the Tertiary in Kansas:[1]

The cementing material of nearly all the Tertiary sands and gravels * * * is calcium carbonate. A few exceptions are known to this rule. There is a sandstone near Long Island, in Phillips County, which is so firmly cemented with silica that a rock similar to quartzite has been produced. On the uplands north of Stockton likewise a silicious cement has been deposited between the grains of sand, producing a rock which is quite like quartzite. Near the Saint Jacob's well, in western Clark County, silicious cement has been deposited between the grains of sand, forming a close-grained rock. But throughout the Tertiary area of the State, with these few exceptions, wherever the sand and gravel are held together by any kind of cement it seems to be calcium carbonate. * * * The degree to which this cementation is carried is astonishingly great.

Carbonate of lime, visibly present, is an almost invariable characteristic of the desert plain—a sign of aridity. All streams carry rock materials in solution, as well as a visible load in suspension; and commonly they are more or less "hard" with dissolved calcium carbonate. But only desert streams deposit this chalky material upon their waste plains in appreciable quantity. The desert stream, not running upon ground already saturated, like the stream of humid lands, is in consequence, as we have seen, dwindled in large part by ground absorption; but nearly complete evaporation will occur where, by thin flooding over earlier broad silt deposits and by flood subsidence, it is left in slack-water sheets. Issuing from its headwater region sensibly fresh, the desert stream in time, upon its waste plain, by evaporation and concentration, becomes barely drinkable. Its final disappearance is characteristically marked by the appearance of a white incrustation; and immediately following complete desiccation there will be arrest and return, by capillarity, of some portion of the downward-soaking water, with addition of its solution load to the surface deposit and to a shallow subsurface deposit.

The intermittent, shifting stream, at a later period running in full volume where before it had run but feebly, will tend by re-solution to pick up this incrustation and carry it forward to more porous ground, where, by deep penetration, it will be contributed to the impurities of the ground water. But the calcium carbonate—making up originally a small part only of the load in solution—will resist re-solution. The chemistry of desert deposits has not been fully worked out. Lime carbonate is insoluble in pure water, but is dissolved by the addition of carbonic acid. This, in small degree, rain collects from the atmosphere. Lime is widely diffused in nature, and presumably, therefore, streams, which have their ultimate source in rain, quickly load themselves to their full capacity, as measured by the carbonic acid present. Hence desert streams reach the waste plain charged with carbonate of lime to their full capacity. Of this chalky material, they can not pick

[1] Univ. Geol. Surv. Kansas, Vol. II, 1897, pp. 267-268.

up, in solution, what had been evaporated out from the scattered fringe of previous flows. That which already had been deposited will remain—so far at least as stream action is concerned—and by repetition of the process there will be accumulation.

But the water of local rainfall may pick it up, and in powdery form its solution will be easy. In so far as local rain reaches to the ground water, some lime carbonate will be carried there. The remainder will be deposited, as before, both at the surface and at a slight depth beneath. Beneath the surface, however, there is everywhere observable a marked tendency to take on the character of root-form concre-

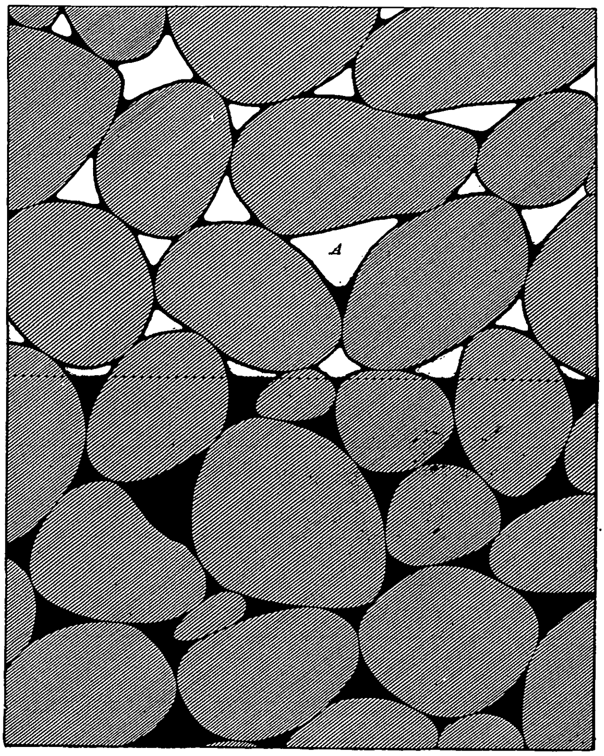


FIG. 305.—Capillary water.

tions, and in this hard form rain water in its brief downward passage will have greatly lessened effect upon it.

Thus it would seem that, in the upward building of an aggradation plain in an arid climate, the building of lime into the mass must necessarily follow as a consequence of aridity. And cementation, in some degree, should follow as well. By interference and union of the lime concretions the ground will be knit together. Frequently, in fact, such knitting is conspicuous.

Furthermore, to some extent individual grains of the groundmass should become coated, and at their points of contact stuck together, as an effect of deep drying. Everywhere, as a rule, there is feeble binding of this character. Deep drying and slight cementation should result as follows:

The ground is merely moistened, as water soaks downward, until some impervious stratum or floor is reached; thereafter, by accumulation, it becomes saturated; i. e., the openings between its grains become completely filled, as shown in solid black in fig. 305. The upper level of saturation by accumulation is the water plane; but even below the influence of capillarity not all of the downward-soaking water will reach the ground-water accumulation. All the way to the water plane a portion will remain behind to wet the grains of the porous ground and partially fill the voids, as at *A* in the figure. That is, every grain of sand, silt, or gravel will detain and hold a film coating of water by adhesion until the interstitial air has taken it up by evaporation. For example, if a box with perforated bottom and deeper than the lifting reach of capillarity be filled with sand, and water in considerable quantity then be added, not all of the water will in time escape at the bottom. Some portion will be removed by evaporation. After dripping has ceased the sand will still remain wet, and will continue wet until dried by evaporation.

In nature this process must result in surface deposition, around grains, of the mineral matter previously in solution in the coating film of water. As upon a larger scale at the surface, partial re-solution, leaving lime only, will follow with the passage downward of an excess of water after subsequent stream runs and after rains. By repetition and the continual separation out of lime carbonate, grains will come to have an appreciable coating of that mineral, and at their points of contact their coatings will be continuous one with another; in other words, there will be cemented union. An ultimate effect would be the filling of interspaces as well—i. e., complete consolidation of the mass.

But as yet, in the Plains Tertiary, consolidation has progressed only so far as to be just appreciable in the mass, as a whole. It is appreciable to the well maker, in that it is not necessary, as a rule, in dry ground, to wall up dug wells, even where, as sometimes happens, the water plane lies at a depth of so much as a hundred feet. Nevertheless, by contrast with the marine rocks beneath, the Tertiary is a relatively porous and loose accumulation upon a hard-rock floor.

Thus the sloping desert plain in a measure performs the same office toward the streams which scatter over it, and in part are dried upon it, as the desert lake without outlet performs toward its entering drainage. The latter receives from its tributary streams, and retains, their very light burden of dissolved mineral matter; and in time, with removal by evaporation of water in amount equal to the inflow, leaving that matter behind, it becomes heavily charged. In like manner the débris slope separates out and accumulates carbonate of lime. By continual deposit upon the surface during growth of the mass, and by continual redistribution downward, the whole mass in time becomes impregnated and its grains stuck together.

It should not be overlooked that some proportion, large or small, of the free lime which is so characteristic of the desert plain doubtless originates in place, by decomposition of the already finely subdivided groundmass, just as, in the headwater region of the streams, there is decomposition of rock materials after their mechanical disintegration by frost action and by sharp variations of sun heat. The agent, in the one case as in the other, would be the local rainfall, carrying solvent carbonic acid. We have to consider here a rainfall relatively very feeble; from it almost wholly the ground water is accumulated, because drainage away of the ground water is exceedingly slow; but often it will fall too feebly, or upon ground too difficult of penetration, to escape complete evaporation before it reaches the plane of saturation. Along the temporary course of a shifting, intermittent stream the local rain, as already pointed out, will find stream-deposited lime ready at hand; but after the stream has for a time taken another course this deposit will become washed out, and subsequent rains will occupy themselves in decomposition to an appreciable extent of the ground materials, so far as they may prove to be readily soluble.

To this local decomposition Professor Haworth is disposed to ascribe in notable degree the occurrence of free lime in desert accumulations.[1] Doubtless there is much chemically decomposable matter in the silt of a débris slope, but the larger particles, including the finer sand, of which there is a large body, is mainly siliceous and insoluble.

THE "MORTAR BEDS."

To the rule of feeble consolidation of the mass as a whole, however, there are striking exceptions. Standing out as horizontal ledges on valley slopes, with the comparatively loose material both above and below, and to be encountered also in well sinking, are sheets of comparatively hard rock. In composition and structure, except as regards the presence of cementing material, they in no way differ from the rest of the mass. They are of silt, sand, and gravel, and their cement is carbonate of lime. They are, in fact, sheets of sandstone. But their included lime is so conspicuous a feature that they have been termed by Professor Hay "mortar beds."

The mortar beds are to be met with in well boring at all depths. Though horizontal, or having the inclination merely of the general slope, they are rarely to be encountered over any considerable area at equal depths or in equal number. That is, they are not widely

[1] Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 270.

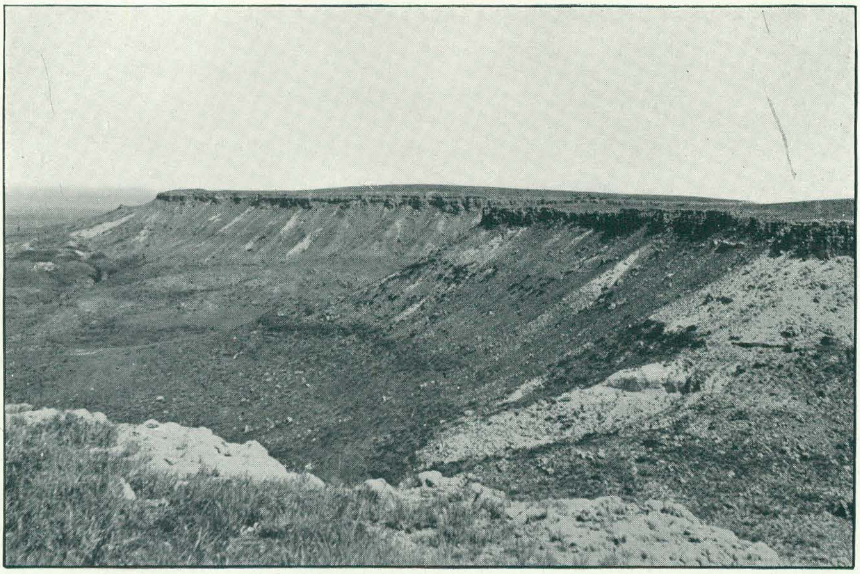
extended "formations." Furthermore, their coarse sands and their gravel commonly show strongly defined cross bedding; and sometimes, in natural section exposures, this cross bedding will be found to be continuous through them, out of soft material above, into soft material again below. In other words, they are not lake beds, nor even beds of original structure, but cementation levels. Apparently they mark fluctuations of the ground-water plane.

During the third stage—the present erosion stage—of stream work upon the Great Plains erosion has not been uninterrupted. There have been pauses, and, in some degree, returns to building, with refilling of valleys. The ground water is only relatively motionless; it has slow seepage movement; but given a graded condition—i. e., adjusted as to slope—of the débris mass through which it is extended, its upper surface will stand motionless, or virtually so, having slight seasonal fluctuation only, because its loss by seepage is compensated by periodic additions from the local precipitation. The position in depth of the ground-water level (strictly a slope), like the level of a lake without outlet, is determined by adjustment between loss and supply.

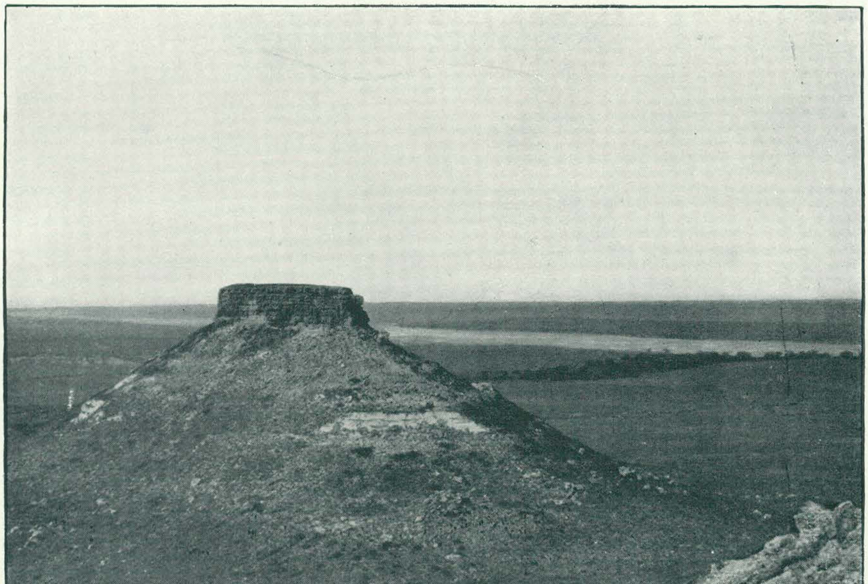
Given, then, stability of climate, with graded stability of the ground surface, the water plane will hold a slightly oscillating position at a depth representing balance attained and maintained between drainage off of the ground water and annual replenishment of it from above. Hence, change of climate toward greater humidity, resulting in progressive dissection of the sloping plain by its traversing drainage, will result also in corresponding lowering of the ground-water level; just as artificially, on a small scale, the ground water is lowered by ditching in marshy ground. But a pause in this process would bring the water plane again to a stand; and reversal, with valley refilling, would raise it.

The old lake evidences of the Great Basin bear record, not only of long progress toward more humid conditions, but of many pauses, long and short, during that change, and of many temporary reversals. And apparently the gently inclined cementation sheets of the Great Plains slope are the corresponding record of like changes there. It is at least clear that they mark cementation planes merely, and are not beds of original structure, since their upper surfaces show straight lines intersecting structure.

But while it thus appears that the process of consolidation has in the main been sharply localized along occasional horizontal planes within the mass, and while also it is hardly to be questioned that the water plane, for considerable periods at a time, has stood virtually motionless at various definite levels, so that a causal relation between a succession of water levels and the succession of cementation levels is reasonably to be inferred, nevertheless the explanation of the maximum



A



B.

MORTAR-BED TOPOGRAPHY AT MARGIN OF HIGH PLAINS.

consolidation along a water level is not apparent. The mortar beds are not merely zones in which the contained lime, common to the mass as a whole, has taken on the character of cement more completely; lime is present in greater quantity as well. It does not appear that they received this excess by downward concentration out of the loose material immediately above, for there is no noticeable freedom from lime there. That there is in fact excess, however, is apparent from the abundant development of concretions, clearly to be noted wherever the mortar beds have extension through fine material. In such cases weathered exposures commonly show a knitted concretionary structure, lines of cross bedding, entering from the loose material, becoming confused and barely traceable. The process of consolidation here appears to be the same as elsewhere in the mass, only carried to an extreme.

There is progressive increase from north to south in the High Plains belt in the degree of cementation, and as cementation in general increases the mortar beds become more numerous. In northern Kansas they are encountered by the well maker as occasional thin sheets only; at the southern Kansas border they are distinctly more numerous and thicker, while in the Texas Panhandle they make up the greater part of the exposures in canyon sections. The erosion topography of the Tertiary gives expression to this change by increasingly sharp development of mesa forms southward. Apparently, also, individual beds become heavier. Since, however, these thick beds exhibit a pronounced horizontal stratification, with marked alternations of relatively hard and soft layers, it is probable that they represent merely a close crowding together in vertical order of many beds. This close grouping will sometimes attain a thickness of 50 feet. Where their lines are well defined their strict horizontality is marked also, but single lines very rarely have uninterrupted extension for so much as a mile. The grouping only, with vertical thinning or thickening, may continue far.

In apparent explanation of this interrupted extension along a single horizon it may be said that strong consolidation is rarely to be observed in the finer materials. Mortar beds are made up mainly of cemented coarse sand or gravel. Recurring to the assumption that they have origin in concentrated deposit at the water plane, the suggested explanation may be extended in this manner: The deposit is made from downward-soaking water, not from the ground water itself. It occurs in largest amount where the largest contribution from above is made, and a relatively small contribution will be made where the ground is relatively impervious.

It remains, as before stated, to explain the action we have here assumed. It is observed, for instance, that the mortar beds are flat and sensibly level along their upper surfaces; that they are most pronounced in coarse material, though often faintly traceable in fine, and yet that frequently they strike through these coarse beds, as indicated in the ideal section shown in fig. 306, leaving uncemented portions above and below. Coarse stream deposits rarely are uniform in thickness, since they are laid down in scour channels and are themselves in turn scoured in the process of the overplacing of other beds. And this disposition along level planes, with disregard of the complex gentle inclinations of structure surfaces, seems almost unavoidably to suggest standing water in the ground, at various levels successively, as the determining cause of deposition.

But as to how the ground water acts or is acted upon at its surface or water plane to bring about deposition, the writer has no explanation to offer. Professor Haworth suggests[1] that the mortar beds have resulted merely from the clogging, in time, of channels of free ground-water movement, the coarse beds constituting such channels. But this view does not take account of the fact that the cementation planes strike through the gravel beds with level upper surfaces, not occupy-

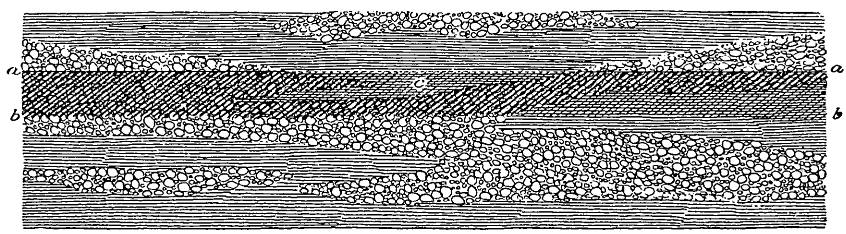
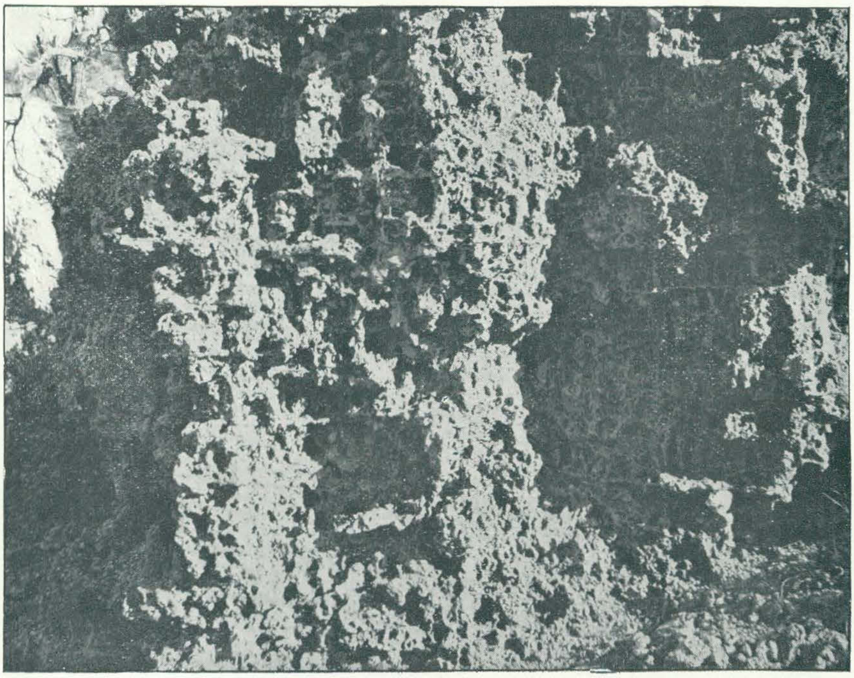


FIG. 306.—"Mortar beds" and original structure, in the Plains Tertiary.

ing their full thickness, nor that, on the other hand, the gravel beds frequently are free from cementation. Indeed, uncemented gravel courses are the main channels of circulation of the present ground water, so far as it has movement at all. At the same time they (coarse sand included) constitute the only ground of appreciable yield for wells; and since anywhere upon the High Plains, within a short horizontal range, yield to the well maker is practically assured at some depth, uncemented coarse beds must be of fairly common occurrence. It appears to be the fact that wherever along planes of cementation coarse material occurs, there binding has been sufficiently pronounced to produce "mortar beds," but that between such planes this open-textured material is rather more free from lime deposit than the fine.

There are several difficulties in the way of the supposition that the excessive lime accumulations of the mortar beds had their determining cause in fixed positions, successively, of the ground-water level. So far as they are exposed in natural section they are more or less in ruins, so that, as a rule, the level upper surface referred to is barely

[1] Univ. Geol. Surv. Kansas, Vol. II, 1897, pp. 270–271.



A. MORTAR-BED STRUCTURE IN SAND.

B. MORTAR-BED STRUCTURE IN SILT.

traceable. If the mortar bed represents secular lingering of the water plane at a general level, its thickness would seem to mark the vertical measure of the minor fluctuations of level at that position through short periods of groups of years. The upper surface would thus indicate an extreme range. It should therefore be of inferior hardness and durability. Possibly it is for that reason that it is rarely well preserved. Wherever any definite surface is even suggested, however, it seems to be level.

Finally, it is hardly more than to be inferred that mortar-bed formation is now in progress at the present water level. The inference merely seems to be reasonable. In this connection Professor Haworth says:[1] "In no instances known to the writer is the cement found in the same horizon with the ground water." He is here speaking of the records from a series of artificial sections—those of the "State wells" of western Kansas Presumably, however, he would not include in this statement his experience from observation of natural sections. At any rate, the present writer does not find that it applies generally. It will indeed rarely happen, in the case of well borings, that they will come upon the water plane in coarse material, for coarse material constitutes but a small part of the total mass. To be sure, from the well maker's point of view, it is in coarse material only that water is found at all. But he regards it as "found" only when it delivers freely. He takes no account of the water plane except as that plane is revealed by rise in his pipe, to a stand at some higher level, after the "vein" has been encountered. Virtually, anywhere in the Plains Tertiary, as shown, the well maker is assured of success at some depth, but he is not able to predict what that depth will be. Where in any neighborhood wells are bored close together, the depths to a suitable "flow" will greatly differ among them, though the pumping lift in all will eventually be from the same level. It would be rare fortune to the well maker to happen upon water in paying quantity—i. e., from coarse sand or gravel—precisely at the pumping level. Therefore, since it is only in coarse material, as a rule, that the mortar bed is formed strongly, there would need to be a large body of evidence to the contrary to destroy the probability that such beds are now forming where the present water plane and coarse beds happen to coincide in position.

But while the writer has no explanation to offer as to the cause of lime deposition at the water plane, the assumption that it actually does occur, and that the mortar beds have their origin in this way, is supported by the fact that it occurs elsewhere under what appear to be essentially similar conditions.

For example, carbonate of lime is deposited about springs of exceptionally pure water rising from the bottom of Lake Mono, a Great

[1] Ibid., p. 267.

Basin lake without outlet, heavily charged with mineral salts. An analysis of the water from one of these springs is given by Prof. I. C. Russell, as follows:[1]

Analysis of water from a spring in Lake Mono.

Constituent.	Gram in a liter.
Silica (SiO_2)	0.0178
Calcium (Ca)	0.0414
Magnesium (Mg)	0.0044
Potassium (K)	0.0088
Sodium (Na)	0.0513
Sulphuric acid (SO_4)	0.0546
Chlorine (Cl)	0.0144
Carbonic acid (CO_3) by difference	0.0991
Total	0.2918

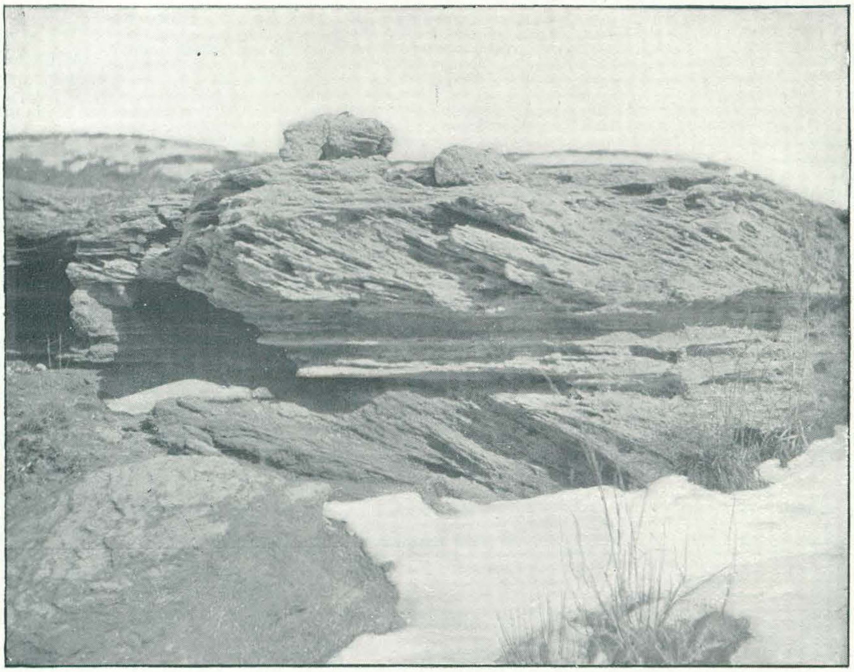
In "probable combination" Professor Russell gives: "Calcium carbonate ($CaCO_3$), 0.1035 gram in a liter." Commenting on these spring deposits, he says:[2]

At the western extremity of the lake are a number of springs, some of which are sublacustral. Two of special interest rise at the bases of tufa [carbonate of lime] crags at a distance of 20 or 30 yards from the lake. That they have been flowing for a great length of time seems evident from the fact that the tufa about them was deposited from waters issuing from the same orifices when the lake stood far above its present level. They are copious, each delivering perhaps 20 gallons of water a minute, but it was not practicable to measure their volume. They are clear and cool and evidently of exceptional purity. At the present time they are not depositing mineral matter. * * *

The positions of the springs rising in the lake near Black Point are indicated in calm weather by the eddies they produce on the lake surface. On rowing over these submerged springs we find that some of them rise from the tops of tufa crags which are covered by 10 or 12 feet of water. These crags are of the same character as those standing on the shore * * * and were formed by the deposition of calcium carbonate from the incoming waters. The submerged towers from which these springs issue are in some instances 8 or 10 feet in diameter and have a height of 20 or 30 feet. They are clustered in groups in the same manner as the tufa towers and castlelike masses mentioned above, which have been left exposed by the receding of the waters of the lake. Unlike the deposits that have been exposed to the atmosphere, their forms are unbroken, showing that the lake has never evaporated sufficiently to bring them above the surface or at least expose them for a long period. The upward rush of fresh water from the orifices in the summits of these sublacustral towers through the denser waters of the lake is in some instances sufficiently strong to deflect a boat when allowed to float over them. * * *

Other tufa domes similar to those we have mentioned rise above the surface of the lake near the shore. * * * They rise in water that is 10 or 12 feet deep to a

[1] Eighth Ann. Rept. U. S. Geol. Survey, Pt. I, 1889, p. 290.
[2] Ibid., pp. 289-290.



A.

B.

CROSS BEDDING IN MORTAR BEDS.

height of about 12 feet above the lake surface. Many of them are vase shaped. * * * The tops of several are hollowed out so as to form basins, and in a few instances these depressions are filled with clear, fresh water that rises through the porous and tubular tufa composing the submerged shaft of the structure. These are typical specimens of sublacustral spring deposits which have been left partially exposed by a recession of the lake waters, but are still points of discharge for the springs that built them.

The water of one of these natural fountains, rising in a lake whose water is utterly undrinkable, is of exceptional purity [analysis given on preceding page]. * * *

Two analyses are given of the denser lake waters. One is as follows (p. 293):

Analysis of the water of Lake Mono.

Constituent.	Grams in a liter.
Silica (SiO_2)	0.2800
Calcium (Ca)	0.2900
Magnesium (Mg)	0.1300
Potassium (K)	1.1600
Sodium (Na)	18.9100
Sulphuric acid (SO_4)	6.8100
Chlorine (Cl)	12.1300
Boracic acid (B_4O_7)	0.1600
Carbonic acid (CO_3) by difference	11.9800
Total	51.8500

The second analysis, which "may be taken as approaching more nearly the average composition of the lake," gives a very slightly increased total of solids. The difference between the spring water and the lake water as to mineral matter in solution is in the ratio of about 1 to 200. But it will be seen from the above table that, as regards calcium, there is hardly any difference at all, the lake containing 0.2900 gram to 0.0414 gram in the spring; or, "in probable combination," as calcium carbonate, 0.6800 gram to 0.1035 gram. And the second analysis even reverses the order of difference, giving to the heavy lake water less of lime than is contained in this spring of "exceptional purity." Yet Lake Mono has made heavy deposits of calcium carbonate, and little else, though of sodium compounds it holds in solution several hundred times more than of this one compound of calcium.

Of the mineral matter in solution in rivers, on the average, Russell says:[1]

In both American and European river waters, so far as can be determined from the data at hand, the average of total solids in solution is 0.1888, and the average of

[1] Geological history of Lake Lahontan: Mon. U. S. Geol. Survey, Vol. XI, 1885, p. 174.

calcium carbonate 0.088765 part per thousand. These figures may be assumed to represent the average composition of normal rivers. It will be noticed that the average for calcium carbonate amounts to nearly one-half of that for total solids.

It will thus be seen that both the Mono spring and the lake itself carry less of calcium carbonate than average river water, the lake being fresher in this respect than the spring. Lime deposition, therefore, is not due to the presence of an unusual amount of lime in either the contributing spring or the water into which it flows.

The inference is that deposition of even the small amount present is due to the presence also, and in much greater quantity, of other mineral substances dissolved in the lake. Calcium carbonate is not only difficult of solution but difficult of retention in solution. The rivers tributary to Great Salt Lake, as shown by Mr. G. K. Gilbert,[1] carry somewhat more than the normal amount of calcium carbonate; yet no trace of it is to be found in the waters of the lake. Commenting on its absence, Mr. Gilbert says (p. 252): "Despite the fact that calcium carbonate is precipitated on the shore in the form of an oolitic sand, none of the analysts have succeeded in finding it in the brine. * * *" Great Salt Lake is much more heavily charged with mineral substances in solution than Lake Mono; presumably because of their presence the large quantity of lime carbonate contributed by its rivers is completely precipitated; and Mono precipitates its lime for the same reason, yet it retains a trace, because the difficulties in the way of retention are not so great as in the case of the heavier waters of Salt Lake. The tufa-crag accumulations around the Mono spring orifices are the more striking, but the distributed deposit in Salt Lake is the more complete. Here the dissolved impurities are 174.4 grams to the liter[2] (Mono contains but 51.9 grams per liter); the streams from which they are accumulated carry about 0.2 gram, on the average, of which more than half is calcium carbonate, and yet to the 174.4 grams this half contributes nothing.

"It is well known," as Mr. Gilbert says,[3] in discussing the composition of the lake water, "that the precipitation of certain substances from solution is favored by the presence of certain other substances. * * *" The comparatively fresh water of springs and rivers is caused to drop its light burden of lime upon contact with heavy waters. On the assumption that the mortar beds are sheets of cementation at the ground-water surface, it would seem to be highly probable that like action for the same reason occurs there.

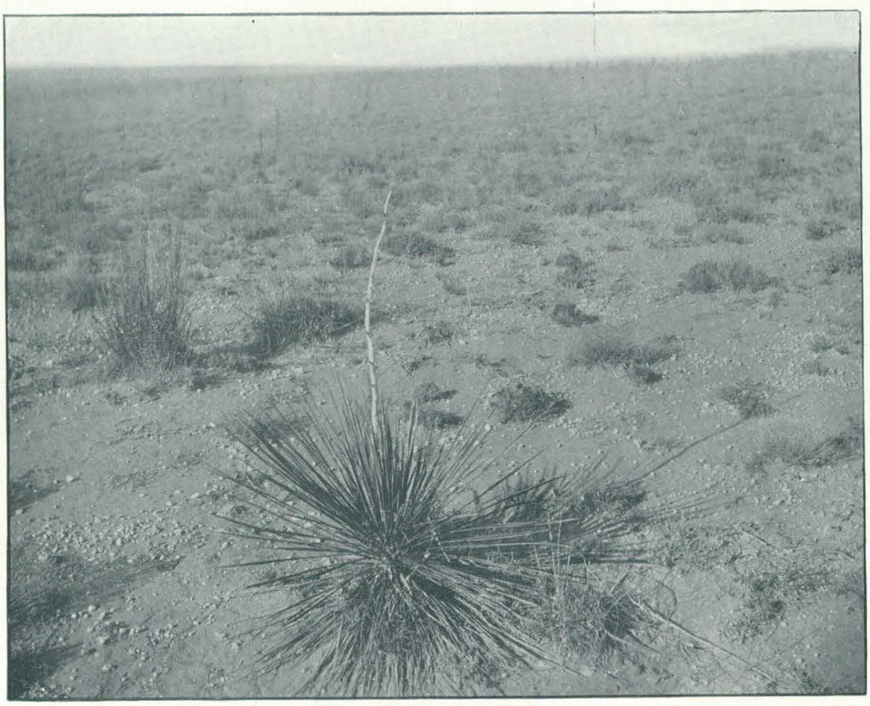
The source of ground water is, in the main, the local precipitation upon the ground surface above it. But in the case of an aggradation plain upon which far-traveled streams are spreading and in part are

[1] Lake Bonneville: Mon. U. S. Geol. Survey, Vol. I, 1890, pp. 207, 253–254.

[2] Ibid., p. 253. Mean of five analyses made in the years 1850, 1869, 1873, 1885, and 1889, at different heights of the lake.

[3] Ibid., p. 204.

A. THIN MORTAR BED PRESERVING UPLAND SURFACE.



B. CARBONATE-OF-LIME GRAVEL.

becoming concentrated by evaporation, the ground water will receive some contribution heavily charged with concentrated solutions. We shall thus have at the water plane "fresh" water, lightly charged with lime carbonate, occasionally brought into contact with other strong solutions favorable to its precipitation. The High Plains are not an aggradation plain in process of building, but fragments of an old one, above the traversing mountain streams. They are not, therefore, receiving concentrated solutions from these streams, spreading upon them, as formerly. Presumably, in consequence, the formation of mortar beds at the present water-plane level is not so marked as formerly.

The desert débris plain may be regarded as in some degree the homologue of the inclosed desert-lake basin; it is the field of precipitation of lime from fluvial waters. Other dissolved materials of streams, equal in the sum of their volumes to the volume of the lime, are retained in solution in the ground water, or are picked up by re-solution after deposit, and ultimately are carried off by slow ground-water drainage. The lime precipitate alone remains. It becomes distributed throughout the mass during its building up. But especially it becomes concentrated, sufficiently to effect a fairly hard cementation at the ground-water level wherever it is extended through coarse material. And if that level fluctuates, with pauses, there results a corresponding series of hard beds, discontinuous horizontally, since the coarse material is not horizontally continuous, and irregularly spaced in vertical section.

HAY'S "GRIT" AND "MARL" FORMATIONS.

Professor Hay, accepting without question the theory of lacustrine origin for the great sheet of the Plains Tertiary, found in the marked contrast of its coarse material, in which the mortar beds are most strongly defined, and the much more extensive accumulations of fine material, apparent reason for separating the mass into two distinct formations, their periods divided by an interval of erosion. The earlier of these formations, to which he assigns all of the coarse sand, the gravel, and the mortar beds, he calls the "Tertiary grit;" the later one he terms "Plains marl." The marl overlies the grit. Each of the formations, again, he subdivides into beds, giving these distinctive names also.[1] He says:

> The circumstances that led to * * * the extensive lakes * * * are not discussed here. * * * . The waters were charged with lime, and all the beds we have included in the term Tertiary grit were deposited. * * * The Tertiary grit filled all the valleys and covered most of the intervening spaces of the Cretaceous surface. * * * When these * * * deposits were completed and the relation in height of land and water was changed, drainage began again, * * * and we have

[1] Water resources of a portion of the Great Plains: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, pp. 569-572.

the period of mid-Neocene erosion [the interval of interruption of lacustrine history above referred to]. * * * Valleys [in the grit] were cut out in a great part of the plains region. * * * There was another change and the region was again covered with water, which deposited over all the plains a bed of marl, varying in thickness from 1 foot to 200 feet. * * * At the end or in the last phases of the plains marl the lakes or inland sea began to be drained again, * * * and we have the post-Neocene erosion. This has lasted to the present day. * * * In one place the plains marl is found resting upon the highest beds of the Tertiary grit. A short distance away * * * it is found resting on a lower bed of the grit, the surface of which is very uneven. Such conditions are to be seen in every valley of the district.

It will be seen that he does not regard the coarse beds as interbedded with the fine, and that he accounts for the presence of coarse material at shallow depths on the assumption that such occurrences mark the summits of the deeply eroded grit.

He gives vertical sections, showing the marl resting upon an eroded surface of grit, and the grit in turn upon an eroded Cretaceous floor. He also gives section records from a number of well borings[1], which are regarded as carrying the suggestion of two distinct formations. The two following are typical:

Section at well No. 43, Cheyenne County, Kansas.

	Feet.
Soil	3
Yellow soil (plains marl)	50
Sandy rock	10
Red clay Sand Quicksand, containing 20 feet of water	110
Total	173

Section at well No. 118, Wallace County, Kansas.

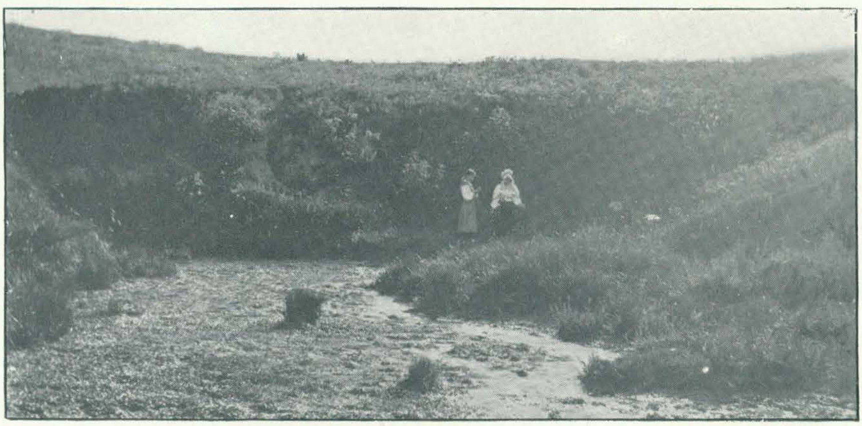
	Feet.
Soil	5
Creamy clay (plains marl)	23
"Magnesia"	4
Running gravel	16
Rock and sand, with 12 feet of water	84
Total	132

These and other well sections to which Professor Hay refers can hardly be said to justify his division of the Tertiary into two distinct "formations." They show, rather, an irregular distribution of soft and hard material, in beds, from top to bottom.

A section (p. 580) which, taken alone, would better have borne out his view, is made up from exposures "in the ravines of the south side of the North Platte, northwest of Ogalalla." It gives "170 feet of Tertiary marl," underlain by 220 feet in all of "grit;" in the main cemented; of varying coarseness; but with very little of fine material. The boring here did not reach to the floor. But "a boring * * *

[1] Water resources of a portion of the Great Plains: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 583.

A. SPRING IN TERTIARY BLUFF WITH MORTAR BED AS FLOOR.



B. ARTESIAN SPRING IN TERTIARY BLUFF WITH MORTAR BED AS COVER.

C. SPRING AT BASE OF TERTIARY WITH RED BEDS AS FLOOR.

19 miles east of Ogalalla * * * continues the section downward" with 100 feet of clay, containing "sand streaks, some several feet thick." It thus shows an exceptional thickness of what should be termed marl underlying the so-called grit.

So far as Professor Hay has shown, there is no essential difference in composition between beds of fine material deeply buried and other beds near the surface. There are occasional differences in color, but they appear irregularly and are not constant along definite horizons. The terms "marl" and "grit," then, it would seem, make groupings of the clay, sandy clay, and fine sand on the one hand, and of the coarse sand, gravel, and cobbles on the other, which are artificial and misleading. The fact appears to be rather that the finer materials make up the bulk of the mass, and that the coarser materials—the so-called grit—are here and there, at various levels and in comparatively narrow belts, extended through it.

Professor Hay describes the marl as "varying in thickness from 1 foot to 200 feet." He assumes for the grit an erosion surface with that range of relief. In other words, prior to the deposition of the marl under still-water conditions, the grit had been eroded by streams to depths in its larger valleys of 200 feet. This rather violent assumption is made on the evidence of the few scattered well borings of the date of Hay's investigations. With the multiplication of wells in later years the value of such evidence is destroyed. Often a new well, within a stone's throw of one which had indicated no gravel for 200 feet, will encounter within that depth several beds of coarse material. On the other hand, a new boring close to one which had stopped in gravel near the surface, seemingly indicating for that position the summit of the "grit" at that level, may miss all coarse masses and extend the whole distance to bed rock through fine material.

LATER VIEWS OF GILBERT AND HAWORTH.

Since Hay's investigation along the western Kansas border, Mr. Gilbert has studied the Tertiary in the Arkansas Valley in eastern Colorado,[1] and Professor Haworth over the whole of its extension in Kansas.[2] Mr. Gilbert's examination was detailed near the mountains, but toward the Kansas line it is described by him as a reconnaissance. So far as he observed the "upland sands and gravels," as he calls them, excepting where they border on Kansas, he pronounces them fluviatile in origin.

After describing the erosion of the Cretaceous floor, which preceded the beginning of the gravel accumulation, he says (pp. 575–576):

Eventually the process of erosion was completely arrested, and processes of deposition took its place. This change was brought about by some modification of conditions

[1] The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann Rept. U. S. Geol. Survey, Part II, 1896.

[2] Univ. Geol. Surv. Kansas, Vol. II, 1897.

which is not yet clearly understood. Perhaps the plains region was depressed at the west, and the slopes thus rendered so gentle that the streams could no longer carry off the detritus which came from the mountains, and it was deposited on the way. Perhaps a barrier was lifted at the east, so that the base-level stood higher. Whatever the cause, the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions, and they thus came to flow in succession over all parts of the plains and to distribute their deposit widely, so that the whole plain in the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains. * * * The range in observed thickness is from 50 to 200 feet.

The chief material is coarse sand, and this is arranged in irregular beds with much oblique lamination, such as ordinarily results from the work of streams. In the sand are occasional pebbles, and these are in places gathered into distinct beds of gravel.

Mr. Gilbert refers, without adverse comment, to the prevalent opinion of geologists that the formation, as it thickens eastward, is a still-water accumulation, in lakes; "but," he adds, "the principal work within the field of our reconnaissance appears to have been done by running water."

Professor Haworth, the following year, extended the examination eastward from the Colorado-Kansas boundary, where Mr. Gilbert had left it; and he reaches for the deepening mass in Kansas virtually the same conclusion that Mr. Gilbert had reached for its beginnings in Colorado. He says:[1]

The relative positions of the gravel, sand, and clay of the Tertiary over the whole of Kansas * * * correspond much better to river deposits than to lake deposits. The irregularity of formation succession, the limited lateral extent of the beds of gravel, clay, and sand, the frequent steepness of the cross-bedding planes, all correspond to river deposits, but are not characteristic of lake deposits. It is difficult to understand how such irregularity of material could have resulted if the Sioux Lake of King, or any other lake, had extended southward across the whole of the western part of Kansas, and had been a factor in the accumulation of the Tertiary materials. It is quite possible that during Tertiary time, in which there were so many changes in the velocity of the water carrying the sediments, lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and very few of lake deposits.

The present writer has described the whole of the great plain of which the High Plains plateaus are but fragments as, in its original condition, an aggradation plain on a vast scale, built to a smooth but sloping surface by the subdividing, shifting, and alternately increasing and failing streams of a dry climate; the initiation of that building is attributed to change of climate from relative humidity to dryness, not to interference with stream grade merely, by deformation; and its present erosion, together with the several recorded interepochs of erosion,

[1] Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 283.

grouped together in the Pleistocene, is attributed to climatic shiftings back toward humidity. The complex structure, finally—an uneven network of gravel courses and elongated beds of sand penetrating a mass of silt and sand-streaked clay—is described as the normal product of desert-stream work under constant desert conditions. The coarse material is not regarded as the product necessarily of strong-running streams, and the fine material of sluggish streams, in alternating epochs, either of humid and dry climate or of high and low inclination of slope, but as the simultaneous product of branching streams of the desert habit, here running in a channel and there spreading thinly. Thus the writer is in accord with Professor Haworth, in the view that the Plains Tertiary, at least within the field of this investigation, embracing the High Plains, is fluviatile in origin. He regards, however, as improbable Professor Haworth's further opinion, expressed below, that the inciting cause of the deep accumulation, burial, and plain building was increased precipitation, while the contrasts of coarse and fine in the materials used in the building, emphasized by sharply defined beds, are to be accounted for on the assumption of many deformations, up and down, tilting the plain alternately to steep and gentle grades. Professor Haworth says (pp. 13-14):

During early Tertiary time the drainage seems to have been similar to that of the present. It is probable the climatic conditions were very different then from those now existing over the Great Plains. The vast amount of material carried eastward from the mountains and deposited in the plains from the Gulf of Mexico northward into Canada implies a correspondingly greater precipitation. There are good reasons for believing the mountainous elevation occurred with relative slowness, but with considerable irregularity. The evidence of this on the Great Plains is confined principally to the character of the materials transported. In some places heavy, coarse gravel beds were formed, the individual gravels in which frequently have a diameter as great as 4 or 5 inches, requiring a great velocity of water to transport them throughout the distance they have been carried. Above and below such gravel beds the material is frequently composed almost entirely of the finest sand and clay and silt, which strongly implies that the movement of the water at that time was not rapid, but rather that it was slow and sluggish.

As is shown later in an article on the physical properties of the Tertiary, these heavy gravel beds and the beds of fine sand and clay alternate with each other, showing conclusively that there have been recurrences of conditions, a rapid movement of the water being followed by a slow one, which in turn was followed by another period of greater velocities. It therefore seems that the terrestrial movements were such, either in the mountains or the eastern part of the plains area, that the velocities of the mountain streams were changing alternately from slow to rapid and again from rapid to slow and sluggish.

The Tertiary plain, as we find it preserved in part in the extraordinary fragments of the central upland flats, seems to bear witness to long-enduring stability of climate, though a marked change of climate, with minor fluctuations, has in fact put an end at last to its building and is bringing about its degradation and removal. The gently graded extension of the plain to so great a distance seems to be evidence also of long-continued freedom from earth movement. Probably the climatic oscillations which marked the Pleistocene, and not ground oscillations, are responsible for its complex channelings and refillings, since during the same period virtual freedom from ground oscillation is indicated in the Great Basin. But the construction of the great alluvial sheet probably marked the close merely of the Tertiary. The event is perhaps best to be regarded as pre-Pleistocene, and as having occurred during an episode of quiet following the orogenic movements which had either directly produced, or had initiated through erosion, notable topographic transformations both in the mountains to the westward and over the Cretaceous floor of the Plains.

Finally, the High Plains, of this fluviatile origin, exhibit an unfailing characteristic of desert alluvial accumulations in that the mass of their materials is impregnated and, as a rule, feebly stuck together with lime carbonate. Where, exceptionally, there is stronger cementation along definite horizons, giving origin to mortar beds, these seem to have been an after effect, occurring during the relatively humid period, with its minor climatic oscillations, and marking fluctuations of level of the ground water.

THE UNCEMENTED COARSE MATERIALS—THE "WATER-BEARING BEDS."

Mortar beds—i. e., beds of cementation—occur both above and below the present water plane. They occur, in fact, at all levels, but not all of the open-textured material of the sand beds and gravel courses, not even the greater portion of it, has been thus cemented and rendered impervious to water. These uncemented gravels, where they lie below the water plane, constitute the "water-bearing beds" —that is, they respond freely to pumping.

They are also the main channels of the present ground-water movement. Where they are cut across and exposed in section by stream canyons they afford means of relatively easy escape for the ground water. In other words, their exposures are marked by rapid drainage off, and such relatively rapid drainage constitutes the normal spring. The water plane is drawn down chiefly by this means. Erosion, with valley cutting, lowers the ground-water level, because these arteries are cut. It is not lowered to the stream level of the dissecting valley, but as a rule lingers well above it, because the gravel courses are not true arteries—are not unbroken for long distances—and connect with one another often only by smaller veins, or not at all. However, it is through such imperfect and complex connections as the gravel courses have that the ground water is drained.

It will thus be recognized that the well, in order to have large delivery, must be in liberal communication with the gravel courses, and that in order to secure the best possible results it must intersect them at as many levels as possible.

A.

B.

BASE OF TERTIARY.

CHAPTER III.

DEFICIENCIES OF CLIMATE.

The climate of the High Plains is described as subhumid. It is variable, from humid to arid, but in the mean annual precipitation there is a marked deficiency. The High Plains are a region of droughts, though not of perpetual drought, since there are humid intervals, in short periods of groups of years; but the mean annual fall is below what is requisite for successful agriculture. Among the periodic variations those of marked deficiency have the longer duration. Yet the humid intervals have enabled the pioneer to achieve a result sufficient to hold out to him the hope, hardly even yet wholly abandoned, that they indicated permanent change of climate.

The extensive western movement of settlers within the trans-Mississippi section some years ago was influenced in a great measure by several successive years of abundant rainfall. There was an undercurrent of opinion, moreover, that the increased rainfall was in some measure due to the permanent occupation of the major portions of eastern Kansas, Nebraska, and adjacent States by an agricultural population. It was argued, and with some show of reason, that the breaking up of the prairie sod and the cultivation of the soil over such a large extent of territory must increase local evaporation and, consequently, the rainfall.[1]

But the records of precipitation within this section, extending over a quarter of a century, disclose several of these humid episodes, offset always by periods of desert dryness, and indicate in the long run climatic stability.

In an arid climate the agriculturist looks upon the rainfall as practically negligible; his dependence is wholly upon irrigation. So far as benefit to growing crops is concerned, the Arid Region may be regarded as virtually without rainfall. In like manner the relative term "subhumid" has come practically to signify a climate in which the natural moisture supply, from rain and snow, falls a little short of what is necessary for agriculture without irrigation. Hence, in a subhumid region provision must be made for at least supplemental irrigation; and the necessity for resort to such artificial aid will be imperative most of the time and advantageous always.

It is the experience everywhere in arid lands that the percentage of arable land that is irrigable—that is, for which water for irrigation is obtainable—is comparatively very small. Values rest much more in

[1] Rainfall of the United States, by Alfred J. Henry: Bull. D, U. S. Weather Bureau, 1897, p. 9.

available water than in land. The arable, but nonirrigable, land is in abundance. The subhumid country, on the other hand, has the advantage of a nearly sufficient precipitation to build upon, so that a given amount of water for irrigation will serve a notably larger area. It is apparent from the records of precipitation on the High Plains that the natural supply would need only to be slightly supplemented to render their entire vast area highly productive. If, however, that small additional supply is not to be had, the High Plains are irreclaimable for agriculture.

FACTORS WHICH MAKE UP CLIMATE.

The factors which, from the point of view of the farmer, go to make up climate are not only precipitation and its distribution throughout the year. The barren Staked Plains of Texas have a precipitation fully equal to that of the major portion of the wheat lands of the Dakotas, and it is of the same type of monthly distribution; but they are in effect much drier, since other conditions, conducing to greater evaporation, notably reduce the soil moisture available for growing crops. These other conditions are: (1) A more spasmodic character of the summer rains, favoring evaporation as against soil absorption; (2) a higher temperature, resulting in a lower "relative humidity," though the absolute humidity or actual moisture content of the air may be higher; (3) more hours of sunshine; and (4) a greater wind movement.

The meteorological records of the United States Weather Bureau afford abundant data for a statement, sufficiently definite for present purposes, of the climate of the High Plains, expressed in terms of normal precipitation, temperature, relative humidity, sunshine and cloudiness, wind movement, and evaporation, both averaged for the year and, what is of much more practical interest, presented for the crop-growing season only. At the same time they show that the changes of climate, which on several occasions have extended the humid area nearly to the foothills of the mountains, and again have contracted it, to the serious injury of established farming interests to the eastward, are but oscillations across a stable mean and have fairly definite periods.

PRECIPITATION.

The Weather Bureau has maintained record stations upon the High Plains at Dodge, Kansas, since 1874; at or near Amarillo, Texas, since 1879; and at numerous other points for shorter periods. We thus have a daily record, among other factors, of precipitation (rain and melted snow) extending over a quarter of a century.

PRECIPITATION BELTS OF THE GREAT PLAINS.

These records of a quarter of a century show uniform decline in precipitation across the Great Plains westward, with rise again to comparative humidity locally in the Rocky Mountains. Upon a climatic map this gradation in precipitation might be represented by north-south belts, indicating four subdivisions westward, as humid, subhumid, arid, and, again, subhumid. The High Plains would be seen to be included within the second or subhumid subdivision. As a topographic zone of virtually no erosion this region of flat uplands would show fading off on the west into the eroded country of the arid belt, but abrupt termination on the east along a much-indented escarpment, well within the subhumid limits. The remaining strip would represent a zone of sharp erosion—a zone of capture by headwater sapping on the part of the multitude of streams of the humid belt. Fig. 307, in section along the slope of the Great Plains, shows the High Plains as a broad terrace of survival within the belt of medium precipitation.

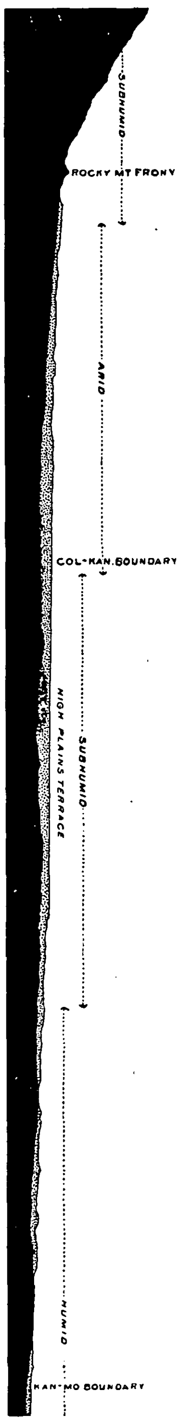


Fig. 307.—West-east section of Great Plains, showing climatic banding and relative position of High Plains terrace.

But a map which should show precipitation only would not be complete as a climatic map. To the northward upon the Great Plains it would not be even approximately accurate. For example, precipitation on the Staked Plains, as represented by the eighteen-year record at the Amarillo station, in the center of the Panhandle of Texas, is 21.94 inches; at Garden, midway across the High Plains, in central-western Kansas, it is 17.38 inches; at Goodland, northwestern Kansas, at about the northern limit of the High Plains, it is approximately 21 inches; while in central North Dakota it is but 18 inches, and at St. Vincent, near the northeastern corner of that State, in the center of a great wheat-growing region, it is only 19.5 inches. In short, the vast barren flats of the High Plains have a slightly greater precipitation than even the major portion of the wheat lands of the Northwest. The precipitation belt, which across western Texas and Kansas includes the High Plains, and is subhumid there, becomes, in effect, humid to the northward and is included within the agricultural area. Its eastern boundary swings gradually eastward, while the western limit of agriculture crosses it, swinging westward. The west-east section shown in fig. 307 is along the parallel of the Arkansas River in western Kansas. So far north as the boundary between the two Dakotas the wheat-growing area would be found to have completely overlapped the precipitation belt, which, south of the Arkansas River, is, in effect, too dry for agriculture without irrigation. The water of rain is in each case the sole reliance, and there is an appreciably greater fall, annually, to the south than to the north; but taking account also of the distribution of the fall throughout the year, and of those factors which make for loss from the soil, it will appear that the somewhat smaller precipitation northward is much the more effective.

PRECIPITATION OF THE CROP-GROWING SEASON.

In his Rainfall of the United States[1] Professor Henry introduces "a departure from the usual methods" by presenting separately, as of more vital interest to agriculture, the precipitation of the crop-growing season. This season he regards as comprising the half year from April to September, inclusive. He says (p. 11): "Tables of annual precipitation tell us how much rain or snow falls on the average during the course of the year, but they afford no indication, directly or indirectly, as to whether the rain comes when it will be of the greatest service to agriculture or whether it falls after the time of maturity of the staple crops." In illustration of the importance of this separate presentation, he divides the precipitation of the United States into "types of monthly distribution," by districts, showing the ratio of the seasonal fall to the annual fall, in diagram form, by monthly percentages of the total. From this showing it appears that while the distribution of precipitation throughout the year is fairly uniform in the States along the middle Atlantic, in New England, in the Ohio Valley, and along the border of the Great Lakes, it is strongly concentrated in the summer months upon the Great Plains. On the other hand, it shows a pronounced maximum during the winter season in the Great Basin, where summer rains are most needed. At Winnemucca, Nevada, near the center of the Great Basin, the midwinter (January) fall is nearly twelve times that of the midsummer (July) fall, with a fairly uniform gradation between extremes, while the Great Plains, with a more evenly graded annual variation, shows a difference between the records of these months in the ratio of about 5 to 1, on the average, the other way.

Selected from Professor Henry's diagrams, fig. 308 strikingly illustrates, by contrast, at four widely separated points in the United States, these types of monthly distribution of precipitation. Lawrence, Kansas, is chosen as representative of the Great Plains. Though

[1] U. S. Weather Bureau, Bulletin D, 1897.

the total precipitation here is above the average of that for the Plains in general, in its monthly variation it is typical of the whole. It will be seen that the distribution, as regards the crop-growing season, is especially fortunate.

A more striking comparison can be made if extremes be taken. Garden, in western Kansas, is upon the High Plains; Winnemucca,

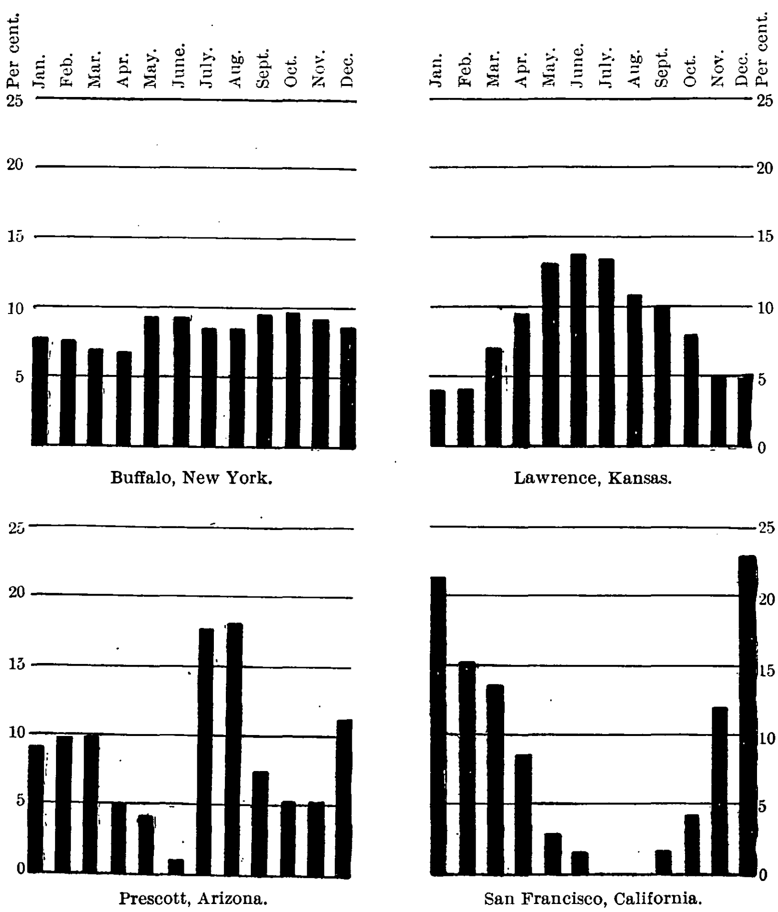


FIG. 308.—Types of monthly distribution of precipitation.

Nevada, is about centrally placed in the Great Basin desert. The mean annual fall at Winnemucca is 8.5 inches. The fall during the half year from April to September, inclusive, is but 2.9 inches. At Garden the record is 17.4 inches for the year, of which 14.1 inches are credited to the six months from April to September, leaving for the nongrowing season a lighter fall than during the same period in even arid Nevada. The "mean annual" record greatly overstates the effective precipitation for arid Nevada, while it understates it for the subhumid High Plains. The complete monthly records at the two points are as follows:

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	The year.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Winnemucca..	1.2	0.9	1.0	0.9	0.9	0.6	0.1	0.1	0.3	0.6	0.8	1.1	8.5
Garden........	0.4	0.7	0.5	1.1	2.5	3.8	3.3	1.9	1.6	0.6	0.4	0.6	17.4

Obviously a fairer comparison would be the following:

Locality.	Apr.	May.	June.	July.	Aug.	Sept.	Apr. to Sept., inclusive.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Winnemucca..	0.9	0.9	0.6	0.1	0.1	0.3	2.9
Garden........	1.0	2.5	3.8	3.3	1.9	1.6	14.1

The disparity is in fact much greater than appears from an examination of the two annual records, and is brought out only by comparison of the crop-season records. It is not fully expressed even then, since the evaporation at Winnemucca is 50 per cent greater than at Garden.

It is in such manner that comparison should be made between the climate of the High Plains and that of the humid region to the eastward. St. Louis, at the eastern margin of the Great Plains, is nearly due east of Garden. The mean annual temperature and the evaporation rate at the two points are about the same. Their precipitation records compare as follows:

Locality.	Jan.	Feb.	Mar.	Crop-growing season.						Oct.	Nov.	Dec.	The year.	Apr. to Sept., inclusive.
				Apr.	May.	June.	July.	Aug.	Sept.					
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Garden	0.4	0.7	0.5	1.1	2.5	3.8	3.3	1.9	1.6	0.6	0.4	0.6	17.4	14.1
St. Louis	2.2	2.7	3.4	3.7	4.7	5.0	3.8	3.5	3.1	2.8	3.1	2.8	40.8	23.8

In his Rainfall of the United States Professor Henry gives charts not only of the mean annual precipitation, but of the precipitation from April to September, inclusive, separately.

It is not to be understood, of course, that the out-of-season fall contributes nothing to the moisture supply of plant growth. It wets the soil, and comparatively little of it is lost through evaporation before the advent of warm weather. It contributes to soil moisture. But mainly it soaks downward, beyond the reach of plant roots, and its larger contribution is to the ground water. Compared with the summer rains, it plays a small part.

SPASMODIC CHARACTER OF THE SUMMER RAINS.—"STORM TRACKS."

The most effective rains are those which fall slowly and are followed by lingering cloudiness. There is then a maximum of ground absorption and a minimum of evaporation. Such rains, as a rule, are widely distributed and occur mainly along recognized "storm tracks." The rains of the High Plains are rarely of this character. The normal "cyclonic" storms cross these uplands in winter only. The summer rains have the character of abrupt, heavy, and brief downpours, are local, and have short and erratic courses. They are usually accompanied by hail, and often do damage to crops from this cause, and accomplish only a minimum of good, owing to their violent character in general. Furthermore, though they are of frequent occurrence during the growing season, considered for any large area as a whole, the distribution of moisture is unequal locally, and their wandering and crossing tracks may here and there leave small areas very lightly watered or even wholly unvisited.

In his introduction to the general subject of rainfall, in the volume already referred to, Professor Henry says:

Cooling by expansion as air ascends is one of the most effective causes of rainfall. The ascensional movement of air is brought about in several ways, chief of which are: (1) The air may be forced up the side of a mountain into a region of diminished pressure and lower temperature, as happens whenever a mountain range runs in a direction at right angles to the prevailing winds. (2) In the warm season the lower layers of the atmosphere, under the effect of solar radiation and probably other causes, frequently reach a state of unstable equilibrium, thus inducing ascensional currents. Summer thunderstorms are largely a result of this process. (3) Last, and doubtless most important of all, is the circulation of air in cyclonic storms, viz, a radial inflow from all sides and an ascensional movement in the center. A very large percentage of the rain of the United States is precipitated in connection with the passage of storms of the latter class.

The summer rains of the High Plains belong almost wholly to class 2.

The principal tracks of the cyclonic storms of the United States are either to the north or to the south, but mainly well to the north. A few cross the northern end of these uplands in April, September, and November. During the ten years from 1878 to 1887, inclusive, the United States Weather Bureau made this matter of storm tracks the subject of a special investigation, and in the resulting publication[1] these facts are elaborately exhibited by means of charts.

It appears that not only are there many more storm tracks to the northward, but that storms follow one another along these northern tracks with the greater frequency. "More than half of the August storms begin and move along the northern circuit, like beads on a string, with great regularity. The breadth of the track covered by them is about 400 miles. This accounts for the fact that in the Northern

[1] U. S. Weather Bureau, Bulletin A, 1893.

States the alternation of warm and cool days takes place with wave-like regularity, while in the Southern States the temperature is almost uniform * * *."[1]

A cyclonic storm may or may not be accompanied by precipitation at all points along its course. A storm is essentially an atmospheric disturbance; precipitation is an incident. The great bodies of moisture-laden air which pass eastward across the Plains (and all storm movement is in that direction) retain their moisture in large measure until that passage is nearly completed. It is because of local conditions effecting this result, and not because the air of the Plains is, strictly speaking, dry, that the fall there is light.

The figures on the Weather Bureau charts indicating storm frequency take no account of sporadic and local storms. These occur mainly out of the paths of the great cyclonic movements. The figures show that the frequency of cyclonic storms increases rapidly to the northward. At the northeastern corner of North Dakota, in the center of a great wheat region, the number is 30 annually. At the center of the Staked Plains of Texas it is 9 annually. During the crop-growing season the figures for the northern point remain proportionately large, while for the Staked Plains they drop to almost nothing; and yet the precipitation at these two points is about the same, both annually and during the summer months.

The purpose of this discussion is to bring out the fact that the character of the precipitation, especially during the half year from April to September, inclusive, for the High Plains and for the Plains to the northward is radically different; that for the High Plains it is of the local, brief, and heavy thunderstorm variety, and that this characteristic constitutes for them a defect of climate.

By way of summary of the foregoing the following extracts are made from the text accompanying the storm-track charts above referred to.[2]

The principal track of winter storms over the North American continent is traced eastward from the Pacific to the Atlantic ocean between the forty-fifth and fiftieth parallels [central through North Dakota]. * * * For the spring months the average track of storms * * * is farther south than during the winter season. The principal track is traced eastward between the fortieth and forty-fifth parallels [central through Nebraska]. * * * In April the region of greatest storm frequency * * * occupies an area extending from the middle Missouri Valley over the middle-eastern slope of the Rocky Mountains, where the average number of storms is in excess of three. [These touch only the northern end of the High Plains.] * * * In the summer season storms seldom cross the western mountain ranges of the North American Continent. A large majority of the storms of those months originate on the middle and northeast slopes of the Rocky Mountains, advance toward Lake Superior, and pass thence to the Gulf of St. Lawrence. * * * In autumn the principal storm track * * * crosses the Pacific coast between the mouth of the

[1] Storms, storm tracks, etc., by Frank H. Bigelow: U. S. Weather Bureau, Bulletin 20, 1897, p. 14.
[2] U. S. Weather Bureau, Bulletin A, 1893, p. vi.

Columbia River and the fifty-fifth parallel, and east of the one hundredth meridian passes almost due east between the forty-fifth and fiftieth parallels [central through North Dakota]. * * * These figures show that the stormiest latitudes are between the forty-fifth and fiftieth parallels * * * and that the number of storms decreases rapidly north and south of those latitudes. * * * A study of the storms of the Northern Hemisphere shows that the longer-lived storms commonly originate in the higher latitudes. The storms which appear on the Pacific coast north of Washington possess greater vitality than any other class of storms traced over the Northern Hemisphere.

SECULAR VARIATION OF PRECIPITATION.—DROUGHTS.

Of hardly less importance than the normal precipitation, in the verdict of the agriculturist against the climate of the High Plains, is its variability from year to year, and the occurrence and duration of droughts. On this point the Weather Bureau records again afford fairly satisfactory data. The record at Dodge, western Kansas, covers a twenty-five-year period. "* * * At least thirty-five or forty years' continuous observations are required to obtain a result that will not depart more than ±5 per cent from the true normal, even if the register be continued indefinitely. The average variation of a twenty-five-year period is about ±5 per cent, and of a forty-year period about ±3 per cent; that is to say, if any period of twenty-five years be selected from a register extending over eighty years, the average of the twenty-five-year period may be 5 per cent above the true normal, or it may be 5 per cent below it."[1] The Dodge record, therefore, can be relied upon within 5 per cent for exhibition of departures from the normal during the last quarter century. The position of this station is at the eastern margin of the High Plains, about 160 miles to the south of their northern termination. The Amarillo station, with an eighteen-year record, is in a northern-central position upon the Staked Plains of Texas.

[1] Rainfall of the United States, by Alfred J. Henry: Bull. D, U. S. Weather Bureau, 1897, p. 10.

The following are the records at these two stations, averaged by months:

Precipitation at Dodge, Kansas.

[In inches.]

Year.	Jan.	Feb.	Mar.	Crop-growing season.						Oct.	Nov.	Dec.	Annual.	Departure from normal.
				Apr.	May.	June.	July.	Aug.	Sept.					
1874..	......	......	......	......	......	......	......	......	......	0.22	0.23	0.05	......	− ?
1875..	0.12	0.10	0.04	0.72	2.26	0.73	3.28	2.06	1.32	0.06	0.00	0.09	10.78	− 9.60
1876..	0.00	0.05	3.59	0.16	1.15	2.53	2.26	1.03	2.13	1.00	1.35	0.15	15.40	− 4.98
1877..	0.18	0.56	0.25	3.38	4.96	3.92	1.79	4.09	0.50	3.34	0.56	4.36	27.89	+ 7.51
1878..	0.21	1.13	1.01	1.06	4.63	2.19	1.61	4.48	0.76	0.09	0.60	0.19	17.96	− 2.42
1879..	0.87	0.08	0.17	0.40	0.90	4.40	3.90	3.75	0.80	T.	0.04	0.12	15.43	− 4.95
1880..	T.	T.	0.04	0.11	3.01	1.59	4.00	5.17	0.32	1.42	2.43	0.03	18.12	− 2.26
1881..	0.15	1.63	0.50	2.38	12.82	1.77	5.06	2.36	3.13	2.19	0.95	0.61	33.55	+13.17
1882..	0.52	0.22	0.24	0.68	3.87	1.51	3.04	1.07	0.15	1.62	0.11	0.11	13.14	− 7.24
1883..	0.44	1.42	0.42	2.40	5.41	4.31	2.61	5.66	1.32	3.32	0.12	1.07	28.50	+ 8.12
1884..	0.08	0.28	1.91	1.07	4.47	7.67	6.40	4.82	0.23	1.50	0.83	1.10	30.36	+ 9.98
1885..	0.52	0.47	0.75	1.39	4.07	2.02	6.03	1.80	3.48	1.06	0.36	1.76	23.71	+ 3.33
1886..	1.82	0.46	1.50	1.90	0.40	5.47	2.07	2.46	2.33	0.45	0.24	0.25	19.35	− 1.03
1887..	0.07	0.53	0.17	2.46	3.69	4.00	1.00	2.28	0.14	0.48	0.35	0.54	15.71	− 4.67
1888..	0.23	0.73	0.93	4.08	2.86	5.16	4.07	3.00	0.78	0.81	0.06	0.23	22.94	+ 2.56
1889..	1.69	0.34	1.38	2.12	1.54	3.43	2.02	2.14	0.86	2.88	0.77	0.00	19.17	− 1.21
1890..	0.42	0.39	0.05	2.90	1.19	1.00	0.22	3.45	0.57	0.89	0.50	0.14	11.72	− 8.66
1891..	0.98	0.27	3.32	2.76	3.36	6.27	5.16	1.36	4.56	3.33	0.12	0.85	32.34	+11.96
1892..	0.25	1.01	2.62	0.40	3.23	3.34	0.66	4.69	1.04	0.73	0.31	1.38	19.66	− 0.72
1893..	0.02	0.34	T.	0.04	1.31	0.76	3.32	1.82	1.74	0.25	0.42	0.10	10.12	−10.26
1894..	0.04	1.03	0.40	1.88	0.95	2.80	2.05	0.15	2.03	0.62	0.03	0.62	12.60	− 7.78
1895..	0.58	2.26	1.31	0.91	0.97	5.32	4.84	2.42	0.06	1.09	0.34	0.21	20.31	− 0.07
1896..	0.49	T.	0.25	5.50	1.13	1.98	5.41	0.73	1.06	2.45	0.34	0.53	19.87	− 0.51
1897..	1.44	2.38	0.26	3.21	1.49	2.31	3.91	3.06	0.60	2.66	0.06	0.20	21.58	+ 1.20
1898..	1.74	0.70	0.24	0.97	10.31	4.57	3.14	2.26	3.16	1.87	0.96	1.54	31.46	+11.08
Means	0.53	0.68	0.89	1.79	3.33	3.29	3.24	2.75	1.38	1.37	0.48	0.65	20.38	....

During the years in which the precipitation is above normal the excess is, on the average, 7.66 inches; during the years in which it is below normal the average deficiency is 4.15 inches; but the number of years of excess were only nine, while those of deficiency were sixteen. That is to say, low as the normal is, two years out of three will be below it; but not two out of every three. Changes are cumulative and exhibit a tendency to rise and fall by slow fluctuation, so that the wet years and the dry years are grouped. The rise is so high during wet years that there is a sufficiency for all agricultural needs. The climate becomes, in fact, humid. The universal green, over tilled and untilled areas alike, during these brief intervals of plenty, is irresistibly alluring to the home seeker, and invariably induces a return wave of population, which as inevitably ebbs back, however, during the following long period of drought.

Precipitation at Amarillo, Texas.

[In inches.]

Year.	Jan.	Feb.	Mar.	Crop-growing season.						Oct.	Nov.	Dec.	Annual.	Departure from normal.
				Apr.	May.	June.	July.	Aug.	Sept.					
1879..	......	......	......	......	......	......	......	......	......	......	......	0.10	......	– (?)
1880..	T.	0.05	0.40	0.16	4.48	4.50	2.11	1.70	0.54	2.40	0.10	0.35	16.79	– 5.15
1881..	0.47	0.74	T.	1.26	5.27	0.10	3.28	0.49	3.18	0.69	0.42	0.26	16.16	– 5.78
1882..	0.33	0.16	0.53	0.66	7.48	1.54	5.65	1.55	3.18	2.32	0.96	0.40	24.76	+ 2.82
1883..	T.	0.53	0.04	0.82	4.56	1.66	2.87	6.56	4.97	5.32	0.04	0.84	28.21	+ 6.27
1884..	0.61	0.27	0.34	1.08	6.29	6.86	1.29	5.60	0.84	5.54	2.14	3.05	33.91	+11.97
1885..	0.45	0.87	1.86	4.67	7.23	9.82	3.62	4.94	0.65	0.60	0.25	2.11	37.07	+15.13
1886..	0.62	1.44	1.49	2.44	0.23	3.45	1.50	4.57	3.00	5.04	0.18	0.09	24.05	+ 2.11
1887..	0.01	0.06	0.19	6.06	7.01	2.39	0.92	3.52	1.67	0.69	0.23	0.08	22.83	+ 0.89
1888..	0.32	0.61	0.40	2.69	3.19	1.34	2.50	2.27	0.71	0.85	0.79	0.84	16.51	– 5.43
1889..	1.63	0.89	1.28	4.86	0.72	1.64	0.88	1.83	1.94	2.99	0.74	0.00	19.40	– 2.54
1890..	2.40	0.01	0.02	3.94	1.69	1.71	0.88	2.89	0.05	......	......	......	......	– (?)
1891..	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1892..	0.42	0.57	2.10	0.21	2.70	1.49	1.85	1.93	0.24	2.85	0.16	1.08	15.60	– 6.34
1893..	0.09	2.03	T.	0.16	2.19	2.03	2.05	2.67	5.27	0.03	0.28	0.43	17.23	– 4.71
1894..	0.02	1.15	0.05	0.85	1.30	3.59	1.82	3.41	2.41	0.39	0.00	0.82	15.81	– 6.13
1895..	1.60	1.92	0.16	1.31	1.78	6.84	2.88	3.87	0.57	2.26	0.81	0.79	24.79	+ 2.85
1896..	0.76	0.41	0.21	1.95	2.20	2.31	7.04	0.63	2.45	3.09	0.35	2.88	24.28	+ 2.34
1897..	2.26	0.65	0.47	1.08	4.44	2.32	2.16	2.71	0.73	1.63	0.08	0.63	19.16	– 2.78
1898..	0.86	0.82	0.35	0.98	3.52	4.81	3.88	4.03	0.48	0.41	0.34	2.06	22.54	+ 0.60
Means	0.71	0.73	0.55	1.95	3.68	3.24	2.62	3.06	1.83	2.18	0.46	0.93	21.94	....

The record of these eighteen years on the South Plains shows as many years of excess as of deficiency, and the duration of the periods of each is the same; but they are long periods. Precipitation was above the normal from 1882 to 1887, inclusive—six years—and below the normal from 1888 to 1894, inclusive—six years also. If the alternation from wet to dry were in single-year periods, a wet year always following a dry one, agriculture might, perhaps, adjust itself to such severe conditions; but it can not hope to adjust itself to a condition in which a few years of prosperity, that is only moderate at best, is followed by several years of drought, with no production whatever, in recurring periods.

Comparison of the records at these two stations, 200 miles apart upon the High Plains, shows only a very rude correspondence between their wet and dry periods. There is closer correspondence between the records of stations near together, as, for instance, those of Dodge, Garden, Fort Wallace, and Goodland. But these show irregularity in detail, and for this the local character of the precipitation is doubtless in large measure responsible. Heavy summer rains, with paths narrower than the distance between any given pair of stations, may take such courses with reference to those stations as to render their records unrepresentative, as compared by single years, of the areas for which they have to serve. But such records will be fairly representative as compared for long periods. They will be found to afford at least a suggestion of secular variation.

In a careful discussion of this question, drawing upon the records of the Weather Bureau, from its beginning, for the entire United States, Professor Henry shows[1] that while there is but faint suggestion of periodicity for the country as a whole, yet if the country be divided into districts, according to climatic types, periodicity will be found to be better defined in all and even strongly defined in some. For example, he says (p. 19): "The South Atlantic and Gulf States, in particular, show a marked deficit throughout almost the entire period [the ten years 1887–1896]. This fact naturally suggests an inquiry into the rainfall of the preceding ten years. The following statement shows the average precipitation at the principal Weather Bureau stations in the region just mentioned for twenty consecutive years in periods of ten years each:

Average annual precipitation in periods of ten consecutive years, 1877–1886 and 1887–1896.

Stations.	Average 1877–1896.	1877–1886.	1887–1896.	Difference.
	Inches.	*Inches.*	*Inches.*	*Inches.*
Lenoir, N. C	50.09	51.40	48.78	− 2.62
Hatteras, N. C	65.58	73.41	57.76	−15.65
Wilmington, N. C	53.06	58.83	47.30	−11.53
Charleston, S. C	54.59	56.82	52.37	− 4.45
Augusta, Ga	46.99	46.53	47.44	+ 0.91
Savannah, Ga	49.83	50.91	48.75	− 2.16
Jacksonville, Fla	53.40	57.69	49.12	− 8.57
Mobile, Ala	62.67	66.61	58.73	− 7.88
Montgomery, Ala	50.97	52.04	49.90	− 2.14
Vicksburg, Miss	54.37	62.04	46.69	−15.35
Memphis, Tenn	52.77	56.76	48.78	− 7.98
New Orleans, La	58.81	61.34	54.28	− 7.06
Shreveport, La	47.34	54.26	40.42	−13.84
Galveston, Tex	46.18	52.40	39.96	−12.44

And again (p. 22): "In the Ohio Valley there appears to be a rough periodicity of about nine years. Thus there were periods of heavy rainfall about 1837, 1847, 1858, 1866, 1875, 1882, and 1890, and of drought in 1839, 1856, 1863, 1871, 1878, 1886, and 1895."

In other districts the records are more confused. Possibly the explanation lies in the local conditions which determine the subdivision into types. The facts of importance in the present connection are,

[1] Rainfall of the United States, pp. 18–24.

however, that the full record of the climate of the country as a whole shows that it is in the long run stable; that since the climate of a geographic subdivision does not change without change of the whole, the climate of the High Plains may be assumed to be stable, in spite of their short record mainly showing instability; and that this minor instability amounts to another defect of their climate, since the wet years do not produce in superabundance, having only a bare sufficiency of moisture, and there is no compensation, therefore, for the years of drought.

EXCESSIVE PRECIPITATION.

Under this head Professor Henry says:[1] "Excessive rains naturally fall into two broad classes: (a) Rains of great intensity and short duration, and (b) light intensity and long duration. * * * The great majority of excessive rains (class a) in the United States occur east of the one hundred and fifth meridian, and principally in the summer months. They are most frequent in connection with summer afternoon thunderstorms." * * * These are the sporadic and local storms especially characteristic of the High Plains. They are excessive merely as to their rate of fall, and, as already stated, have diminished efficiency on that account.

TEMPERATURE.

The records of the Weather Bureau afford abundant data also for comparative statement of normal temperatures over the Great Plains region, both for the year and for the crop-growing season separately. While there is remarkably uniform increase of temperature northward, on the eastern Plains, the isotherms (lines of equal temperature) turn southward upon the High Plains subdivision, especially during the crop-growing season, indicating for that region a nearly equable temperature. That is, during the summer months the line of 65°, for example, passes nearly north-south along the High Plains. The normal crop-season temperature of North Dakota, on the other hand, is 10 degrees higher. This means a progressive diminution of evaporation to the northward, and a notably greater effective humidity in the Dakotas, though, as we have seen, the precipitation there averages slightly less than upon the High Plains.

"RELATIVE HUMIDITY."

The use in meteorology of the term "humidity" is more special than its popular use; as when, for example, to illustrate from extremes, we characterize the climate at St. Paul, in the Upper Mississippi Valley, as humid, and the climate at Yuma, in the Colorado desert, as arid. The normal precipitation at Yuma during the half year, April to September, is hardly more than a trace—0.5 inch; at St. Paul it is

[1] Rainfall of the United States, pp. 52-53.

20.4 inches; and yet the air of this virtually rainless desert contains, absolutely, 0.13 per cent more moisture than that of the highly fertile agricultural basin of the Upper Mississippi. What is known in technical language as its absolute humidity, or actual moisture content, is, during the half-year period mentioned, 0.13 per cent greater. In the month of June it is 1.38 per cent less, but in August it is 1.47 per cent greater.

At the same time, however, its capacity for moisture is greater and in much larger measure, so that comparing the actual moisture content at Yuma, large though it is, with what it might be if the air there were charged (other conditions remaining normal) to its full capacity, or "saturated," and making a like comparison for normal conditions at St. Paul, it appears that the air of the desert region is much further from a condition of saturation than that of the humid region. The latter region is in effect, or relatively, much more humid.

Among the elements which contribute to precipitation, this moisture content of the air (except as precipitation for the time being reduces it) is its most stable feature. Other elements, among which in this connection temperature is the most important, are comparatively very variable through short periods of time. But they vary without affecting the moisture content, except as they may cause it to precipitate a portion, and thus reduce it, by lowering the level, as we may say, of the capacity of the air for holding moisture to and below the level of the quantity it actually contains. This capacity is increased or diminished as temperature rises or falls. But it is the capacity only, not the actual quantity of water vapor in the air, which is thus varied.

The normal moisture content at Yuma, as we have seen, is high, somewhat higher even than that at St. Paul, but the normal temperature, and in consequence the possible moisture content, is very high. At Yuma it rarely happens that the variation of temperature below the normal, or the cooling of the air below its average condition, brings the capacity of the air for moisture down to and below the quantity it actually contains, resulting in supersaturation and producing rain. This is a rare occurrence at any season, and it almost never happens during the summer half year; and since the drop to this critical point is so great, it will still less frequently happen that falling temperatures will go far below it, and continue below it long, producing copious rain.

With a virtually constant quantity of contained moisture, the point at which a condition of saturation will be brought about by the lowering of temperature, and therefore the lowering of the capacity of the air for holding moisture, may best be defined in terms of temperature. Thus, at Yuma, in July, with the normal amount of moisture in the air, the highest temperature at which precipitation can begin, i. e., the normal "dew-point" temperature there, is 60.1 degrees; but the normal temperature in July is 91.5 degrees. This is a much greater range (31.4) than is ordinarily compassed by temperature variation in that region. Hence the likelihood of any rain there is small, and of long-continued and heavy rain is practically nil; and this is so in spite of the fact that moisture sufficient for even a tropical precipitation is ever present in the atmosphere. On the other hand, at St. Paul, in July, the range between the normal and the dew-point temperature is only 13.9 degrees. Therefore, while at St. Paul the absolute humidity is less than at Yuma, nevertheless, what is called by meteorologists the relative humidity is much greater. The air in its normal condition at St. Paul is closer to saturation and less "dry," in the sense that by evaporation it takes up moisture at a slower rate. And as to precipitation, it is like a water vessel that is already nearly full and can therefore easily be made to run over.

Relative humidities may be illustrated in the same way. The condition of the air at St. Paul may be likened to a water barrel with open bung filled nearly to this opening. The bung in such case represents the saturation level, or the point (dew point) at which precipitation would begin if the water content (in nature the invisible vapor content) were to increase, the temperature remaining stationary at the midsummer normal. With the water content stationary, however, and the temperature varying, by rising and falling as it does in nature, we should have to imagine a vertical row of bungs which could be opened at will. The possible content of the vessel could thus be either increased or diminished; but evidently changes of the possible content would have no effect upon the actual content unless the level of the one were brought below that of the other. On the other hand, the condition at Yuma, comparatively, would have to be represented by a much more capacious cask with but a few inches of water in the bottom. Compared to what the cask would hold if filled to its open bung (representing the saturation level, or dew point, at the normal midsummer temperature), this amount of water would be small. It would be small relatively. In that sense the absolute humidity (the actual vapor content) of the air at Yuma is small. But this few inches of water in the large cask, if poured into the barrel, would be a relatively large amount there. At St. Paul the air can hold but a small amount of vapor because it is cool; at Yuma it can hold a large amount because it is hot. At Yuma it is charged far below its capacity; therefore the relative humidity there is small, evaporation continues rapid, and the air seems dry. But an equal quantity of vapor in the cool air at St. Paul, with its small holding capacity, would constitute a high relative humidity, evaporation would be slow, and the air sensibly moist or humid—even more so than it is in fact.

The ratio of this actual content to that required to produce saturation (and precipitation) is most conveniently expressed in the form of a percentage. Thus, for example, at Yuma the normal relative humidity in July is given as 42.8. It is 42.8 per cent of saturation. At St. Paul it is 65.9.

A like comparison, with contrasts less violent, however, may be made between the barren High Plains and the great wheat-growing Northwest. In spite of the fact that the precipitation record shows a slightly greater fall at Amarillo than at St. Vincent, in spite of the fact, as the records show also, that the air normally carries more moisture in the southern Plains region than in the northern, the climate of the southern region is less than humid, or subhumid. That is to say, the relative humidity at Amarillo is less than at St. Vincent.

The Weather Bureau records at each station, among other climatic factors, take account (1) of the actual moisture content of the air (as vapor pressure); (2) of its dew point (as a temperature), and (3) of its normal temperature, but mainly in order that the liability of rainfall and the relative humidity may be determined. For, manifestly, it is a matter of small consequence what amount of moisture is actually in the air, unless at the same time it is known what amount is necessary to bring about the condition of supersaturation that alone could result in rain, and therefore how far the actual content falls short of this amount.[1]

Thus the normal relative humidity at Amarillo in July is 56.8, or 56.8 per cent of saturation; at St. Vincent it is 79.7. On a map which should show the normal relative humidity during the April-September

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[1] "If water be introduced drop by drop into a vessel exhausted of air, such as the receiver of an air pump, the drops will be observed to disappear. They have evaporated or changed into the form of vapor. This evaporation will continue until a certain pressure of vapor is reached, after which any additional drops will remain liquid. The vessel is then said to contain saturated vapor. The pressure of saturation depends upon the temperature; the higher the temperature the higher the pressure of saturation. If, instead of a vacuum, the vessel had contained dry air, it would have evaporated precisely the same amount of water.

"Water vapor is always present in the air to some degree, although invisible until it condenses into minute particles of water, when it is seen as fog or cloud. Whatever the vapor pressure at any time, if it remains constant while the temperature is lowered, a point will be reached where condensation commences. This temperature is called the dew point. A further reduction of temperature causes a visible fog or deposit of dew. If the temperature be raised, the dew is again evaporated and disappears from view. Let the temperature rise still higher, and there is no moisture to supply the evaporation. The vapor is then said to be dry or superheated. If the number expressing the vapor pressure in the air at the time of an observation be divided by the number expressing the pressure of saturation due to the temperature at that time, the quotient obtained is a fractional part of saturation. This fraction is called relative humidity, saturation being 100 and absolutely dry air 0. Vapor pressure is expressed in terms of inches of mercury column which it can support. Absolute humidity, or the quantity of water contained in a given unit of air, is nearly proportional to the vapor pressure. It is stated in number of grains in weight contained in a cubic foot of air. The dew point is expressed in degrees Fahrenheit, as are other temperatures.

"Since relative humidity is a function of temperature, it does not constitute a means of comparison as to the quantities of moisture actually present in the air at different places and times. However, it is not the absolute humidity, but the percentage of saturation, which makes the extremes of temperature most annoying to animal life. Statements of relative humidity, therefore, in connection with those of temperature, give information concerning the comparative discomfort of life in different climates."—Arizona Weather, by Edward M. Boggs: Ariz. Agr. Exp. Sta., Bull. 20, 1896, pp. 5-6.

It should be added that hot air, which is at the same time "dry," and which is "comfortable" to animal life, since the evaporation which it causes keeps down bodily temperature, is, on the contrary, harmful to plant life, and to cultivated plants especially is seriously harmful, necessitating resort to irrigation in order to compensate for the loss sustained from excessive evaporation.

half year for the Great Plains as a whole it would appear that there is greater avidity for moisture over the southern Plains than over the northern. The air is more dry. Though precipitation is the same, owing to wider departures from the normal temperature, the air takes up soil moisture more rapidly.

SUNSHINE AND CLOUDINESS.

With a given amount of moisture already in the air, the rate of evaporation varies with the air temperature; but in direct sunshine the soil, and a layer of air in contact with it, may be raised to a temperature considerably higher than that of the air as a whole. Hence the loss of soil moisture will be the greatest, other things equal, in that region which has the largest number of hours of continuous sunshine.

The annual reports of the Weather Bureau give charts of the "average annual cloudiness," in parts, on a scale of 0 to 10, of the possible cloudiness. In the Plains region, it appears, the number of hours of sunshine, both for the year and for the summer half year, diminishes from south to north. At Dodge, upon the High Plains in western Kansas, and, in order northward, at North Platte, Nebraska, at Pierre, South Dakota, and at Bismarck, North Dakota, the records of annual cloudiness are averaged as follows:

Dodge	3.8
North Platte	4.4
Pierre	4.3
Bismarck	4.6

WIND MOVEMENT.

Wind contributes to the drying out of soil moisture by stirring the air layers, thus greatly accelerating the diffusion of the vaporized moisture through the air as a whole. In still air this diffusion takes place with comparative slowness. The rate of evaporation diminishes as saturation of the air is approached, and if the air remains undisturbed, upper dry layers can receive moisture only at the rate at which it can be transmitted through the lower moist layers. If there were no vertical component in the wind—i. e., if the air always moved in lines parallel to the ground surface—there would be no effect from it one way or the other upon evaporation. But wind contributes to the vapor loss of soil moisture, and of the moisture of foliage as well, by continually bringing relatively dry air into contact with it directly; and the stronger the wind the more vigorous and effective this action.

Another factor is change of temperature. A south wind, for example, may bring warm air, thus further increasing evaporation by raising the temperature; while either a north wind or a wind from off a mountain range may so lower the temperature that the algebraic sum of its two opposite effects may even amount to a reduction of evaporation.

Here again the High Plains are at a disadvantage compared with that large area of the Northwest having an equal or even slightly less precipitation. They have more wind in notable degree, and during the crop-growing season the direction of the wind is prevailingly from the south, while, as a rule, in the northern region a nearly reverse condition prevails.

The data are rather meager for statement of the normal wind conditions of the Great Plains as a whole. All of the requisite facts are noted only at stations of the first class, and among the large number of weather-record stations those of the first class, taking continuous note, automatically registered, of wind velocity, duration, and direction, are comparatively few. Of these, however, there is one upon the High Plains, at Dodge. Bismarck, in central North Dakota, on the same meridian as Dodge, and 9 degrees to the north, is another, and may be taken as fairly representative of the northern region of equal rainfall but greater effective humidity.

Following is an interesting presentation of the full records at Dodge and at Bismarck for 1897, as given in the annual report of the United States Weather Bureau for that year:

Velocity, duration, and direction of wind at Dodge, Kansas, in 1897.

1897.	Miles an hour.											
	1h a.m.	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Noon.
January	9.2	10.2	10.0	10.7	11.3	11.8	11.1	11.1	11.8	12.6	13.4	13.6
February	9.1	8.8	8.1	8.5	8.4	8.6	8.9	9.0	9.3	9.5	10.2	10.2
March	12.7	11.5	10.4	9.9	9.6	9.8	10.3	10.2	11.0	12.8	14.2	14.0
April	11.6	11.6	11.6	11.3	10.0	10.1	10.9	11.6	14.0	15.8	16.5	16.6
May	9.2	8.2	7.7	7.3	7.1	6.4	6.8	6.9	9.0	10.6	12.4	13.0
June	12.1	10.7	9.5	9.4	9.1	8.6	8.2	8.8	10.9	12.6	14.0	14.2
July	11.4	10.7	10.2	8.9	7.6	6.8	6.9	7.3	9.8	12.5	14.3	15.3
August	7.3	6.3	5.9	6.0	6.3	6.7	5.9	5.9	7.4	9.1	10.1	10.2
September	10.4	9.4	8.3	7.0	7.5	6.8	5.6	6.1	6.8	10.5	13.2	14.5
October	10.5	10.7	11.0	10.4	10.0	9.0	8.2	7.7	8.6	11.1	13.5	14.4
November	8.8	8.3	9.0	8.9	8.7	8.3	8.2	8.4	8.0	10.0	12.4	12.8
December	9.0	9.3	9.1	8.8	8.9	9.2	9.4	8.8	9.2	10.2	12.3	13.6
Year	10.1	9.6	9.2	8.9	8.7	8.5	8.4	8.5	9.6	11.4	13.0	13.5

Velocity, duration, and direction of wind at Dodge, Kansas, in 1897—Continued.

1897.	Miles an hour.											
	1h p. m.	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Mid-night.
January	13.5	13.5	12.8	11.8	10.6	9.3	8.2	8.0	8.4	9.1	9.0	8.7
February	10.9	11.7	11.2	11.5	11.1	10.4	8.4	6.8	7.7	7.9	7.8	7.9
March	14.5	15.2	15.3	16.4	16.1	15.8	15.5	13.7	12.9	13.0	14.0	13.5
April	15.8	15.5	15.1	14.8	14.3	13.8	13.3	12.4	11.0	11.6	11.2	11.1
May	13.8	13.8	13.9	14.8	14.9	15.2	14.9	13.5	10.1	9.5	9.9	9.7
June	14.3	15.6	16.8	17.5	17.8	18.0	18.1	16.0	13.2	13.3	13.4	13.2
July	15.1	15.5	16.1	16.2	16.7	16.0	16.1	14.8	12.2	10.5	11.2	11.1
August	10.6	10.8	10.8	11.1	10.8	10.9	10.5	9.5	7.7	7.2	7.2	7.6
September	15.3	15.8	15.7	15.8	15.8	15.3	14.9	12.2	10.8	10.0	10.0	9.8
October	15.2	15.0	15.3	15.2	15.0	15.0	12.8	10.2	10.2	10.2	10.4	10.5
November	13.6	14.3	14.3	13.8	13.4	12.1	9.4	8.7	9.1	9.0	9.0	9.4
December	14.8	14.7	15.8	14.4	14.5	12.0	9.3	8.3	8.2	7.7	7.3	7.4
Year	14.0	14.3	14.4	14.4	14.2	13.6	12.6	11.2	10.1	9.9	10.0	10.0

1897.	Miles an hour.		Duration, in hours.								
	Mean	Max. vel.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
January	10.8	36	121	79	7	43	140	92	71	182	9
February	9.2	36	105	124	17	106	68	76	51	117	8
March	13.0	51	96	106	32	148	124	95	42	95	6
April	13.0	50	127	61	21	119	117	62	24	179	10
May	10.8	40	45	112	40	199	233	78	6	15	16
June	13.1	67	65	70	13	118	351	73	10	18	2
July	12.2	41	53	52	14	82	376	81	9	68	9
August	8.4	32	48	110	30	145	245	89	39	33	5
September	11.1	40	48	45	8	118	448	28	12	2	11
October	11.7	39	84	72	3	73	302	74	64	69	3
November	10.3	37	110	41	5	65	193	118	42	137	9
December	10.5	48	115	61	16	65	77	89	97	219	5
Year	11.2	......	1,017	933	206	1,281	2,674	955	467	1,134	93

Velocity, duration, and direction of wind at Bismarck, North Dakota, in 1897.

1897.	Miles an hour.											
	1h a. m.	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Noon.
January	10.9	11.5	10.2	9.5	9.6	10.4	9.4	9.7	9.5	9.6	9.9	11.3
February	7.5	6.7	6.8	6.9	6.8	6.4	6.7	6.7	6.8	6.6	7.3	8.4
March	7.7	7.9	8.4	8.7	7.8	8.4	8.6	8.5	7.7	8.5	9.2	9.2
April	8.4	8.3	7.6	7.0	6.7	6.6	7.2	7.5	8.7	10.1	10.9	11.9
May	8.3	8.0	7.7	7.7	7.2	6.6	7.4	8.7	10.6	11.6	13.6	14.1
June	7.1	6.3	6.6	6.0	6.8	6.5	6.7	7.6	8.6	9.7	10.6	11.9
July	7.1	6.0	7.0	6.6	6.3	6.6	6.4	6.0	6.8	7.9	8.4	9.1
August	6.1	6.3	6.7	5.9	5.5	5.3	5.5	6.2	6.7	7.6	8.6	9.8
September	7.0	6.9	7.8	6.7	6.4	6.2	6.2	5.8	6.3	8.2	9.9	10.6
October	7.6	8.9	8.7	7.8	7.5	7.4	7.4	7.2	7.3	8.5	10.0	11.7
November	5.4	5.3	5.9	5.5	6.0	5.9	6.5	6.7	6.1	6.9	9.0	9.9
December	7.3	6.3	6.0	6.3	6.6	6.4	6.0	5.5	5.2	5.6	6.6	8.1
Year	7.5	7.4	7.4	7.0	6.9	6.9	7.0	7.2	7.5	8.4	9.5	10.5

1897.	Miles an hour.											
	1h p. m.	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Midnight.
January	12.4	12.2	13.8	13.5	12.5	11.8	10.5	9.9	9.4	9.5	9.4	10.4
February	9.8	10.8	11.2	11.4	10.8	10.5	9.4	8.8	7.9	8.1	7.7	7.6
March	10.1	10.2	10.3	10.5	10.8	10.8	9.9	8.6	7.6	8.0	8.1	7.8
April	13.1	14.2	15.6	15.6	15.9	15.0	14.5	12.8	10.5	9.5	8.9	8.7
May	15.4	15.6	15.8	16.0	15.4	14.6	14.8	13.9	10.7	8.7	7.9	8.4
June	12.3	12.8	13.5	12.9	12.6	12.4	11.3	10.3	9.5	7.8	7.6	7.0
July	10.3	10.8	11.3	11.3	11.1	10.7	10.8	10.7	9.2	7.7	7.9	7.8
August	10.4	11.2	11.1	11.6	11.1	10.6	9.9	9.5	8.5	7.8	7.0	6.4
September	12.0	12.9	13.5	14.0	14.0	13.0	12.1	9.7	7.9	7.6	7.9	7.3
October	13.4	13.7	14.1	14.2	14.3	12.5	10.5	8.2	7.1	7.4	8.2	7.2
November	11.4	12.7	12.9	12.9	12.3	10.5	8.5	7.4	7.1	6.5	6.3	5.3
December	9.5	9.8	10.3	10.9	10.5	8.2	6.6	7.9	7.8	7.9	7.7	7.5
Year	11.7	12.2	12.8	12.9	12.6	11.7	10.7	9.8	8.6	8.0	7.9	7.6

1897.	Miles an hour.		Duration, in hours.								
	Mean	Max. vel.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
January	10.7	47	31	37	46	80	24	20	18	403	85
February	8.2	48	31	129	91	63	20	31	33	184	90
March	8.9	35	97	96	109	107	26	16	40	194	59
April	10.6	47	148	42	60	128	47	32	64	169	30
May	11.2	36	113	61	95	148	102	23	14	183	5
June	9.3	41	97	51	94	187	70	40	25	135	21
July	8.5	35	97	52	90	165	76	35	38	147	44
August	8.1	48	69	91	114	146	79	11	34	173	27
September	9.2	34	22	36	134	165	65	29	27	210	32
October	9.6	39	72	31	58	137	66	33	46	280	21
November	8.0	36	92	56	90	68	43	33	44	253	41
December	7.5	40	26	63	53	112	52	21	66	305	46
Year	9.2	......	895	745	1,034	1,506	670	324	449	2,636	501

The mean velocities, both for the year and for the crop-growing season alone, were notably greater at Dodge than at Bismarck. During the crop-growing season the hours of no wind, or of calm, at Dodge were 53; at Bismarck they were 159. And the hours of southerly winds—i. e., from either the south, southeast, or southwest—during the crop-growing season were, at Dodge 2,962, and at Bismarck 1,548. Of due south wind during this season, the hours were 1,770 and 439, respectively.

EVAPORATION.

In evaporation tests the record made is not of the actual evaporation loss. That could not well be determined. There is determined, rather, by experiment what the loss would be from free standing water, measured in inches of its lowered level. The actual loss from the soil is of course much less, but under like soil conditions it will everywhere bear the same ratio to the possible loss.

It appears that upon the Great Plains, outside of the distinctly humid belt, the average annual evaporation, under the most favorable condition of a free-water surface, largely exceeds the total annual precipitation. For example, the evaporation at Dodge is 54.6 inches and the precipitation only 20.4 inches; at Bismarck the ratio is 31.0 to 18.5. The precipitation is even a little less at Bismarck than at Dodge, but, as we have seen, the relative humidity there is greater, and consequently the rate of evaporation is slower. At St. Vincent the annual loss is 22.1 inches and the annual gain but 19.5 inches. So, even in the wheat-growing Northwest, evaporation exceeds precipitation, or would exceed it upon a lake surface. In the Lower Mississippi Valley, on the other hand, the reverse condition exists, and at New Orleans, where the precipitation is 60.3 inches, the evaporation is but 45.4 inches. Standing water there would gain by direct rainfall 14.9 inches in excess of the loss it would suffer from evaporation, but at St. Vincent it would lose, on the contrary, 2.6 inches, and at Bismarck 12.5 inches, while quite uniformly upon the High Plains this loss in excess of gain would be about 35 inches annually.

The High Plains may be taken as very nearly a unit area with respect to evaporation, while to the north of the Kansas-Nebraska boundary there is rapid decrease toward the northeast. Amarillo has an evaporation record of 55.4 inches; Dodge, 54.6 inches; while, in order northward, North Platte has a record of 41.3 inches; Bismarck, 31 inches, and St. Vincent, 22.1 inches. Yet at each of these points the precipitation, both annual and during the crop-growing season, is about the same, varying little from 20 inches.

SUMMARY OF DEFICIENCIES.

The climatic deficiencies of the High Plains are virtually summed up in this last statement of comparative losses from evaporation. The climate is essentially arid, or at least verges upon aridity, in that the air is dry and robs the soil of moisture excessively. Comparatively the climate of the northern Plains is humid, though in the same precipitation belt. It appears from the foregoing that humidity, in the general sense here used, is not a matter of rainfall, primarily, but of the condition of the air with respect to saturation. In this respect the High Plains are arid, and their rainfall or precipitation record, taken alone, therefore is misleading. A precipitation equal to that even of the famous Red River Valley of northwestern Minnesota does not suffice to render them humid.

The truer index of climate is the relative humidity of the air, or its percentage of saturation under average conditions, especially during the crop-growing season. Precipitation is to be regarded as resulting from a disturbance of the normal condition of the atmosphere—a disturbance, in the first place, of temperature, lowering it and thereby reducing the capacity of the air for holding moisture below that of its actual content. The High Plains are subject to a wider range of temperature than are the Plains of the Northwest, and the drops below the dew-point temperature are commonly greater, producing heavier precipitation; but at the same time they are more local in effect and of shorter duration, so that the total annual fall is not greater.

Summing up, then, in comparing the climate of the High Plains with that of the agricultural Northwest, it appears, as a matter of scientific record, that though the amount of precipitation in the two regions is the same, both annually and during the crop-growing season alone, yet the High Plains are at a more or less marked disadvantage, in that (1) summer rains there are violent and of brief duration, as a rule, rather than gentle and long continued, as they commonly are to the north; (2) secular variation from the normal precipitation works greater harm; (3) the normal summer temperature is notably greater; (4) the relative humidity is notably less; (5) there are more hours of sunshine; (6) there is more wind, which, during the summer, is prevailingly from the south, is warm, and therefore has a drying effect, whereas during the same season in the Northwest the prevailing winds are northerly; and, finally, (7) it is found that, following as an effect of the brief ponding rains, the high temperature, the low relative humidity, the almost uninterrupted sunshine, and the persistent high winds, evaporation is greater in a marked degree.

In short, despite the fact that their rainfall is fully equal to that which produces phenomenal wheat crops in the Northwest, the summer climate upon the High Plains is dry. In a sense, precipitation may be regarded not as a normal factor but as an accident of climate, and, so regarding it, it may be said that the High Plains comparatively are arid, and require a heavier precipitation than those of the Northwest to produce like results.

Finally, the long records at Amarillo and at Dodge dispose in the negative of the question whether the climate of the Plains is undergoing change for the better, or, indeed, any change whatever of a permanent character. Daily observation, extended over a quarter of a century, plainly exhibits stability, in the long run, while the oscillations above and below the mean, in groups of years, are to be regarded as operating on the whole as a disadvantage, working more harm in dry years than can be compensated for in years of plenty.

CHAPTER IV.

IRRIGATION NECESSARY TO AGRICULTURE.

So long as any considerable body of land in the humid zone of the Plains remained unoccupied, no experiment in agriculture was attempted to the westward in the "short-grass" country. The eastern limits of the Great American Desert had been pushed back so far as to include in the agricultural area the humid belt of undulating prairie, carpeted with long grasses and with trees bordering its numerous streams; but the flat upland stretches of the High Plains, streamless as well as treeless, appeared still unmistakably to have the character of an irreclaimable desert.

Distinction had been drawn between prairies and plains proper. The desert was recognized as beginning only where the prairies left off, extending thence to the mountains. Another distinction was now made in further subdivision. It was noted that the western half of the so-called arid plains remaining was considerably eroded and had flat areas preserved only in small isolated patches, while the eastern half, with its closely knit sod as distinguished from bunch grass growing in tufts, was unscarred and flat, excepting where mountain streams had cut valleys across it in north-south order at wide intervals. Consequently with the pioneer cattleman of the extreme western belt it came to be said that to journey eastward was to go "out on the Plains," upon seemingly interminable stretches of flat land. From his side the Plains proper lay to the eastward; beyond extended the undulating prairies of the humid region.

The western belt of dry-climate erosion descends toward this central uneroded belt, and the eastern belt of humid-climate erosion drops away from it; but erosion on the east is being extended westward by head-stream sapping on the part of a multitude of small spring streams draining off the upland ground water, and there has resulted here a fairly definite and nearly continuous boundary having the character of an eastward-facing escarpment, as shown on Pls. CXIII and CXVIII and in figs. 300 and 307. From the prairie side the intermediate region therefore stands in light relief as uplands, and it is from this side that it has received the appellation of the High Plains. But aside from distinctions by topographic difference, it came to be recognized also that the central flats differed from the extreme western belt on the one hand in the character of their rainfall mainly, and from the extreme eastern belt, on the other, mainly in the volume of it. By the western stockmen they were designated the "rain belt," by which was meant that desert conditions therein were in a measure mitigated merely.

With the final complete occupation of the eastern prairies, however, and the demonstration there of a fertility and productiveness not previously suspected, the term "rain belt," applied to this lightly watered fringe of the desert, came to be in large part responsible for an attempt which immediately followed to reclaim still another zone from the Arid Lands. The attempt was made by cultivation and planting alone, without artificial watering. It was an experiment in agriculture on a vast scale, conducted systematically and with great energy, though in ignorance or disregard of the fairly abundant data, indicating desert conditions, which up to that time the Weather Bureau had collected. Though persisted in for several years with great determination, it nevertheless ended in total failure. Directly and indirectly the money loss involved was many millions of dollars. Full measure of the harm resulting should take account also of the immigration into other regions of a class of people broken in spirit as well as in fortune.

The movement of settlers onto the High Plains was an inroad. The only population there at the time consisted of a few stockmen, making common use of the public range. The newcomers were farmers and town builders. Elsewhere in the Arid Region stockmen, holding the public lands as common range, had had to contend with immigrating farmers, but always in small numbers and with the advantage on the stockman's side that, having been first on the ground, he already held the desirable ranch sites. The farmer's aim heretofore had been agriculture by irrigation along the stream bottoms; at most the stockman had been merely inconvenienced; the interstream areas in any case were left in his possession undisturbed. But in this instance irrigation was not in contemplation; the interstream areas, not the valleys, were invaded, and in some parts of the High Plains, notably in western Kansas, the stockmen were completely dispossessed.

The movement was an inroad in the sense also that it began abruptly, and rapidly brought in a large population. The humid zone merges into the subhumid by insensible climatic gradations; but, as we have seen, the High Plains, as approached from the eastward, are distinctive topographically. A strip immediately adjacent on the east is minutely cut up by the multiple spring-creek headwaters of eastward-flowing streams originating there, so that transition is from a region of intense degradation to flat uplands of seemingly boundless extension. This eroded strip, furthermore, is one of headwater capture from the High Plains, lying within the subhumid belt to which the High Plains themselves belong. The undulating prairies, of humid climate, begin well to the eastward, so that in climate also there is perceptible change, as between prairie and uplands, proportioned to the breadth of this intervening belt captured from the latter. There is equally marked difference in soil, for that of the upland flats is unstirred by surface run-off and is the product merely of decay in place.

Responding, then, to both climatic and soil differences, the grass covering of the High Plains differs also, and in marked degree, from that of the eastern prairies. Though of a lawn-like continuity, the growth is too short for cutting; but the depth and firmness of its sod and its nutritious quality, retained the year around, were taken as demonstration at least of fertility of soil. The universal green with which each spring it carpeted the High Plains came to be regarded as a sure promise that planting to wheat would at once result in another notable extension of the agricultural area.

The gradual westward progress of emigration had received a definite check at the farther limit of the prairies; between the prairies and the High Plains the minutely eroded headwater strip intervened. Emigration had halted until the prairie lands of all grades had first been fully taken up. In proportion, then, as the movement had for a time been stayed, it now proceeded quickly and in larger volume.

THE AGRICULTURAL EXPERIMENT.

From records of the Weather Bureau, presented in the last chapter, it appears that while the climate of the High Plains is in the long run subhumid, it varies greatly nevertheless through groups of years from fairly humid to arid; and that, furthermore, since rise above the mean has to be of notable amount before humid conditions are attained, the periods favorable for merely fair yields of humid-climate crops are comparatively of brief duration.

Though immigration had an abrupt beginning and continued rapidly, it did not take on the proportions and assume the character of a "boom" until after several years. That is, the movement was not from the outset advertised and promoted. It was prolonged and swelled by these means on the part of railroad companies and town builders; but the explanation of its inception is to be sought rather in the fact of the prevalence of exceptionally heavy rains during the years (1883–1885) just preceding.

Sherman County, in western Kansas, may be taken as fairly representative of the central area of the High Plains into which immigration was heaviest and in which the "boom" was most actively conducted. Of flat uplands this county has nearly 1,000 square miles. The total upland area of the High Plains belt, closely approximating the total cultivated area of the State of Iowa in the census year 1890, is about 40,000 square miles. In 1885 the population of Sherman County was 1 person to 10 square miles; the next year it was 3 to 1

A. THE CARPET OF GRASS

B. CLEAN SWEEP OF THE PRAIRIE FIRE.

square mile. In 1889, three years later, it had risen to nearly 6. During the next four years, up to 1893, it increased but little; and by 1896 it had dropped to 4. The height of the "boom," as well as its heaviest penalties and the end of it, was in 1893. During the decade 1885 to 1896 the possibilities of irrigation in the valleys from the larger streams were barely considered. Settlement and all attempts at farming were confined to the uplands. Expectation had been that it would be possible to achieve upon these smoother and more easily tillable plains a reclamation similar to that which had been so easily accomplished in the State of Iowa, for example, and the first attempts in this direction had been abundantly encouraging. The yield, not only of wheat, but of every variety of crop experimented with, exceeded expectations. An idea of the character of these crops may be had from photographs *A* and *B* of Pl. CXXVII, though these photographs were actually taken at a later date in a similar season of plenty upon the uplands farther south.

With such demonstration, under slightly improved climatic conditions, of the possibilities residing in these vast unbroken stretches of fertile land, it is not to be wondered at that in the ardent desire to turn

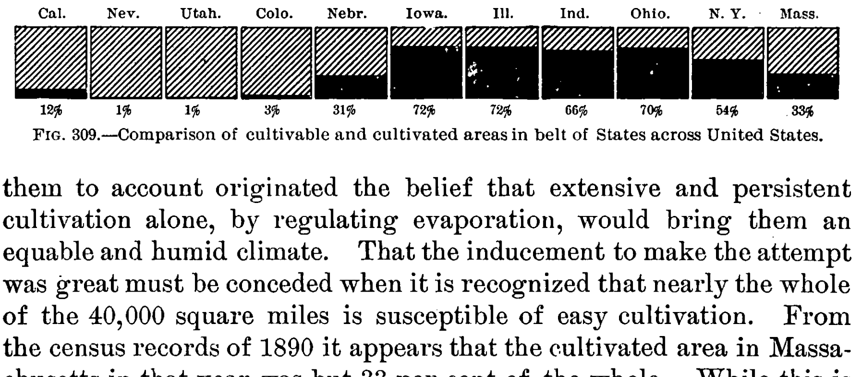


FIG. 309.—Comparison of cultivable and cultivated areas in belt of States across United States.

them to account originated the belief that extensive and persistent cultivation alone, by regulating evaporation, would bring them an equable and humid climate. That the inducement to make the attempt was great must be conceded when it is recognized that nearly the whole of the 40,000 square miles is susceptible of easy cultivation. From the census records of 1890 it appears that the cultivated area in Massachusetts in that year was but 33 per cent of the whole. While this is not the measure of the cultivable area in that State, it is nevertheless true that the area in Massachusetts which is as easily cultivable as nearly the total area of the High Plains is much less than 33 per cent.

Fig. 309 gives the ratios of cultivable areas to areas cultivated, in 1890, in a belt of States from Massachusetts to California. The cultivated area in New York is 54 per cent; in the North Central States it ranges from 66 to 72 per cent; in Colorado it is 33 per cent; in Utah and Nevada, 1 per cent, and in California 12 per cent. Even the reclaimed area in the prairie State of Iowa, almost precisely equal to the upland area of the High Plains belt, is notably inferior in ease of cultivation to the latter. The cultivated area in California is less than half the area of the High Plains, and is furthermore handicapped, in the main, by necessity for artificial watering.

The maximum of cultivation upon the High Plains was reached in 1893. Fig. 310 presents a relative statement of the total areas and the areas cultivated in that year in the North Central States and upon the High Plains, respectively. Considering the extraordinary ease of cultivation there, a comparatively small result has been achieved in the latter region.

Much is heard of the high productiveness of the so-called Arid Lands, when by irrigation they are brought under cultivation, and of

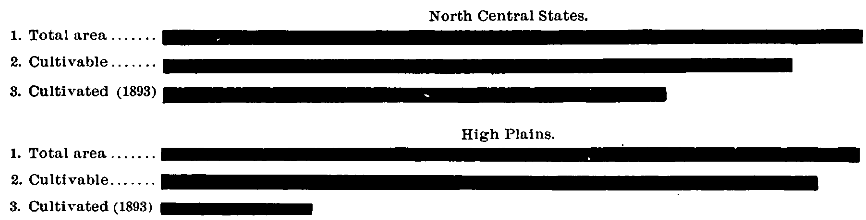


FIG. 310.—Comparison of cultivable areas and areas cultivated in 1893 in North Central States and on High Plains, respectively.

the importance and value of the results already achieved in their reclamation. In the main these statements are not exaggerated. But ideas which are greatly exaggerated nevertheless prevail as to the proportion of the areas reclaimable and actually reclaimed. The total area of the Arid Region may be taken, in round numbers, to be 800 million acres. Of this total it is estimated that not quite one-half is cultivable—that is, if irrigation were not necessary, so much could be farmed with profit—but it is estimated also that, from all sources,

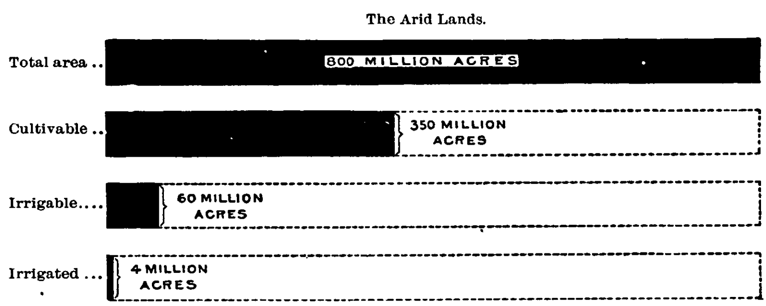
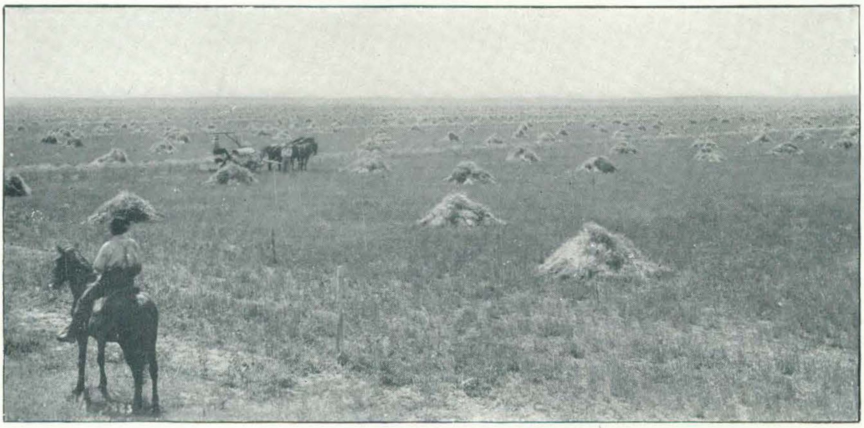


FIG. 311.—Comparison of cultivable, irrigable, and irrigated areas of the Arid Lands.

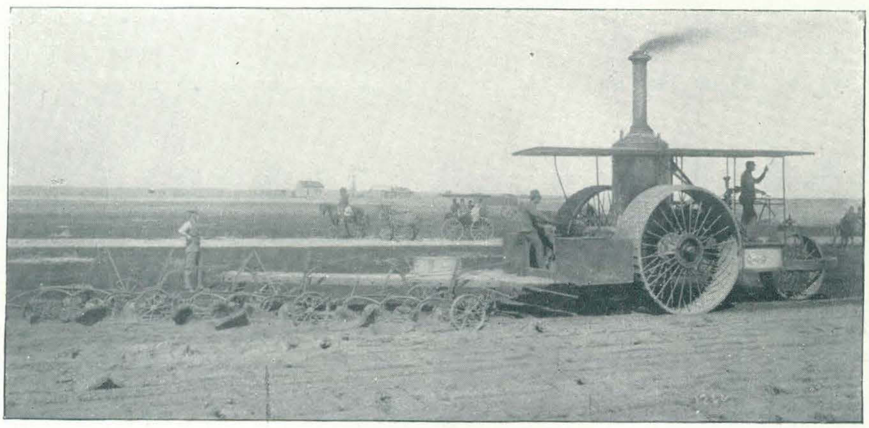
there is water available for the irrigation of not more than 60 million acres. In other words, only 7 per cent of the whole is reclaimable—a proportion notably less than that in rock-encumbered Massachusetts. Finally, the actually irrigated area, of which we hear so much, is but 4 million acres, or one-half of 1 per cent of the whole.

As a zone mistakenly regarded as arid, and which was now to be reclaimed from that apparent condition merely by persistent cultivation without irrigation, the High Plains appeared to be exceptionally



A. A WET-YEAR CROP.

B. A WET-YEAR CROP.



C. PLOWING BY STEAM.

favored. They had no mountainous tracts with bordering wash plains of coarse débris, bare of soil, to be deducted from the total. There was presented, on the contrary, a dead level of nearly uniform fertility, having the appearance of farming land of the choicest quality. But the hope of reclamation had no scientific basis. No consideration, for example, was given the all-important question whether, quantitatively, the possible saving in evaporation losses would be of practical account. That was left for determination by actual trial. The hope had had its origin rather in the pressing need for another ample expansion of the agricultural area, and in the fact that the High Plains seemed to meet requirements ideally, excepting only in one particular. The plan proposed for remedy of this single defect was not of a kind calculated to discourage effort. It was merely to proceed with the occupation as rapidly and on as large a scale as possible, leaving that task to the

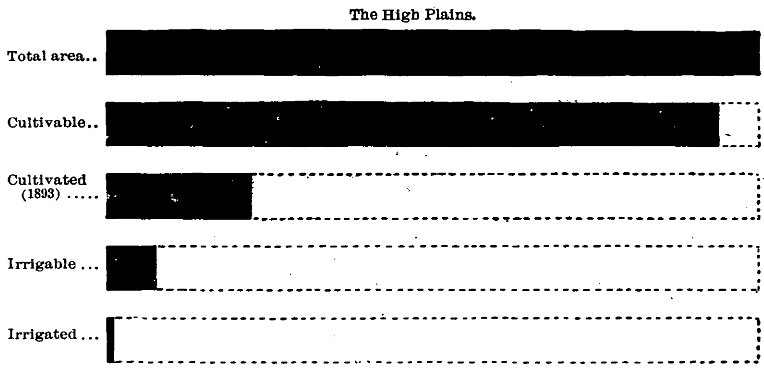


FIG. 312.—Comparison of cultivable, cultivated (1893), irrigable, and irrigated areas of High Plains.

operation of natural agencies under the new conditions. It was not contemplated that there would be need for artificial aids, such as supplemental watering—i. e., irrigation.

The costly undertaking was not entered upon as an experiment, however. From the outset its success was taken to be assured, and the immigrant as a rule invested in it the whole of his possessions. As a rule, also, he mortgaged his lands in following years.

If the multiplied indications of virtual aridity presented by the Weather Bureau records during a quarter of a century could not be accepted as conclusive, they now at least may be so regarded in the light of this added evidence from a practical test involving the continuous cultivation for more than a decade of some thousands of square miles. Including its valley areas, in which there has been some progress in reclamation by irrigation, the condition of the High Plains belt at the present time is comparable to that of the Arid Lands as a whole. Its cultivable, or more strictly speaking its tillable, area is relatively much greater; but its irrigable area is small, while that actually irrigated is comparatively minute.

In more detailed statement of what was actually accomplished by this experiment in agriculture, fig. 313 is presented, giving the areas planted each year for the twelve years, 1885–1896, upon the flat uplands in Sherman County, western Kansas. Immigration was heavier into southwestern Kansas; on the other hand, it was lighter farther south. It will be seen that the area planted had slow increase from 1885 to 1888; that in the year 1889 it was trebled, though in the following year it fell back halfway, and that it then rapidly increased for three

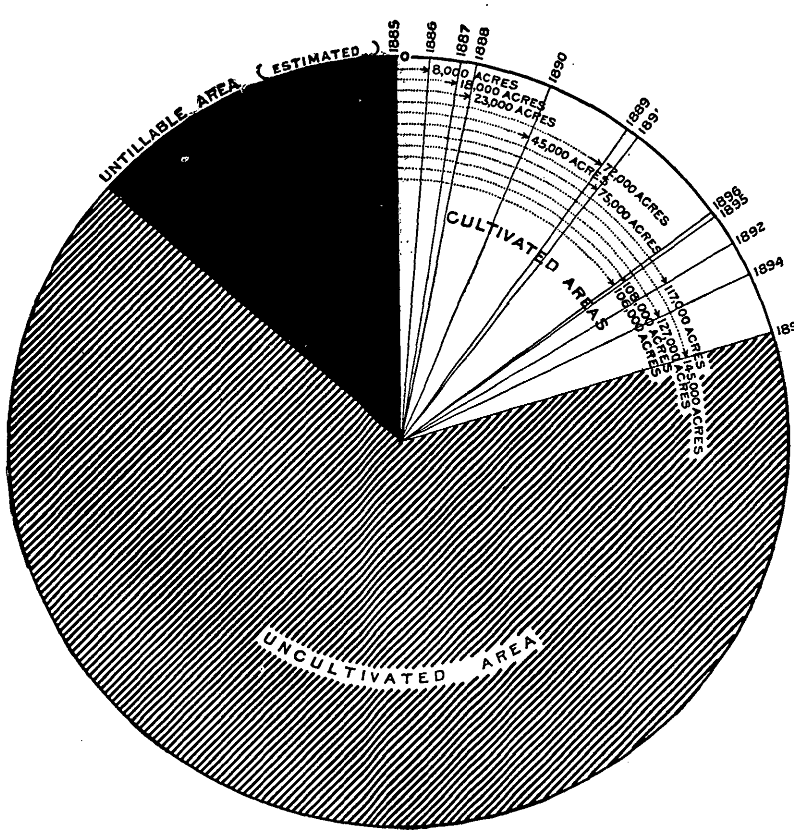


FIG. 313.—Comparison of cultivable area and area cultivated each year for twelve years in Sherman County, Kansas.

years, reaching the maximum in 1893. But the years of heaviest planting as a rule coincided with the years of light rainfall, and were those of heaviest loss. For example, in 1888 there was a heavy fall and abundant harvests from the small area planted. The trebled area of cultivation in 1889 followed in consequence of this encouraging showing; but the rainfall in 1889, on the other hand, was light, and the resulting loss was large in proportion as the expense of planting had been heavy. The following year there was some discouragement and diminished planting. However, the small profit, due to a small rise here in the inches of precipitation, led to the belief that cultivation was after all beginning to tell, and the "boom" may be said to have started. Immigration and planting rapidly increased. In 1891 there was an exceptionally heavy fall, and as this was coincident with liberal planting there was a large profit. The area planted the next year was increased by fully 50 per cent; but the climatic conditions that year were not so favorable, and there followed marked decline in profits. Little discouragement resulted, however, and 1893 showed another notable increase in the area under cultivation. But 1893 was a year again of desert dryness, and there was complete loss. Drought continued for the next two years, to 1896, inclusive, making four consecutive seasons of no return, yet the acreage cultivated diminished but slowly. The failure of 1896, however, resulted in total collapse and heavy emigration, and though 1898 brought again a humid maximum the abundant rains of that year fell mainly upon abandoned lands and the scanty, unharvested crops of a previous season.

Briefly summarizing, we have: (1) a one-year period (1888) of humid-climate conditions, which gave origin to the agricultural experiment; (2) a one-year period (1889) of arid conditions, yet of heavy planting and therefore of total loss; (3) a one-year period (1890) of light planting, but of fair precipitation and moderate profits; (4) a two-year period (1891–1892) of heavy planting coinciding with heavy precipitation, and therefore a period of large profits; (5) a four-year period (1893–1896) of continuous heavy planting, but with the calamitous accompaniment of continuous drought, and, finally (6), in 1898, a return to humid conditions, though after all effort had come to an end.

Especially instructive are the results achieved during the six years from 1891 to 1896, considered in the two groups, first, of two good years (1891–1892), in which heavy planting coincided with heavy precipitation, and, second, of four following years of unbroken drought (1893–1896), in which planting even increased until brought to an end by the exhaustion of working capital.

DROUGHT-RESISTING CROPS.

Among the several cereals wheat continued the favorite, but at the same time there was active experimentation on a small scale with sorghum and other varieties of cane, with a view to their use as supplemental feed for sheep and cattle. Energy continued to be devoted mainly to farming for export; stock raising and the growing of forage for stock were altogether incidental. Nevertheless, the results of the experiments with sorghum and other dry-climate canes are the only ones which contain anything of promise for the future of the High Plains.

In fig. 314 we have the relative mean values of the acre yields of wheat in western and eastern Kansas, first, for the humid two-year period; second, for the arid four-year period, and, finally, for the entire period of the experiment. The four-year drought was felt in eastern Kansas as well, but there was some profit there over the cost of production. During the two wet years, on the other hand, the

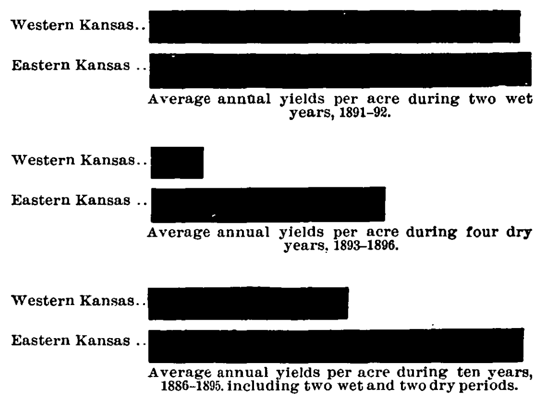


FIG. 314.—Comparison of acre yields of wheat in western and eastern Kansas.

High Plains made very nearly as good a showing as the East. But, averaged for the whole period, their yield fell short of a profit.

If now, taking western Kansas alone, the results with wheat be compared with those with sorghum, as in fig. 315, there is apparent for the latter a marked advantage, as well as a profit in some measure, under all conditions. Other crops of the humid-climate varieties, which were found to do well during wet years, were corn, rye, barley, oats, and

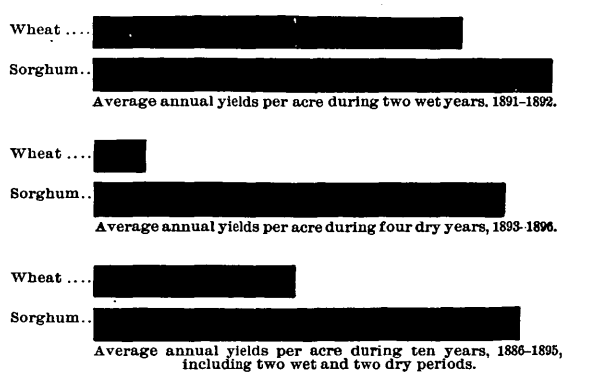
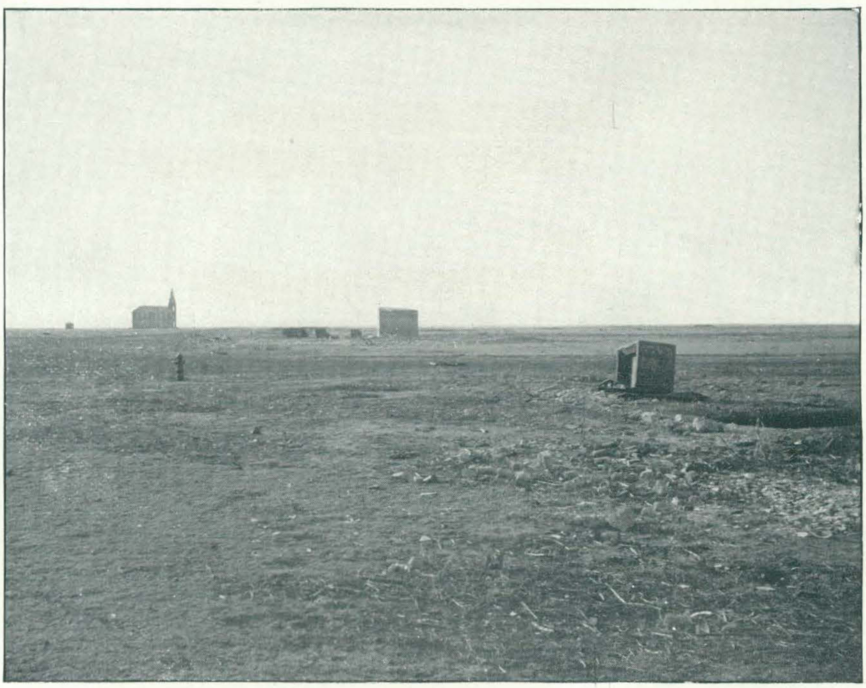


FIG. 315.—Comparison of acre yields of wheat and sorghum in western Kansas.

potatoes. Grouping these as humid-climate crops, for comparison with results from sorghum, etc., it will be found from the values of the acre yields of the former that on the average they were notably below the acre yields of the latter. The numbers of cattle and sheep had been considerably increased also, and sorghum acquired its superior value

A. ABANDONED SCHOOLHOUSE.



B. ABANDONED TOWN.

largely from the fact that in dry seasons it was needed for forage and found its market on the ground. Its high value, as here given, was in a measure fictitious, in the sense that it would not have been nearly so great if its product had been large—that is, if the total acreage had been devoted to its growth. But relatively it was a successful crop, none the less.

The comparative areas devoted to these humid-climate and dry-climate

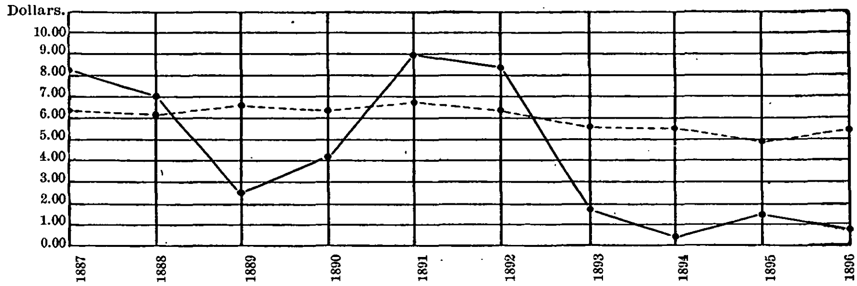


FIG. 316.—Comparison of values of acre yields of humid-climate crops (solid line) and drought-resisting crops (broken line) in western Kansas.

crops, respectively, as averaged from the reports of several counties in western Kansas, are graphically exhibited in fig. 316. It will be seen that the area devoted to cane (chiefly sorghum) had slight increase during the 1887–1896 decade and was comparatively small, while that devoted to the cereals (chiefly wheat) had great increase and large fluctuations. But from fig. 317, giving the values of the acre yields of

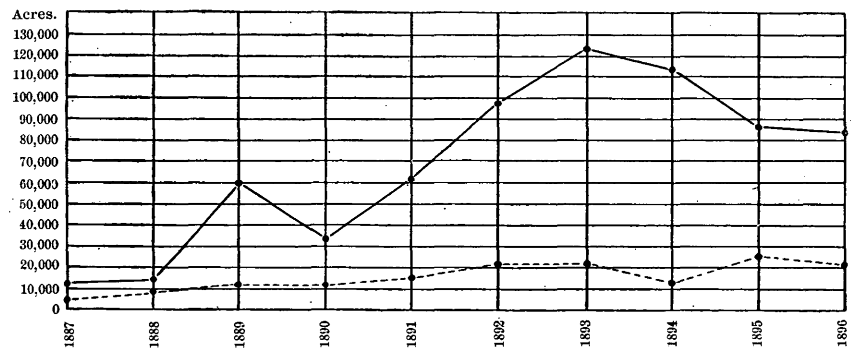


FIG. 317.—Comparison of areas planted to humid-climate crops (solid line) and to drought-resisting crops (broken line) in western Kansas.

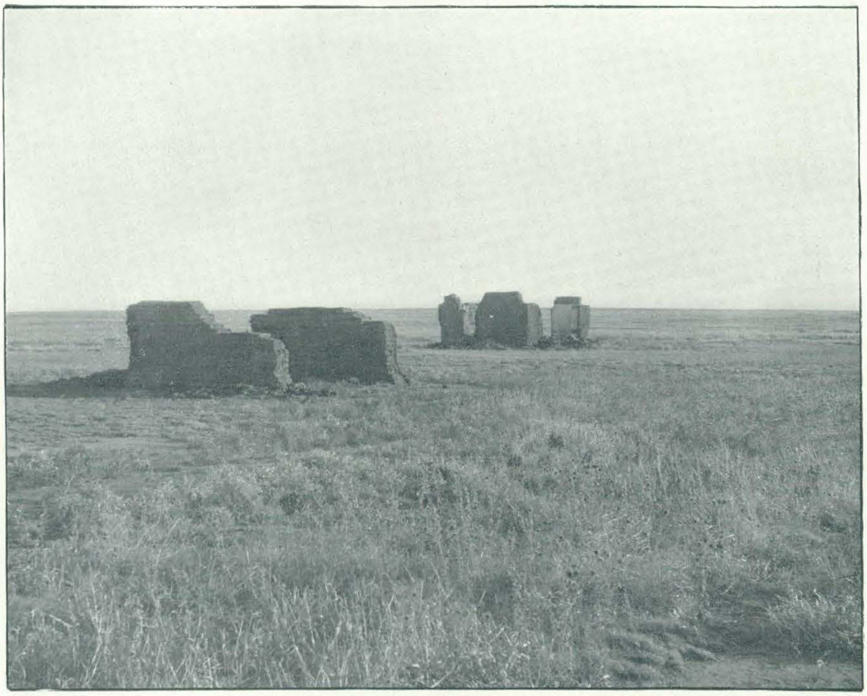
humid-climate crops and dry-climate crops, it appears that the latter retained a nearly uniform and high value. Though the yield of sorghum in tons per acre diminished somewhat during dry periods, its value per ton increased, and there is therefore shown a slight tendency toward a maximum, coinciding with each minimum yield of wheat.

The lesson of the crops, which seems to be conspicuous here, is that it pays on these subhumid plains to raise cane forage if there be stock at the same time to which to feed it, and that even in the periods of drought the drought-resisting crops will produce a yield of some value. In short, it is not practicable upon the High Plains to farm for export. Without supplemental watering the average yield of the cereals and of farm products in general will fall below the cost of production.

THE VISIBLE EVIDENCES OF FAILURE.

An idea of the magnitude of the scale on which the attempt to farm the High Plains was made, especially in western Kansas, as well as of the great aggregate losses that must have resulted from the utter failure of this attempt, is strikingly to be had from the frequent spectacle of abandoned towns systematically spaced apart upon the flat uplands in anticipation of a dense but uniform farming population, for which they were to have been points of supply. In disregard of the possibility of failure, the first step in the occupation of the country was the building of these well-appointed towns. Their sites now, as a rule, are marked merely by parallel rows of cellar excavations, with iron hydrants perhaps at street crossings, and by occasional isolated public buildings of brick or stone from which all doors and windows and interior furnishings have been removed. Frame structures of every description have been carried off bodily to distant valleys for use there as ranch buildings. Outside the towns sod was employed almost universally in the construction of farmhouses. Of these even the roof beams have been removed, leaving only the plastered sod walls remaining as rapidly crumbling ruins. The rectangular subdivision system of the Land Office is indicated almost universally by plowed roadways, blocking out square-mile sections, within which the old plowed fields, amounting in the total to millions of acres, are slowly returning to grass, while occasional leaning fence posts, with dangling strands of barbed wire, mark the former lines of many thousand miles of fencing.

The great body of emigrants have either returned to the East or have drifted farther west. A small percentage has scattered along the bottom lands of the larger valleys. On the vast upland flats, however, an occasional settler remains, and he has become a "stock farmer." His location is always first to be discovered by means of a windmill wheel turning above the horizon. A field of sorghum surrounds the house, and a "bunch" of cattle range without its rectangular fenced inclosure to a radius not too great for easy return to the pumping trough. The stock farmer is merely "holding on," waiting for a change of climate. It is his bunch of cattle, making use of the natural grass crop, which enables him to do so. But as a rule his hope and his ambition are, after the temporary unfavorable conditions—as he regards them—shall have passed, to return to the growing of wheat for export.



A. SOD-HOUSE RUINS.

B. CISTERN NEAR SOD-HOUSE RUINS.

SOIL STORAGE AN APPRECIABLE AID TO FORAGE CROPS ONLY.

Scientific cultivation takes account of the fact that it is practicable to retain in the soil a larger portion of the moisture which it absorbs immediately after rain than is retained there under ordinary methods of tillage. Rainfall is disposed of by natural processes in three ways: A portion sinks into the ground; another portion runs off; a third is evaporated. So far as immediate plant use is concerned, the run-off and evaporation losses are complete.

Of the absorbed portion utilization is only partial, however. This ground moisture does not long remain in the soil zone, and for utilization of it plants require time. There is a tendency for it all to continue downward and eventually come to rest as a contribution to the ground water, below the "water-plane" level of which the ground pores, by long repetition of this process, have become saturated. If the soil and subsoil be dry, this downward tendency will for a time be aided by the pull of capillarity. By capillary tension water is drawn from moist ground into dry, whatever the direction, and at first the strongest pull will be downward, aiding gravity. After the passage of a surplus the effect of capillarity, however, is to slow descent.

The action of evaporation is not wholly superficial; it is penetrating as well. It will be felt in the partially air-filled pores, at a slowing rate, immediately following the first downward passage of water in large volume; and with drying near the surface capillary tension overtakes and vigorously returns some portion of this water toward the surface. In this return, growing plants are nourished, but in part also there is contribution to the earlier complete loss by evaporation.

In soil storage, scientific cultivation, by packing the ground at a slight depth, creating a floor, and by formation of a "dust cover" above, accomplishes a detention within the zone of growth of that portion of the rainfall which had not at once escaped from the surface by run-off and by evaporation. It diminishes both downward and upward escape.

This detention is partial and imperfect. The resulting gain can be but slight. It will be of importance where only a small addition to the normal supply is required. But the additional supply needed upon the High Plains for wheat is large.

Soil storage has telling effect during periods of minimum rainfall in humid lands. In a region where drought is the normal condition it should amount to an appreciable aid in the growth of dry-climate crops, such as the sorghums, if economically practicable; but it could not sustain wheat through a normal season upon the High Plains.

CHAPTER V.

IMPOSSIBILITY OF GENERAL IRRIGATION.

The settlers upon the High Plains were from the East and without experience in irrigation. They were not unacquainted with the large results which had been attained by artificial watering in the Arid Region, but the means there employed involved the grafting upon simple farming of unfamiliar engineering practices for which they had no inclination. Furthermore, the upland areas of the High Plains belt were so far removed from streams that their watering in this manner appeared obviously to be a vast undertaking. Though projects for diversion of the Arkansas, the Platte, and even the Upper Missouri to this central region had early been broached, they had received little attention, and upon failure of his original programme the Eastern emigrant abandoned the field as abruptly as he had entered it.

THE MOUNTAIN STREAMS OF INSUFFICIENT VOLUME.

Meanwhile, however, Western irrigators had begun canal and ditch development along the valley of the Arkansas.

EXPERIMENT WITH THE ARKANSAS.

The town of Garden, in western Kansas, had its inception as an irrigation community. Here extensive diversion works, taking water from the Arkansas River, accomplished the reclamation not only of a breadth of river bottom, but of a considerable acreage also upon the uplands. There was no storage of the out-of-season flow, nor any attempt to utilize flood flow; but the possibilities of the normal run of the river at this point were realized to the full. The upland area thereby reclaimed, however, though sufficient to give origin to a town of some importance, amounted to an insignificant fraction of the whole. It could not, for example, without exaggeration in size be clearly shown upon the general map of the High Plains (Pl. CXIII). A like demonstration of insufficiency of the easily manageable supply during the crop-growing season was made along the Platte in central Nebraska.

The results actually attained were in themselves abundantly worth while, but as a measure of the possibilities of general reclamation of the High Plains they showed that the mountain streams were wholly unequal to the task, unless recourse might be had to storage.

MEAGER POSSIBILITIES FROM STORAGE.

Complete storage, not only of the out-of-season flow, but of the very heavy flood flows of all seasons as well, would manifestly call for engineering constructions of great size and cost. It was generally believed, in the absence of detailed information bearing upon the volume of water which might thus be obtainable, that the volume would be ample. It may easily be made apparent, however, that any such estimate is greatly mistaken. Not even with the fullest storage and practically complete utilization could the mountain streams be made to avail for irrigation of any considerable portion of the High Plains.

Storage on any great scale, in the sand-wash beds of the Arkansas and the Platte, is out of the question. As we have seen, the arid belt to the west of the High Plains, originally overspread and built up by streams from the mountains at a rate more than sufficient to offset any erosive work of its local precipitation, now finds the mountain streams, confined in valleys across it, cutting down to a new grade, leaving the intervalley areas to the effects of desert erosion unobscured. The arid belt is without the sod covering which in the next climatic zone to the eastward, also above grade, prevents concentration into lines of drainage and the beginnings of degradation. In crossing it, therefore, the mountain streams receive a notable contribution to their burden of silt. Flood storage upon the Plains, even if practicable, would in consequence be uneconomical, in that the life of reservoirs would be too short. They would too soon become silted up. But such storage in the absence of natural dam and reservoir sites along the trunk-stream valleys would not be practicable. This will be the opinion of engineers. It will be reached from a point of view which those who are not engaged in large undertakings of the sort do not often take. Storage should be in the mountains and distributed among the tributaries rather than wholly on the main trunk of a stream in the foothills. Then, in order to minimize the inevitable large losses of a desert stream by ground absorption and by evaporation, diversion and application in irrigation should take place as close to the mountain foot as practicable.

For example, to utilize the Arkansas in the arid belt would result in the reclamation there of a larger area than upon the High Plains, in proportion as the loss in getting it to irrigable lands in the former case would be less; and the difference would be marked. At least these mountain streams owe a first duty to the lands they traverse first; but since lands close at hand are watered at a smaller cost in evaporation and seepage losses, they should first be served to as large an extent as possible, if the result desired be the largest possible measure of reclamation.

As to just how large a measure of reclamation is practicable, upon examination it is at once apparent that within the arid belt alone there are cultivable and fertile lands, accessible by canals and ditches, in larger amount than could be covered by the total annual flow of the mountain streams, floods included. In other words, with the fullest and at the same time most economical utilization of the run-off from the mountains, it would be found that the supply would fall short of demands before the High Plains could be reached. That it must so fail is at once apparent when it is noted how inconsiderable is the catchment area within the mountains which has drainage eastward as contrasted with the vast area of the Plains over which it is proposed to distribute mountain water, and when, furthermore, it is seen that the mean annual precipitation in the mountains is far from heavy, is in fact light as compared with that, for instance, of northern Washington. The important fact to be recognized here is that the streams which traverse the Plains from the Rocky Mountains—their pulsations in floods included—are not strong-flowing rivers, such for example as the Nile, or the rivers of India which issue from the Himalayas. To parallel the case of India and the Himalayas, the Plains region should slope the other way and the Appalachian humid region to the east should drain, not to one side into the Gulf, but westward across it. As the case actually stands, there is not water enough from the Rocky Mountains completely to utilize even the extreme western and arid subdivision of the Great Plains.

The High Plains present a larger expanse of accessible and cultivable lands than this arid belt. To reach them across the latter would involve so much loss from seepage and evaporation that the area reclaimed would be much smaller than could be reclaimed close to the mountains, and an area in proportion to the whole insignificant. But the claims of the arid belt could not be thus wholly disregarded. Hence, even with complete storage and under an equitable arrangement, the High Plains could expect to receive no appreciable benefit. It is very doubtful, however, whether complete storage will ever be found to be economically practicable. It may be accepted as certain that it will not in any case be undertaken for the reclamation of lands at a distance when lands are to be found close at hand which are reclaimable at less cost.

The experiment of upland irrigation from the Arkansas River near Garden was at first strikingly successful. Three long canals and many miles of distributary ditches were constructed, and although the upland area thus brought under cultivation was relatively minute the large profits resulting operated to hasten the discouragement of those who up to this time had been depending upon the meager rainfall alone. It failed in turn, however, because of increasing demands on the river in the arid belt to the westward, in Colorado, resulting finally in the drawing off of its total run during the growing season. It soon came to be facetiously remarked of this elaborate and welldevised irrigation system that it constituted the finest display of dry ditches in the Arid Lands.

The out-of-season flow of the Arkansas at Garden still goes by, but large undertakings already on foot looking to storage in the mountains foreshadow the eventual complete disappearance of the river in western Kansas, except as it may from time to time be briefly rejuvenated by floods too large to be manageable.

THE CANADIAN AND THE PECOS.

From examination of the map (Pl. CXIII) it may at first sight appear that the Canadian and the Pecos rivers offer some hope of reclamation for the Staked Plains plateau, since the western arid belt seems not to be represented there; but in the case of those streams, as in that of the Arkansas and the Platte, the same objection applies, namely, that they are not great rivers. The Pecos Valley west of the Staked Plains could make full use of all of its waters; and while the valley of the Canadian is not well supplied with bottom lands within the High Plains belt, it nevertheless broadens just without, to the eastward, and the stream may readily be utilized there, before the humid zone is reached, to as great extent as impounding and control of its flow may render possible. In the case of either stream the point of its diversion to the upland area, on account of the general high elevation there, would of necessity be well toward its headwaters. The Pecos is mainly fed along the western side of its valley below this point. Its volume where it could be taken out is so small it is not unlikely that it would not even survive the losses incident to diversion and long canal transportation. Furthermore, the initial cost of impounding and of diversion works, together with the cost of maintenance, would be prohibitive, in view of the small result that under any possibility could be achieved. The latter considerations apply equally to the Canadian.

Probably the early experience in upland irrigation, by diversion of the Arkansas at Garden, where the problems were of the simplest character, is the last that will be made.

LOCAL STORM-WATER STORAGE.

The High Plains have been described as flat, as, in fact, characteristically presenting to the eye the appearance of a dead level. This impression is strikingly conveyed in Pls. CXIV and CXXVI (pp. 610 and 682). The old Tertiary plain, of which the central uplands are remnants merely, has been described as flat originally (with imperceptible inclination eastward), and as having since Tertiary time retained that character within the subhumid zone, because protected there by its sod covering against the beginnings of erosion and the development of surface drainage. It has been pointed out also that since the cessation of plain building and the initiation of destructive processes the only effective erosion has been performed by traversing mountain streams cutting transverse valleys, and by streams of the humid region to the eastward carrying back the eastern boundary as an escarpment by headwater sapping, fed and aided in this work by escape of the upland ground water at the escarpment foot. In the main this is an accurate statement. There are here and there lines of depression along which drainage is faintly traceable, but it is doubtful whether any of them have had their origin in the erosive work of surface run-off, and it is only rarely that they carry through, to contribute to canyon cutting on the east.

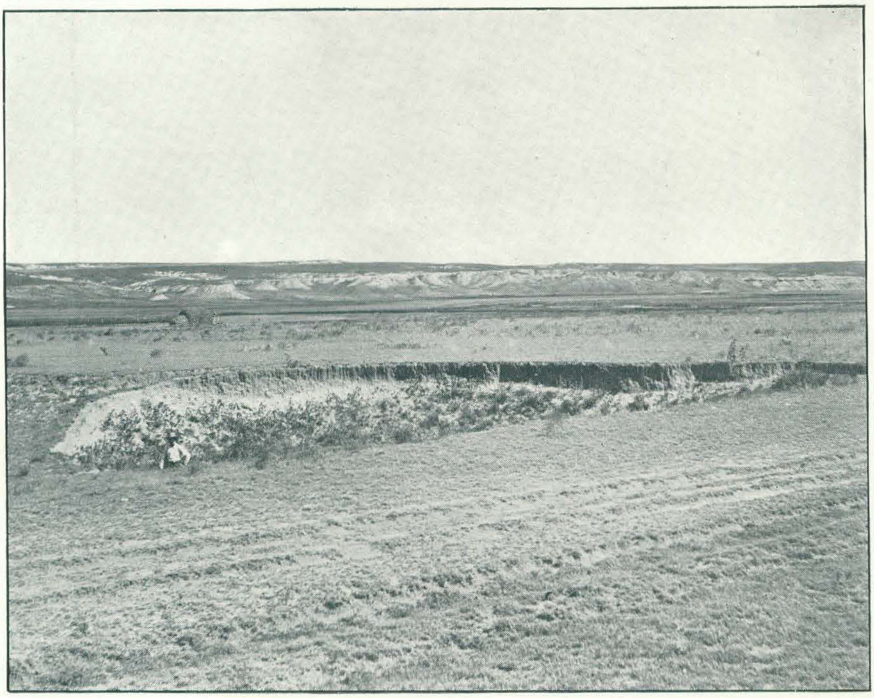
NATURAL STORAGE BASINS.

But while the old surface is virtually unscored by drainage, it is, on the other hand, extensively pitted with saucer-form depressions. These depressions are quite accurately circular where there is no coalescence, and they range in diameter from a few feet to several thousand yards. The smaller ones rarely coalesce; there appears to be a law of occurrence by which they are spaced apart; but the large basins frequently fall into discernible west-east lines. With these coalescence is not uncommon. Hence, in the west-east direction, approximately, shallow and irregular troughs sometimes extend for several miles.

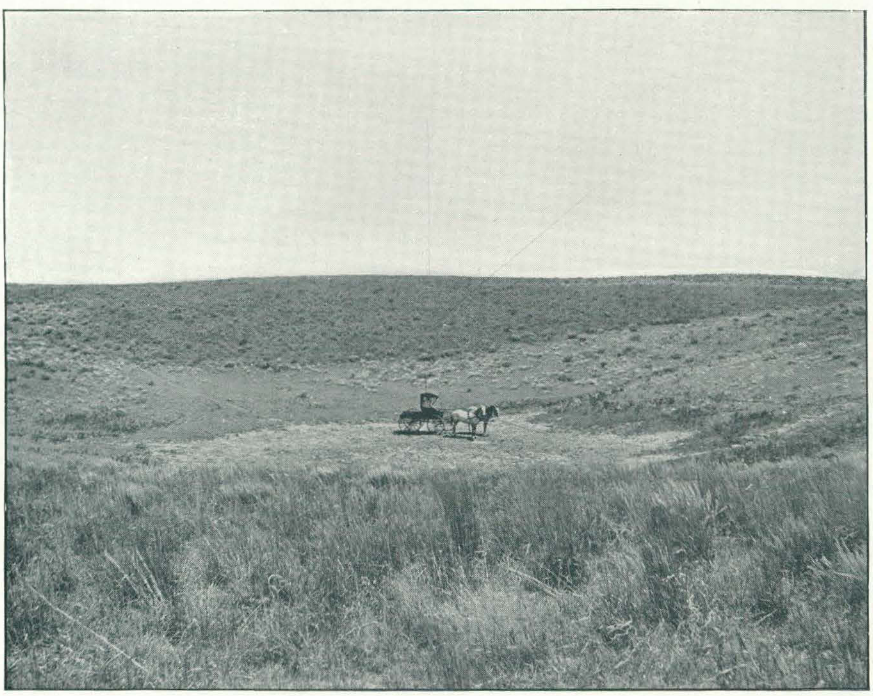
It has been repeatedly urged that these basins of the uplands might be converted into storage reservoirs for the upland storm water. Though there is obvious absurdity in the suggestion, since they are perfectly adapted to storage by nature and yet accumulate little or nothing, still it should receive attention, if for no other reason than that it is persistently advanced.

Precipitation in a desert is of rare occurrence. A peculiarity of it, however, is that usually it is not light in its fall, but assumes the character of a heavy downpour, abrupt at beginning and ending. It is not necessarily of brief duration; it is on the other hand local. For instance, such a downpour may occur within one township and yet an adjoining township receive nothing. But the township receiving a heavy downfall may be visited by light rains only during several succeeding seasons. Desert stream beds in like manner are subject to sudden floods, and it is by floods mainly that the large results in erosion observed in regions of degradation in arid lands are accomplished; but this vigorous work is performed only at widely separated points, and over small areas, during any single season, and at other points the season following. It is for this reason that a desert region of degradation always conveys the impression of active destructive operations recently suspended, as if by radical and abrupt change of climate.

As their universal sod covering bears witness, the High Plains have



A. DEEP AND SHARPLY CUT BASIN.



B. DEEP AND OLD BASIN.

a precipitation differing from that of the arid belt, in that it is often of a gentle and widely distributed character, though light. But the High Plains are subject to rains of the cloud-burst type also. The basins then become ponded. Because, however, of the infrequent and local occurrence of these heavy rains ponding is rare. Normally the natural storage basins are no more than moist on their floors—enough to produce "hay bottoms" of the taller growing grasses, even in wet years—and usually they are dry. Ponding, in fact, is quite exceptional.

There is no remedy for the difficulty. As a rule there is no surrounding area of the flat surface having natural drainage tributary to a basin, and to create a tributary area would be too large an undertaking. Occasional exceptions are the large basins. The comparatively long slopes of their rims afford opportunity for the initiation of drainage which may develop considerable length in the general direction of inclination of the plain and on the upgrade side of the depression. In such basins water will sometimes accumulate to a depth of several feet. The silt washed in during ordinary seasons, and the puddling effected by the trampling of cattle after ordinary rains, prevent rapid loss by ground absorption. Very nearly the sole loss is by evaporation. In consequence, an occasional basin, here and there, will usually hold some water the year through (Pl. CXXXIV, *B*).

But though the depressions are natural storage basins, they are not natural reservoirs, since they can not be emptied. The plain is too nearly flat; its grade, ranging from 5 to 10 feet to a mile would necessitate too great a length of outlet ditching.

Finally, a storm of the cloud-burst type, which alone has sufficient volume of fall to accomplish local ponding, can not be counted on to occur in the same place oftener than two or three times in a decade.

UNDERGROUND RESOURCES.

We have seen that for any appreciable result in supplemental watering of the High Plains, the mountain streams, even assuming complete storage of both their out-of-season flow and their flood flow, have insufficient volume. That is, the surplus from the western humid region—i. e., the mountains—having first to serve an intervening arid zone, would have nothing left for the subhumid zone. It is equally apparent that there is nothing to be hoped for from the local storage of storm water, since these heavy downpours, in excess of immediate needs and so suggestive of abundance, are much too local and infrequent in occurrence at any given point. In short, there are no surface waters, or run-off, to be drawn upon from either far or near. The question, therefore, at once suggests itself: Are there not water resources underground?

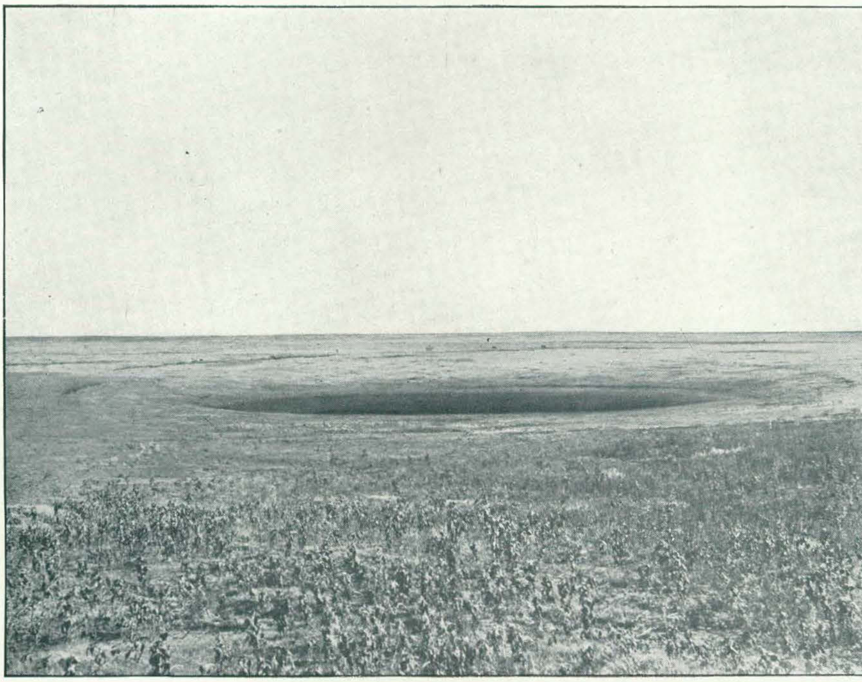
ARTESIAN WATERS.

As soon as it became apparent that from some source, either above or below ground, it would be necessary to piece out the insufficient precipitation, the question of a possible artesian supply was raised. Experimental borings were first made on the uplands, and later in the valleys. No flowing wells were secured from any borings upon the High Plains proper, and only a few, and these of small yield, in the valleys. There was no success, for instance, on the low bottom-land terrace of the Arkansas Valley at Garden; but westward in that valley, close to the Colorado boundary, a light flow was obtained over a small area, just as, farther westward along the valley, up to the base of the mountains, small artesian areas had previously been discovered. Similar unimportant success was had in other valleys, as, for example, the Canadian; but in no case was a flow obtained sufficient for the irrigation of more than a few acres. In several cases of deep boring upon the uplands, in which after passing completely through the thick cover of Tertiary gravels the floor had been penetrated, deep-lying waters with artesian rise were encountered, but their height of rise was never found to be sufficient to produce a flowing well. It would stop short not only of the ground surface, but even of the water plane of the ordinary ground water.

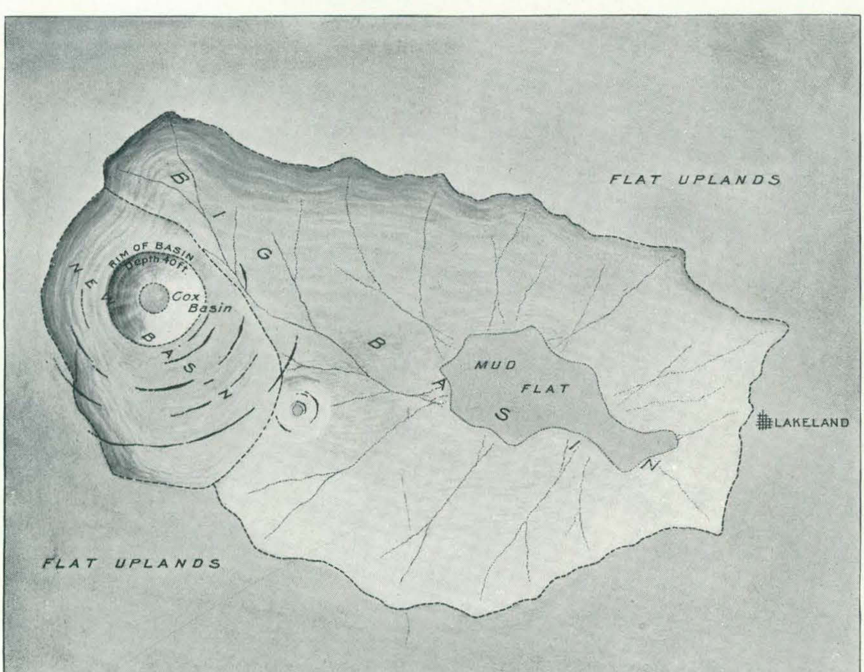
This question of a possible artesian supply sufficient for any considerable result, like that relating to the volume of the mountain run-off, may be completely disposed of in the negative, if considered quantitatively. Mr. Gilbert has shown[1] that to the westward, in the Arkansas Valley, the Dakota sandstone and other possible water-carrying formations do not have uninterrupted extension eastward. Within the dry belt in Colorado such beds are here and there, over considerable areas, exposed by erosion, or have been wholly removed—that is, their intake areas are not wholly in the mountains, but in part lie within the desert belt. In other words, the Dakota sandstone is not here the continuous sheet for great distances it is found to be beneath the plains of South Dakota. Furthermore, extensive deep-well exploration has experimentally developed the fact that its yield, and that of all other porous beds within reach, is slight and has virtually nothing to promise for irrigation.

But even assuming the presence of water-bearing rock sheets, such as sandstone, under impervious covers, such as shale, having uninterrupted extension eastward to a distance as far out as the High Plains, it will become at once apparent, on examination, that the largest possible supply must fall far short of requirements. To obtain a fairly approximate idea of what the volume of that supply may be it is

[1] The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1896, pp. 560–574.



A. COX BASIN, NEAR LAKELAND, KANSAS.



B. MAP OF COX BASIN AND VICINITY, SHOWING SOD CRACKS.

necessary merely to note, as in the case of the mountain streams again, the relatively small size of the mountain catchment area. The eastward surface drainage is separated from the westward surface drainage by the "continental divide"—an irregular line of high ranges. Erosion in these ranges has in the main exposed granite cores—that is, the region is not one of bedded rocks, slightly inclined merely and deeply sculptured. Such a region, entire, might constitute but a single catchment basin for underground waters—one having a single direction of underground movement—while upon the surface comprising several basins of divergent run-off. The mountain ranges here, however, serve as divides for underground and surface drainage alike.

The areas of actual intake for underground drainage toward the High Plains are relatively very small. They consist either in the outcrops, along the mountain flanks, of the porous rock sheets which, far to the eastward, constitute the deeply buried water carriers; or they may be patches of those porous sheets lying close to the mountains, within the desert strip, from which erosion has removed the impervious covers.

The source of supply of much the greater portion of the artesian water to be found beneath the Plains is precipitation in the mountains, yet we have seen that this mountain precipitation is in the first place moderate only, and that, on the other hand, the greater portion of it runs off.

Arid plains absorb a large part of their rainfall. Upon the High Plains there is virtually no run-off, ground absorption and evaporation disposing of the whole. But in mountains, on rock slopes of high grade, much the greater portion of the rain and snow fall escapes in streams. The annual contribution to the artesian accumulation, in fact, must be very much less than the contribution to run-off.

Artesian water is a stored accumulation—continually subjected to losses by drainage, but continually resupplied. The annual contribution to it is relatively small; its stored volume may in time, however, become large. Nevertheless, the question of practical concern here relates solely to the volume of its annual increment.

For irrigation of the High Plains a large volume of water annually would be required. Taking that volume to be not more than a foot in depth over the whole area, the drawing off of this amount from artesian beds would involve the complete exhaustion of something like 4 feet in depth of saturated rock each year. Exhaustion of the total stored supply therefore, by voluntary flow in amount sufficient to meet requirements in full, even if such a thing were possible, which it is not, would be a matter of only a few years. In much shorter time, and with partial emptying only, "head," or hydraulic pressure, would be so far weakened as to cause the voluntary delivery of wells to cease.

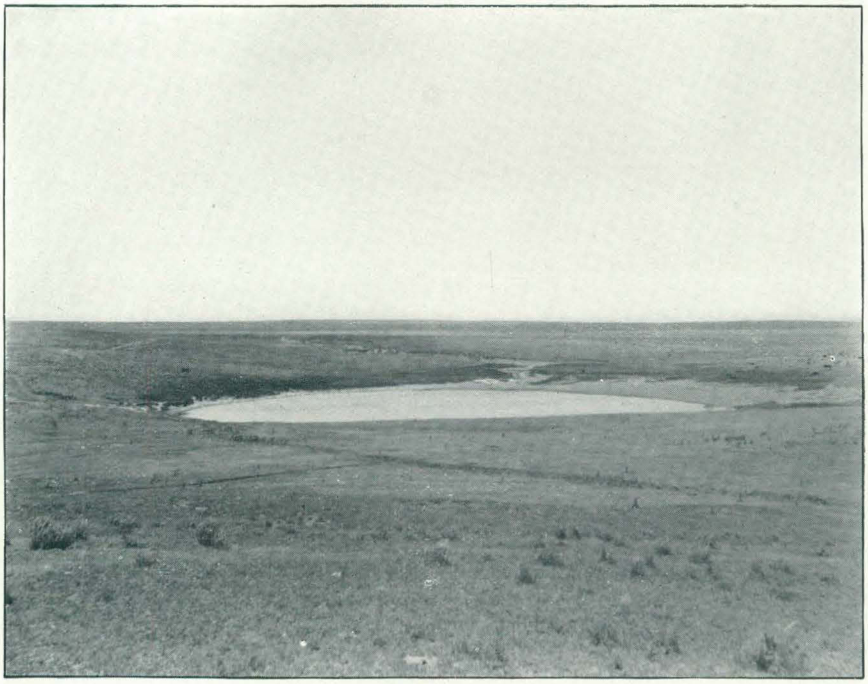
The volume of the annual increment, as we have seen, is inconsiderable; at least it is so in comparison with the volume of water required for complete reclamation. But even this small amount could not be drawn upon to the full. The stored accumulation under artesian conditions is in a measure comparable to that in a lake; there is escape at the outlet equal to the sum of the tributary contributions. The rate of escape, or loss, of artesian water is accurately adjusted to the rate of its replenishment (after saturation of the porous rock sheets has been accomplished); head, manifesting itself by rise in a bore hole, being merely an expression of the heavy frictional resistance encountered during transit through the pervious beds. More strictly speaking, the retarded accumulation in a porus rock sheet is like the water under heavy frictional resistance to flow in a grade-line pipe of great length. The upward pressure is hydraulic, not hydrostatic—i. e., the water, though confined below its natural level beneath a cover, is nevertheless in motion laterally. Only a portion of the original supply, therefore, can be drawn off, diminishing head to a certain safe limit, rather than completely exhausting it. Thus, even under the assumed ideal conditions of far and unbroken extension of water-bearing rock sheets, with like continuous extension above of an impervious cover, artesian water must be rated much below surface run-off as a resource in irrigation.

As appears from Mr. Gilbert's investigations, the assumed ideal condition of uninterrupted extension of pervious rock sheets, with like extension of overlying impervious sheets, does not exist. There is not, in the first place, an unbroken impervious cover; erosion here and there within the arid belt has removed it and exposed the water-carrying beds over considerable areas, permitting upward escape of their imprisoned waters. In addition, deformation along many lines, across their direction of slope, has broken and vertically displaced the pervious beds themselves. In some cases, even, erosion, within small areas, has removed them.

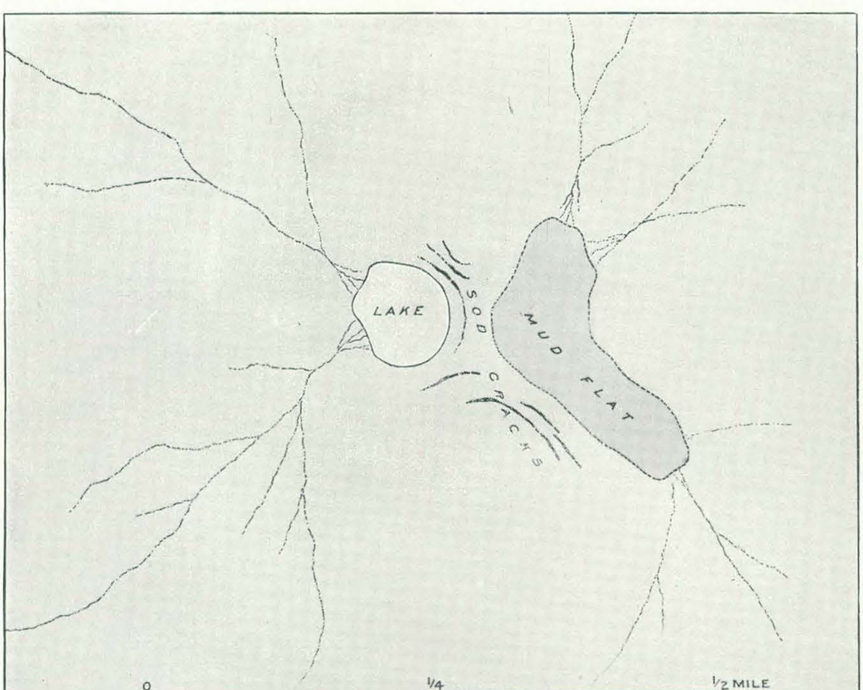
The many attempts to secure flowing wells at the upland surface, everywhere unsuccessful—though slight artesian rise is found to be not uncommon—may be taken, therefore, as experimental demonstration, bearing out the unavoidable inference from the above theoretical considerations, that for irrigation of the uplands there is no artesian resource whatever.

LOCAL ARTESIAN MANIFESTATIONS FROM THE GROUND WATER.

Among the popular notions as to the occurrence of artesian water, it is accepted that such water is always deeply subterranean, that it is never to be encountered in unconsolidated material, and that invariably it has a distant source of supply. In the case, however, of certain artesian developments within the High Plains belt, which have



A. BASIN IN VALLEY, REVEALING WATER PLANE OF GROUND WATER.



B. MAP OF BASIN, SHOWING SOD CRACKS.

attracted much attention in that region, it is clear that the phenomena result from causes local to the Tertiary gravels, and acting not upon deep-lying waters, but upon the ordinary ground water, which has its origin not at a distance in the mountains but in the local precipitation.

The one essential condition in the development of artesian phenomena is confinement under pressure beneath a cover. All water in porous material, if filling the pores to saturation, must rest upon a floor—i. e., upon relatively impervious material. Artesian water must, in addition, be under confinement beneath a cover, and will therefore exert pressure upward as well as downward. The cover need not necessarily be a bed of hard rock; it may be an interbedded sheet of clay in an alluvial mass. It may not be strictly impervious even, and there may be also—in fact there usually is—escape in some measure at its down-grade margin. Because of the enormous frictional resistance to flow, so called, in any ground material, however porous, underground water has so slow motion that it accumulates and assumes, or tends to assume, a nearly horizontal position along its upper surface. If an overlying impervious bed have inclination steeper than the inclination of this water plane, its dip may bring it into contact with the latter. Down-grade from the line of meeting of the water plane with the under surface of the more steeply inclined impervious cover the conditions for confinement under pressure will be satisfied. Beyond this line of contact the ground water will be artesian—that is, when a way is opened for it it will rise, seeking to attain the position its surface would otherwise have had. This theoretical surface, not strictly horizontal but gently sloping toward the lower margin of escape, is termed the "hydraulic grade plane."

When, by boring, the cover is perforated, the question whether there will result a flowing well or merely rise to some higher level within the bore hole will depend on what the level of the ground surface may be. If at that point the ground surface happen to lie above the hydraulic grade plane to which the confined water seeks to rise, there can not be a flowing well. At many points beneath the flat uplands there is artesian rise stopping short of the surface; but, as we have seen, there is nowhere a case of rise to the general upland level, or even a close approach to it.

In some instances, however, notably those of the Meade Artesian Basin, near Meade, southwestern Kansas, and of the Yellow House Basin, on the Staked Plains of Texas, where locally the ground surface has been depressed to such extent as to lie below the general water-plane level of the upland ground water, there are flowing wells. Seemingly, in the case of these and other large basins, the one essential requirement for development of artesian phenomena—an impervious cover bearing down the ground water below its normal level—is met by the presence within the unconsolidated Tertiary of clay sheets having broader extent than the basins themselves, assuming that the basins have had origin in ground settlement rather than in any kind of erosive excavation, and that the included clay sheets of the alluvial mass are therefore basined also.

ORIGIN OF THE BASINS.

This conclusion, that the innumerable hollows in the High Plains surface, large and small alike, are due to ground settlement, rather than to some process either of original construction or of subsequent erosion, seems to be unavoidable. As to the shallow, saucer-form depressions more especially, it is obvious that they are not, for example, the work of running water. From a statement merely that the general surface is uneven, it might perhaps be urged as a possibility that they are survivals of an early faint constructional topography of the stream-built plain, in which subdividing and reuniting currents, running upon broad, low ridges of their own creation, had left low areas between; but the plain is not properly to be described as uneven. Its normal character, despite the great number of basins, is emphatically that of a dead flat upland, lightly pitted here and there, the pits or basin hollows having wide range in size, yet as a rule circular and definitely outlined. That is, there is nothing of the nature of undulation between them; the surface in general is no more affected than would be a sheet of clay lightly dented by marbles of various sizes.

The likelihood of origin by wind excavation can not be admitted, for the surface is too firm. Not only is it protected by a closely knit sod, but the soil beneath is "adobe," comparatively hard. There are occasional sandy tracts upon the High Plains—tracts of traveling sand resting upon the adobe surface—and these have a ridge-and-hollow topography of a quite different type, thoroughly characteristic of wind action; but the sod plains proper, on which appear the basins we are considering, show no dust in the air during high winds, except where cultivation has removed the grass covering and loosened the firm soil. Dust storms are common in the arid belt to the westward; but upon the High Plains, away from settlements, the air blows clear. Furthermore, on their floors and slopes alike the basins themselves, as a rule, are thickly carpeted with grass.

Concentric sod cracks.—There are other small depressions, not broad and shallow, or saucer-form, but relatively deep and bowl-shaped. They occur only in the valleys, not upon the flat plain. In rare instances each of these types will have the appearance of having been newly formed, and in each case the characters which convey this suggestion seem unmistakably to point to origin in settlement of the ground.

With the deeper hollows the feature suggestive of recent ground

TYPICAL "BUFFALO WALLOW."

settlement is a sharply cut rim, the inclosed area having been abruptly dropped. In Pl. CXXX the photographs show, in the one case, a pit of this character; in the other, a bowl-shaped hollow, the marginal escarpment, if there ever was one, having been rounded off by age. Within the shallow upland basins, on the other hand, the evidences of recent progress in deepening are arc-form sod cracks, either following the gently rounded margin, or concentric with it, at varying distances upon the flat plain without. Pl. CXXXI presents a photograph and a map of such a depression, locally known as Cox Basin. The map shows, in addition, a larger basin, the rim of which the smaller one, at some later date apparently, has indented. Because of the occasional occurrence of standing water in these depressions a town near by, now abandoned, was known as Lakeland.

The writer's attention was directed to Cox Basin by a stock grower, after whom the basin had been named, and whose ranch headquarters were in the valley of Crooked Creek near by. He had been accustomed to take advantage of the occasional presence of water in the hollow, during rainy seasons and for short periods thereafter, for pasturage of his stock upon the neighboring dry uplands. During the first few years of his familiarity with the locality there had been no encircling cracks. These had abruptly appeared after a season of unusually heavy rains. When first observed they showed openings only an inch or two in width; but beneath the sod, which stretched before breaking, these openings were found to be wider. In fact, along the greater portion of its length each crack was bridged across. At first, as a rule, the sod bridges were sufficiently strong to support cattle, but continual crossing of them along trails to water had in several instances resulted in their breaking down, with consequent injury to the cattle. At the time of the writer's visit no new cracks, and no growth among the old ones, had been noted for two years. Several still retained their original sharp outlines and a depth here and there of 6 feet or more, but the majority were shallow and grass-grown.

Cox Basin is not upon the uplands. It occurs at a level a little below, within the region of a much larger depressed area. It has, in consequence, drainage tributary to it. For this reason it holds water more frequently and in larger amount than do the upland basins generally. It would seem that to this fact may be attributed the apparently more rapid growth, and the accident of the occurrence at the present time of encircling cracks plainly denoting ground subsidence.

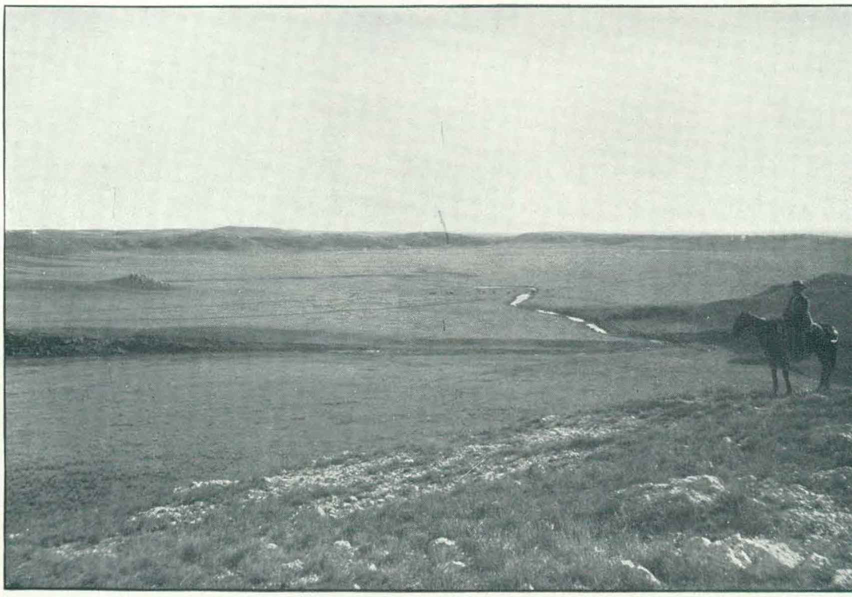
Settlement within the Tertiary.—Appearances indicate basining of the alluvial surface as a consequence, first, of rain water accumulation in initial faint unevennesses of the plain; second, of percolation of this ponded surface water downward to the ground water in largely increased amount from these small areas of concentration, rather than from over the whole surface uniformly, with the result that the alluvial mass is appreciably settled beneath the basins only. The inference is at once suggested that this settlement takes place as the combined effect of mechanical compacting of the ground particles and chemical solution of the more soluble particles. Finally, these effects should be cumulative, resulting in the growth noted, since, with enlargement of the basins, concentration of rain water within them will be on an increased scale.

Over comparatively small areas surface effects should be symmetrical, but beneath basins of great breadth—and some have breadths of several miles—the depths of settlement at points wide apart within the same basin, as well as the conformation of the basin rims, should reflect the broader variations of structure beneath. Depths should be least above beds of clay and greatest over areas of coarse channel deposits. The occasional very large basins are in fact invariably unsymmetrical—undulated on their bottoms and of irregular outline. It is doubtful, however, whether the very large, irregular basins are to be explained in this way, as will be developed presently.

Nowhere upon the uplands is the depth of settlement in the case of the small circular basins so great as to reveal the ground water; but these occur also, though less frequently, over the bottom lands of the valleys, where the valleys have not yet cut through the Tertiary to bed rock, and one of these bottom-land basins, selected for illustration (Pl. CXXXII), contains a perennial pond. The pond is without perennial surface drainage into it. It is also without outlet. That it is the ground water, however, exposed merely by local depression below the water-plane level, is clear from the fact that in several instances water is encountered at the same level in neighboring wells.

Caving of the Red Beds floor.—The depth of the Tertiary in the case of this lowland basin, revealing the water plane, is comparatively slight. While, therefore, the presence of concentric sod cracks here also indicates settlement, compacting of the Tertiary in explanation of it can no longer be appealed to. Only where the depth of the Tertiary is great and settlement is relatively faint does that inference seem justifiable. In this particular locality (the upper valley of Bullard Creek, Englewood County, southwestern Kansas) the underlying rocks are the Red Beds, containing salt and gypsum, and the Permian shales, which in south central Kansas carry the famous rock-salt deposits. Farther southeastward, in the heavily eroded fringe of the humid belt where the Tertiary cover has been removed, the Red Beds are seen to be extensively pitted by the breaking down of solution caverns.

Here, then, is a satisfactory explanation of basins in the Tertiary cover where the cover is thin. Where it is thick some different explanation appears to be necessary. The great multitude of the basins are small. They range in size from the so-called buffalo wallows to saucer-form depressions a thousand yards or more across and



A. BIG BASIN, CLARK COUNTY, KANSAS.

B. BASIN HOLDING WATER AFTER RAIN.

with depths at which windmill towers need to be of unusual height in order to catch the wind. They are often, over broad areas, so numerous as to lie within a stone's throw of one another, though, as before stated, there seems to be a law of occurrence according to which actual coalescence is prevented. Yet they may be equally numerous over tracts where the depth of the Tertiary is several hundred feet.

At the surface of such a deep mass of loose material the upward-transmitted effect of caving within the rocks of the floor should be a broad and shallow depression, not a pit. The disturbed mass should have the form of an inverted cone, the base, at the surface, much broader presumably than the depth of the apex, at the point of caving within the floor. Most of the basins, however, are small, indicating points of disturbance at slight depths within the Tertiary itself.

Because the thick, alluvial accumulation is not entirely free from cementation, nor entirely homogeneous in structure, a deep-seated disturbance beneath it might perhaps at first have scattered effect at the surface, as if proceeding from a number of points spread apart, at various shallow depths within it. The basin effects in such case should be grouped, which they are not; and, furthermore, with development, they should eventually merge, forming a single large depression, with irregular outline and uneven floor. While large, irregular depressions exist, they are not numerous, and there is no suggestion in such cases of development out of groups of small ones.

Equal occurrence of the shallow basins where the floor is Cretaceous.—The chief difficulty in the way of accepting caving within the rocks of the floor, in explanation of the saucer-form hollows, is the fact that the Tertiary of the High Plains does not everywhere rest directly upon the Red Beds. Over the greater part of western Kansas, for example, Cretaceous rocks, mostly sandstones and shales to a great depth, constitute the floor; yet small basins are no less numerous there.

The very large and irregular depressions do not have this universal distribution. As has been stated, there is no gradation in size from the largest of the circular forms up to these very large irregular ones.[1] And in the case of the latter, deep-well borings, wherever they have penetrated to the floor, encounter the Red Beds, containing salt or gypsum in notable quantity, either immediately beneath or close beneath. Commonly there is immediate or early change in the color of the material brought up, from a prevailing gray to blood red, after passage through the alluvial Tertiary.

Sink holes.—St Jacob's Well and the Meade Salt Well.—In several instances, associated with the large, irregular basins and occurring close to their rims, are sink holes.

From a point near Meade, southwestern Kansas, the eastern front

[1] An idea of about the maximum size attained on the uplands by basins of the shallow, symmetrical type may be had from Pl. CXXXIV, *B*.

of the High Plains extends northward less sharply defined and not so high. Up to southern Kansas this front is a line of "breaks." From the neighborhood of Meade, however, the breaks cease to be the upland margin, but constitute, instead, a second step within the eroded zone, turning in a curving escarpment eastward and northeastward, until faded out by the general decline in elevation.[1] This northeastwardly curving line, marking a change from comparatively gentle undulation to a topography of pronounced relief, also marks approximately the southern limit of the Cretaceous in Kansas and the emergence from beneath the Cretaceous of the Red Beds, to constitute in turn the floor of the Tertiary.[2] For a distance back of this line, where presumably the Cretaceous is thin, large irregular basins are numerous, while downgrade from it the deeply incised Tertiary has a topographic configuration, not of any recognized plan, but tumultuous and disorderly and imperfectly drained. Here are numerous basin expansions which the traversing drainage obviously has not shaped, by erosion, but which it finds passageway through merely because they have intersecting rims. Erosion has in large measure obscured their outlines, but the most conspicuous suggestion is that of differential settlement, not stream excavation.

Within this zone, 19 miles east of Meade, is Big Basin, approximately circular, about a mile in diameter and 100 feet in depth. It has no drainage out, and drainage into it frequently results in shallow ponding at various low areas over the floor. Notching the rim at the southwest is a smaller basin, also without outlet, and separated from the larger one by a low divide. A short distance to the east is still another, called Little Basin, and on the rim of this is a sharply cut sink hole, St. Jacob's Well.[3] Here, again, the water plane of the ground water is revealed. The floor of Little Basin, close to the foot of its encircling bluff, shows a number of shallow depressions, apparently the nearly healed scars of other and earlier sink holes. St. Jacob's Well has every appearance of having been rather recently formed.

A mile and a half southeast of Meade, and close to the rim of the Meade Artesian Basin, is the Salt Well, locally so called—the largest sink hole of the High Plains region. Here, also, the ground water is revealed.

The sudden appearance of the Salt Well is a matter of history. It dates from March, 1879. Its position is in a broad, flat saddle, between a small hill and the slope from the uplands on the east to Crooked Creek Valley, at a point a little below the opening of the latter out of the Meade Basin. The pit not only fully occupies the saddle, but its encircling cracks cut well into the rising slopes on either hand.

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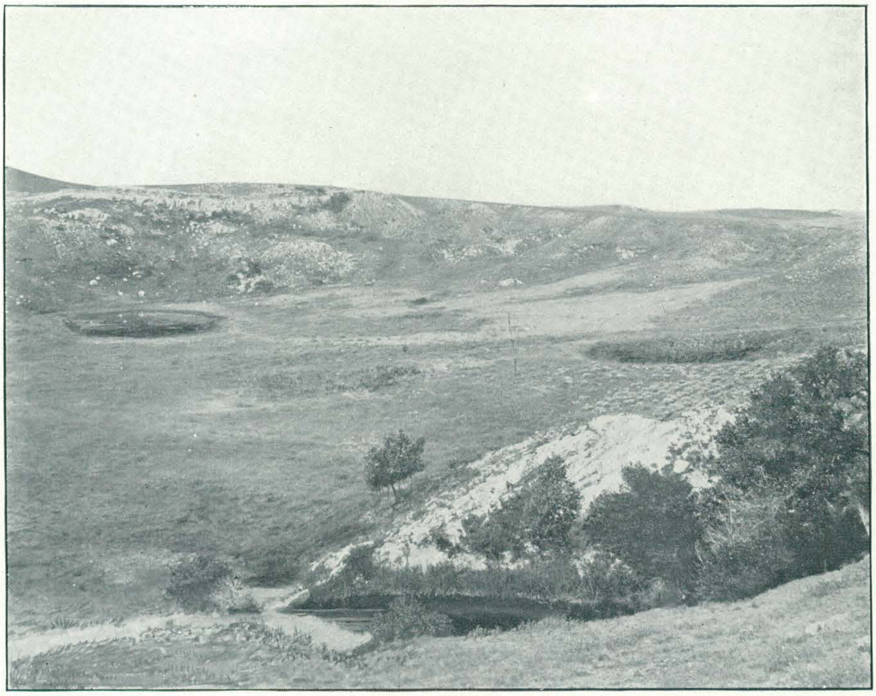
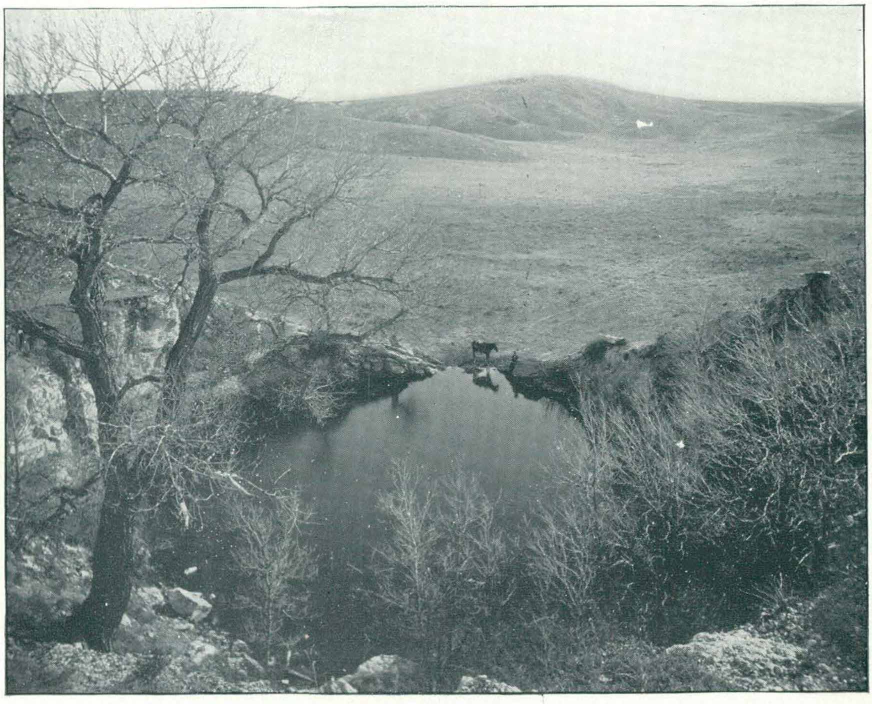
[1] See general map, Pl. CXIII.
[2] See Univ. Geol. Surv. Kansas, Vol. II, 1897, Pls. XLIV and XLVII.
[3] See general map, Pl. CXIII, *d*.



A.



B.

ST. JACOB'S WELL, CLARK COUNTY, KANSAS.

Near by, to the east, upon the uplands, formerly ran the famous "Jones and Plummer" cattle trail, leading from northern Texas to Dodge, Kansas. A mile or more to the south a branch from this overland route, which in those years was much traveled, passed into the valley for over-night camping purposes. The trail led through the saddle directly across the present site of the sink hole. Cattle trails and road ruts, sharply terminated at either edge, are still discernible. Thus, in this thinly settled country the spot was not off from beaten tracks, but lay literally in the path of one.

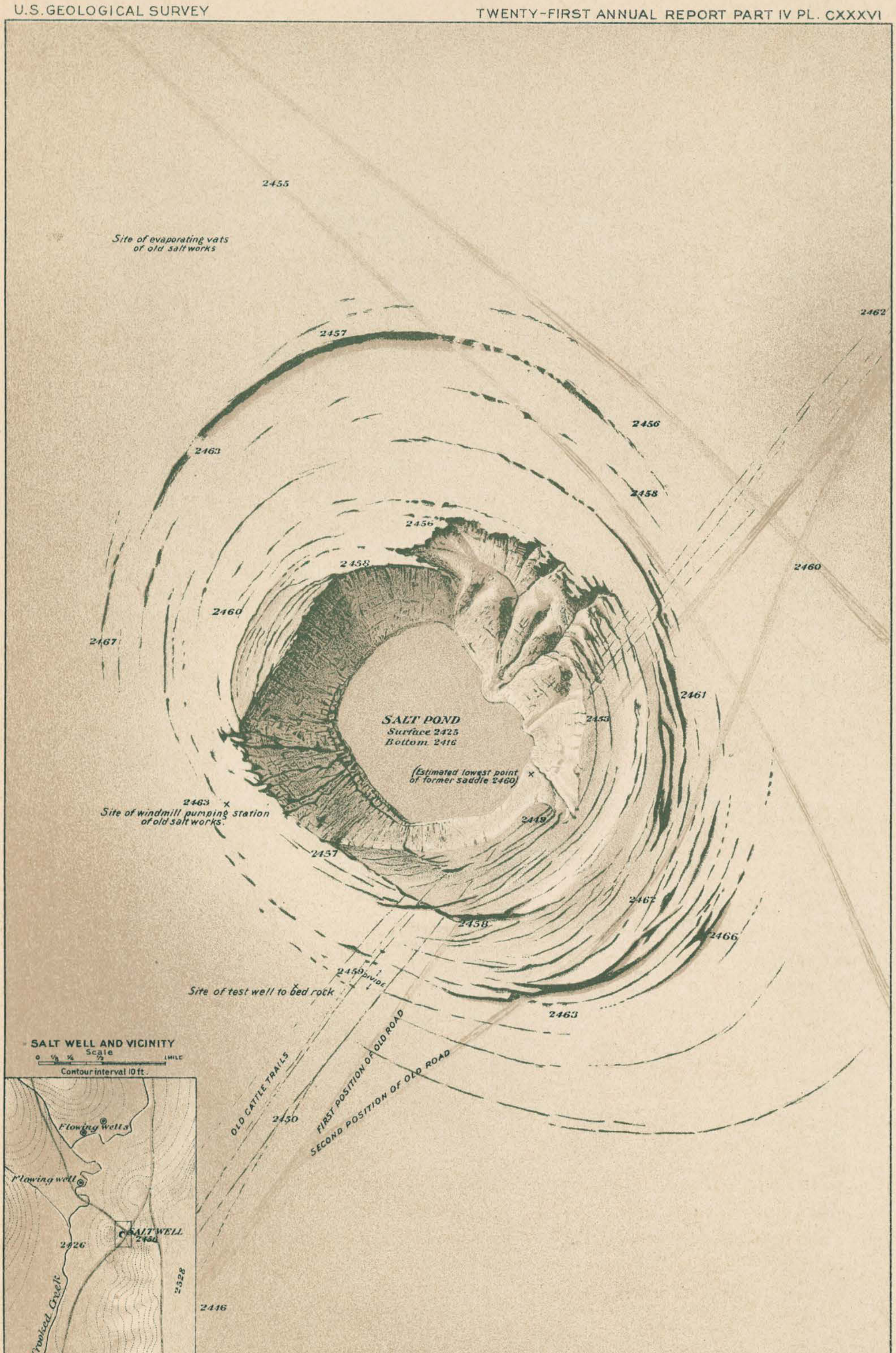
Fourteen miles to the north was the small town of Pearlette, now abandoned. The Pearlette Call, in its issue of May 15, 1879, referring to the sudden appearance of the pit, said: "Considerable excitement has been created in this section of late over the discovery of a salt well. * * * Since the 3d of March a piece of ground some 175 feet in diameter has sunk, and the hole is now filled with water to a point 14 feet below the surface. Soundings have shown the water to be from 30 to 75 feet in depth. On the 3d of March a wagon passed over the spot where the well now is, and the ground, which is high, was then hard and firm. The track made by the wagon at that time is plainly visible on each side of the well. On the 26th of March it was found in its present shape."

From the first the water in the pit, unlike that in St. Jacob's Well, has been strongly saline, though the ground water in neighboring wells has no taste of salt. A test boring at a point just beyond the outermost sod crack on the south encountered fresh water at a level less than 2 inches above that of the salt pond. An old dug well on the valley slope a half mile to the northeast shows water within 6 inches of the same level. The water exposed in the pit is clearly the common ground water, its level merely lowered slightly by evaporation. As shown by the photographs, Pl. CXXXVII, the ground material here is close textured. It is lightly cemented sandy clay. The passage of the ground water through it must therefore be slow, affording opportunity for evaporation in the open pit to lower the water plane appreciably. As appears from the above newspaper statement, the depth to water at the time of discovery was but 14 feet, with a depth below water to the bottom of 75 feet, making a total depth of 89 feet. The total depth at present, measuring from the assumed former position of the lowest point in the saddle, is 44 feet. From the highest point on the rim, where it has cut into the rising slope on the west, the depth is 44 feet also. The depth to water is 35 feet and the depth in water 9 feet. The pond, along its greater diameter, is 126 feet across. The greatest distance across at the ground surface is 216 feet. The ovalform depressed area surrounding, as outlined by the sod cracks, is 360 by 400 feet. The bottom is 5 feet below the creek bed in the adjacent valley.

The early measurements of depth may not be trustworthy, but it is probably true that at first the pit was deeper than at present, as well as more sharply outlined, and that it had steeper walls. The testimony of a number of persons now resident in the neighborhood who visited the Salt Well shortly after its discovery is in agreement to the effect that the walls were then unbroken and steeper than now, that there was no apparent ground settlement of an outer zone, and that there were no encircling cracks. In support of the latter statement is a later, shifted position of the old road coming up from the south, to a course which could not now be followed on account of the widely gaping cracks. Apparently filling has taken place to an extent measured by the depth of settlement within the area inclosed between the outermost cracks and the brink of the pit proper. The testimony of early observers also is to the effect that the contained water, standing high at first, slowly sank, reaching about its present level within a few weeks.

The test boring referred to came abruptly upon bed rock of a deep-red color at a depth of 292 feet, after passing easily and rapidly through clay, sand, and gravel (though little of the latter) in alternating layers. The floor was penetrated to a depth of 16 feet. Toward the bottom, while still in the loose material of the Tertiary, the presence of salt began to be perceptible to the taste, and saltness thereafter increased.

A curious fact in connection with the Salt Well is that its strongly saline water at times has a high temperature—according to common report, close to the boiling point. The temperature of the ground water in this region, winter and summer, varies less than a degree from 59 degrees. Where exposed, however, as on Bullard Creek, it falls in winter, especially in cloudy weather, approaching that of the air. In winter the high temperature in the Salt Well falls also. During a period of freezing weather in January the writer found it cold to the hand both at the surface and as brought up in a bottle from the bottom. But in July a bottom temperature of 156 degrees was obtained, and this held to within 3 feet of the surface. Near by, in the test boring, at the same level, it was only 59 degrees, the prevailing ground-water temperature. The temperature of the upper 3 feet in the Salt Well at the same time was 89 degrees, and the air temperature 94 degrees. The water was found to be stratified, according to the density of its saline content; that is, an upper layer, 3 feet in depth, and at all points within this depth, contained about one-third less salt per unit volume than the remaining 6 feet, extending to the bottom. The surface of the lower stratum, and the plane of contact between the two, was definitely marked by water-logged twigs and grass stems, which the wind had brought in and which had sunk in time through the comparatively fresh water, but hung suspended with their upper ends at a uniform level in this nearly saturated solution



Surveyed by W. D. Johnson

H. C. Hunter, del.

THE SALT WELL

SCALE OF FEET

0 50 100 150 200 250

Figures indicate elevations above sea level

SEIBERT COMPANY, LITHO, N.Y.

beneath. Some weeks later, after several days of cloudy weather, no rain having fallen meanwhile, the water temperature at the surface was 76 degrees, and at 6 feet below only 98 degrees. Further observation and experiment led to the conclusion that the much higher temperature of the lower stratum is due to the storage of sun heat, the upper layer of comparatively fresh water acting after the manner of the glass covering of a greenhouse, permitting direct rays of the sun to enter and warm the salt water below, but preventing the escape of reflected rays.

The layer of comparatively fresh water would seem to have been extended across the other from the surrounding ground water. Presumably the raising of temperature in the salt water beneath did not lighten the latter sufficiently to overcome entirely its superior weight, due to the contained salt. During progress of the sinking to bed rock in the test well near by a record of temperatures was kept. As in borings everywhere, there was increase with depth, but it was slight.

It was surprising that there should be stratification as between the brackish water and the brine; it is not clear why, if the salt comes from below, impregnating the fresh water above, it should stop short of the ground-water surface. It has been suggested, since borings to a depth of from 100 to 200 feet in this neighborhood usually encounter artesian water, rising to a level sometimes above and sometimes below the ground-water plane, that the upper level of the salt water here marks the local artesian grade plane, and that artesian water, carrying salt, has risen merely to its level of equilibrium. The case here is not parallel with that of a tubular well in which the ground water, after its floor has been reached, is "cased out" by the tube. The Salt Well below its actual bottom presumably continues, in effect, as a loosely filled-in shaft, affording comparatively free passage for water, because the Tertiary structure, containing clay sheets, is broken down. The ground water is not cased out. It extends through the Salt Well and across the perforation in the artesian cover beneath. Hence, on this assumption that the water plane of the ground water has a higher position than the artesian grade plane, there should be downward passage into the artesian body, rather than rise from the latter into the overlying ground water. In principle the case is like that of a bucket of water suspended in a larger vessel filled to a little below the level in the bucket—upon removal of a plug in the bottom of the latter, flow will be downward.

As shown on the map and in the accompanying photographs (Pls. CXXXVI and CXXXVII), there are old shore lines about the pond, at slight elevations above the present shore, indicating fluctuation in level. The total range seems to be greater than that of the seasonal fluctuation of the ground water. It may be accounted for in part by evaporation on the one hand, and rain-water contribution on the other.

The horizontal ground-water movement in such close-textured material is exceedingly slow under these light heads. In another instance, where a basin in a valley bottom exposed a broad surface of ground water, also in clay, the writer found a lowering of nearly 3 inches below the surrounding water plane, as determined by test borings. It was clearly an effect of evaporation, which had continued through several weeks of cloudless hot weather just preceding. The basin had a small drainage area tributary to it, and some days later, immediately following a heavy rain, it was found that the relative positions of pond surface and water plane had been reversed, the former standing about an inch above the latter. The time required thereafter to establish equilibrium was nearly two days. Probably the greater fluctuations have half-yearly intervals, the summer level being, as a rule, low and the winter level high.

In the case of the Salt Well, the tributary drainage to which is insignificant, the losses probably greatly exceed the gains. The direction of easiest movement of water here is vertical, since vertically beneath the ground is broken, and recovery from the recurring losses, therefore, should be continually from below. It is possible that the effect of this continual upward resupply is to lift the low-lying salt water, and that at the time of the observation noted its summit elevation fell short of the pond surface by 3 feet.

The assumption is made that the Salt Well has had origin in caving within the Red Beds floor, and that a cavernous opening there had been created and subsequently broken down through removal in solution of an interbedded salt deposit. This type of depression is strongly in contrast with the saucer-form hollows, though the latter at times also exhibit the phenomena of concentric sod cracks. The sod crack is evidence of ground settlement, with a horizontal component—that is, it is merely the most prominent sign of a shallow land slip. Land slipping has followed upon the sudden caving of the Salt Well, the comparatively loose Tertiary gradually moving in from all sides to fill the pit. It might be supposed, in like manner, to mark a broadening and fading out in the case also of the shallow basins of the uplands. But while the sod crack always means land slipping and filling, the fact in this latter case seems to be that it is an evidence of deepening and growth rather than of the commencement of healing. Along the slopes of arroyos, where they make back into the eastern border of the High Plains, and about arroyo heads, it is almost an invariable accompaniment of erosion. Pl. CXXXIX, *A*, shows an arc-form sod crack at the head of a faint arroyo. In fact it is apparent in many instances that the numerous broad and shallow drainage lines of the upland border, grass-grown and without a central ditch, are due more to subsidence and creep than to erosion proper. The arroyo bottom is commonly marked

A.

B.

THE SALT WELL.

by chains of pit holes, as in Pl. CXXXIX, *B*, culminating at times in depressions so large as to pond and hold the total of its maximum flow, thereby checking further extension. These effects are obviously the result of the action of downward-percolating rain water upon open-textured ground material above the level of permanent saturation. To any interested observer having wide familiarity with the High Plains surfaces it would seem that the conclusion must be inevitable that the small saucer-form hollows, away from arroyo connections, are equally the effects of surface waters acting at shallow depths within the Tertiary, compacting and settling it at points, as the arroyo drainage does along lines.

The sink holes, such as St. Jacob's Well and the Salt Well, also the great depressed areas, such as Big Basin and the much larger Meade Basin, to be considered presently, may be attributed to caving, resulting from removal of soluble masses within the underlying rocks. The sink hole is a detail merely, illustrating this process. As a topographic form it is necessarily ephemeral, as note the rapid closing of the Salt Well. Quite likely the gradual basining of a large tract witnesses the appearance and disappearance of many sink holes. Apparently the bowl-shaped hollows are their scars. But the innumerable upland basins, especially where the floor is Cretaceous to great depths, are clearly to be ascribed to grain-by-grain processes of readjustment and compacting, at work within the Tertiary only.

To this view it might be objected that elsewhere extensive alluvial surfaces do not exhibit a like faint topography of symmetrical hollows. But the subhumid High Plains, as we have seen, are exceptional in that they are virtually without surface run-off and are not subjected to erosive action. They would thus seem to afford exceptional opportunity for the working out of appreciable or visible results by a feeble process that possibly after all is in some degree operative upon alluvial plains everywhere, though relatively impotent in humid lands because there brought into competition with erosion.

Disorderly topography of the "breaks."—Caving v. erosion.—The topography of southwestern Kansas below the line of breaks referred to is not only tumultuous and disorderly in detail and imperfectly drained, but it rapidly softens down here and there into broad expansions, not without through drainage, and in a measure modified into some semblance of stream valleys, yet obviously not the work of stream erosion. Such an area occupies something more than 100 square miles in southern Clark County. The town of Englewood lies within it, near the western border. It extends also into Oklahoma. The Cimarron River enters and leaves it, in each case between low canyon walls; the Big Sandy discharges upon it, and, in flood, manages to struggle across; Fivemile Creek fades out entirely upon it, and the headwaters of Bullard Creek are decapitated at its western margin by the comparatively recent small depression already referred to. It is being built upon, rather than excavated, by much of its tributary drainage.

Shortly after passing out of the Englewood Basin, the Cimarron enters Oklahoma again and issues upon the Salt Plain. Here is another low area which, obviously, from its configuration, is not explainable by erosion except in a secondary way, although erosion has been vigorous in the surrounding hills.

The drainage of the entire region is more or less brackish, from dissolved salt, or hard, from dissolved gypsum. Where the Tertiary cover remains, disorderly tilting is frequently in evidence in the variously inclined positions of the mortar beds. Where erosion has removed the Tertiary, exposing the Red Beds, inclined beds of gypsum often bear witness also to diverse tilting.

In the "gypsum country," to the south of the Salt Plain, caving is visibly in progress. Occasional interstream areas, thinly mantled with alluvium, are extensively pitted by funnelform sink holes, and some of these connect by open shafts with underground drainage systems, which follow intricate courses along beds of gypsum, contributing eventually to the deeply incised surface streams, from openings in their canyon walls. The lighter surface drainage is sometimes disarranged and diverted from former courses, still plainly traceable, by settlement of cavernous expansions along these underground channels, creating basins overhead and sink-hole openings, into which sometimes the surface streams disappear. (Pl. CXLII, p. 720.)

THE MEADE ARTESIAN BASIN.

There are no large depressed areas in the "gypsum country," however. These lie to the north, where basining appears to proceed rather by the displacement of salt deposits on a large scale. Below the margin of the Cretaceous, where the Red Beds take its place as the Tertiary floor, the whole region to a greater or less extent has been affected by differential settlement. Back a little from the margin, where the Cretaceous is yet thin, or else where post-Cretaceous erosion possibly had removed it in embayments, there are individual basins, surrounded wholly or in part by flat uplands. Head-stream sapping, carrying back the upland escarpment, in several instances has cut into these, establishing drainage out. Among large basined tracts of this marginal type are Scott Basin and the Meade Artesian Basin. Centrally located, however, upon the great plateau of the Staked Plains, are the two others, previously mentioned—the Silver Lake and Yellow House basins[1]. Cheyenne Bottoms, in central Kansas, well to the east of the High Plains, a rudely circular depression about 8 miles in diam-

[1] See general map, Pl. CXIII, *a*, *b*, *e*, and *f*, for the positions, respectively, of these four large depressions.

SOD CRACKS ENCIRCLING SALT WELL.

eter, though with a gap in its rock wall on one side, is quite possibly also a basin of subsidence[1].

As to the Silver Lake and Yellow House basins in the interior of the Staked Plains plateau, it is not known that the Red Beds there lie immediately beneath, or close beneath. It can only be inferred that they do. Well borings have not penetrated to the floor. But, like the Scott and Meade depressions, these two are distinctly different in type from the saucer-form hollows which abound there also, in that they are very large, unsymmetrical, and of uneven depth. Like the Meade Basin, they exhibit the phenomenon of artesian rise in wells stopping short of bed rock, and therefore wholly in the Tertiary. The wells which show rise to the surface, however, are several only, and have feeble flow.

The floor of the Meade Basin comprises about 55 square miles, or 35,000 acres. This artesian area at one time excited wide interest over the High Plains. There seemed to be offered the prospect, not only of rich irrigation development of a considerable tract, but of artesian relief in like manner for other large depressed areas and shallow, broad valleys. The prospect was all the more enticing because the Meade wells were of comparatively light depth, not in hard material, and therefore inexpensive to make. Owing to the widely accepted notion that all artesian waters are, of necessity, far derived, it was assumed withous question that the artesian stratum here discovered was universally extended beneath the uplands, though without sufficient head to reach to the general upland level. On such an assumption there should be rise to some height in wells upon the uplands everywhere. On the contrary, it is found that there is no universally extended artesian stratum, and no rise in wells whatever except where, under a rare combination of peculiar and favoring conditions, it is locally developed from the ordinary ground water.

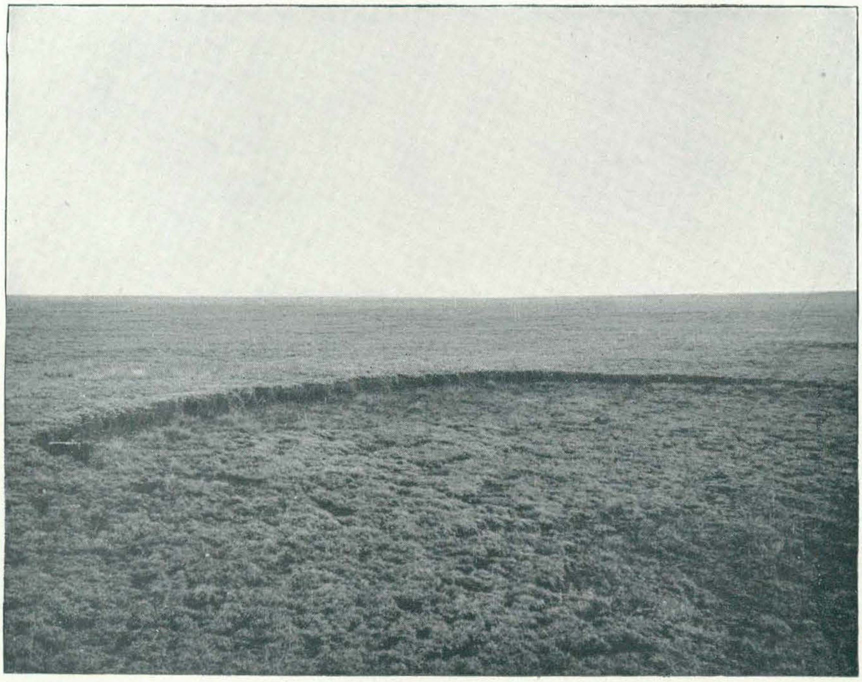
In the case of the Meade Basin these requisite conditions are present and exceptionally favorable, and there is artesian rise in borings sufficient to produce flow; but this voluntary delivery at the surface has origin in the same vastly extended body of water which wells upon the uplands everywhere encounter, inert, at almost prohibitive depths. The facts all point unmistakably to local basining of the water plane, by depression of a broad interbedded clay sheet of the Tertiary,

[1]It is ascribed by Professor Haworth to stream erosion. He says: "In addition to the streams already described a number of smaller ones of considerable local interest occur. A few of them have peculiarly shaped valleys of erosion, which are different in some respects from any features connected with those described, in that wide, short valleys of the fry-pan form are produced. The best developed instance of this kind is in the Blood Creek Valley, near Great Bend, locally known as Cheyenne Bottoms." (Univ. Geol. Surv. Kansas, Vol. II, 1897, p. 42.) It should be noted, however, that the famous Kansas salt mines are not far distant. Also, that caving is not unknown to this region is shown from the fact that in 1898 a sink hole suddenly appeared, within a night, at the railroad station of Rosel, 40 miles to the southwest, carrying down several of the station buildings, revealing in their place merely a pond, at a depth of about 70 feet and about an acre in extent, surrounded by abrupt walls.

resulting apparently from extensive caving and settlement within the Red Beds, beneath. Depression of the upland surface to a level below that of the water plane is not alone sufficient. There must be coincidental occurrence of the interbedded clay sheet. In the case of the small basin hollow shown in Pl. CXXXII, across which the water plane is extended undisturbed, this impervious stratum presumably is absent.

Widely extended beds of clay or sandy clay are not uncommon. Naturally they make up the larger part of the so-called "Tertiary gravels." In alluvial building they are the deposit of the fringe of the stream network. As we see in the case of modern plain-making streams, the shifting courses nevertheless shift slowly, and the slack-water lagoons even may have considerable persistence, depositing fine silt. There will be interwoven channel deposits beneath, and in time channels are certain to take shifting courses again above. The wells of the Meade Basin, like those of the several other basins mentioned as developing artesian phenomena, reveal such sections. In many other depressed areas, as also upon the uplands frequently, borings encounter only sands and gravel to the bottom.

Ordinarily no inference as to the possibility of occurrence of upward pressure in underground water is to be drawn from local topographic configuration. It is true merely that the lower the ground surface the greater the likelihood that a known upward pressure will be sufficient to result in a flowing well. As commonly employed, the term "artesian basin" does not necessarily imply corresponding basining at the surface. In the case, however, of the several relatively small areas of the High Plains, which have flowing wells, such as the Meade Basin, it does. There local ground settlement is primarily the cause of artesian development. The depressed areas are artesian basins precisely for the reason that they are basins topographically. Where there is flow at all it will be found that two requisite conditions have been satisfied: the floor lies below the surface level of the ordinary ground water; and beneath the floor again, serving as a cover, is a clay sheet, or connected grouping of clay masses, basined also. This clay sheet, interbedded with the more open-textured Tertiary material, must have broader extent on all sides than the depressed area, and a marginal depth beneath the uplands less than that to the free water plane. The actual basining of the ground water is effected by the clay sheet. Strictly speaking, the artesian basin is that of the under surface of this buried impervious, or relatively impervious, stratum. It is definitely limited by the line of dipping contact of the impervious stratum with the water plane. The area of artesian effect is that within which water will rise in wells which open a way for it. The area, however, within which there will be rise to the surface and flowing wells will be smaller,



A. SOD CRACK AND LAND SLIP.

B. PIT HOLES ALONG ARROYO.

and it will rarely happen that the floor of the superficial basin will be low enough to result in any flow whatever.

The sunken area at Meade is not without outlet. It is traversed by Crooked Creek. As the map shows, its floor has the form approximately of an isosceles triangle. The length of the base from *a*, near Wilburn, to *b*, near Meade, is 19 miles. The creek, when it flows at all, follows this long line with barely perceptible motion and in broad meanders. The greatest width, from the third point, *c*, to about the center of the base, is 7 miles. In this direction, due southeast and at right angles to the course of the stream, the floor is gently inclined, though to the eye, because of its great extent, the inclination is not apparent. It is faintly concave as well. The total fall is about 100 feet; 80 feet of this fall, however, occurs in the first third of the distance. The final third is nearly horizontal, though containing shallow secondary basins. This faint southeastward slope is terminated by relatively abrupt rise again to the upland plain. The mean grade of the hollowed profile is 14 feet to a mile.

Critical examination of the region, especially of the south and east, brings out the fact that the basin has been tilted, and that in this tilting and settlement the eastern embracing arm of uplands has shared, The traversing stream or creek bed—it is a stream foı only a few days in the year—has been diverted from a course a little north of east and turned sharply backward toward the southwest. It enters the triangular basin area, not at the highest point of its hollowed and tilted floor, but at one end of the long side, and it follows along the flat zone there across the direction of general inclination.

Its mean grade in the 19 miles, as measured on a direct line from *a* to *b*, is 4 feet to a mile. The actual distance along meanders is 27 miles; the true mean in consequence is less than 3 feet. For a considerable part of this distance, beginning near the middle, the course is nearly horizontal, and here the stream has built up its bed, natural levees following its meanders.

In detail, the floor has faint undulation, or, more properly, coalescing basin hollows. In the last two or three decades these hollows have several times during brief flood stages of the stream become filled with water. The creek at such times has in large part wholly abandoned its single defined channel, subdividing and wandering broadly, spreading sands, or lingering for days and weeks in slackwater expansions and ponds without outlet, depositing silt.

The vastly extended uplands on the west have gentle inclination eastward, or a little to the south of that direction. The embracing arm of high flats on the east is seemingly to the eye a brief extension without deformation of this great plain. Its mean width is about half that of the basin it incloses. The "breaks" mark its outer or eastern limit, from which descent to the uncovered Red Beds along stream lines is rapid. Opposite the basin this southwestwardly turning arm of upland is found to be hollowed. Here, also, stream-head sapping along the irregular line of breaks has most narrowed it (*d*, on Pl. CXLIV, p. 724).[1]

The western uplands show bending in a double curve to the basin floor, rather than abrupt termination at a rim. The fold is steep, and it has been incised by erosion; but in profile along several lines it may still be made out.

On these profiles at one or more levels there are indications of terracing, and toward the basin outlet at Meade a terrace of this character broadens to a narrow intermediate plain. The obvious suggestion that Crooked Creek at one time had filled the basin, creating a lake which had left shore lines, and that eventually this lake had cut down an outlet, is not however to be entertained. The flood stages of the upper creek endure for only a few hours, and the intervals between floods are years. The assumed body of water would have had to have great depth and an area but little less than the catchment area of the stream above. The actual flooding noted is comparatively trivial in volume. It is the measure very nearly of the total inflow at each flood period. The escaping stream, which usually has continued to flow for several days after inflow had ceased, is merely its drainage off. The terracing would seem rather to indicate stages of basining and successive reductions of the affected area in the successive stages.

Settlement is in the main responsible, apparently, for the narrow arm of the depression extending northward from Fowler to Wilburn. It would seem that it might be taken in like manner as accounting for the arm extending out of the basin southward, forming for a space the lower valley of Crooked Creek. This lower arm does not have the smoothly hollowed cross section of the upper one, though its grade is hardly less gentle. It has strongly incised tributary arroyos, and is itself modified into a fair semblance at least of a normal valley of erosion. There are, however, especially on the west, toward the arroyo heads on that side, descending profiles again of the upland surface, showing in arroyo sections mortar beds and the original alluvial bedding planes bending down to the eastward, just as in the breaks elsewhere there is evidence of settlement in lines or chains of basins, determining and controlling drainage.

The upland strip lying to the east of the Meade Basin continues southward, walling in Crooked Creek Valley on that side also. The eastern breaks here head the many tributary valleys of the Big Sandy. Sand Creek, the southernmost of these tributaries, has cut backward toward Crooked Creek, at right angles to the course of that stream, until only a neck of uplands, about a mile in width, intervenes (at *e*, and southward). About its head the upland surface dips toward

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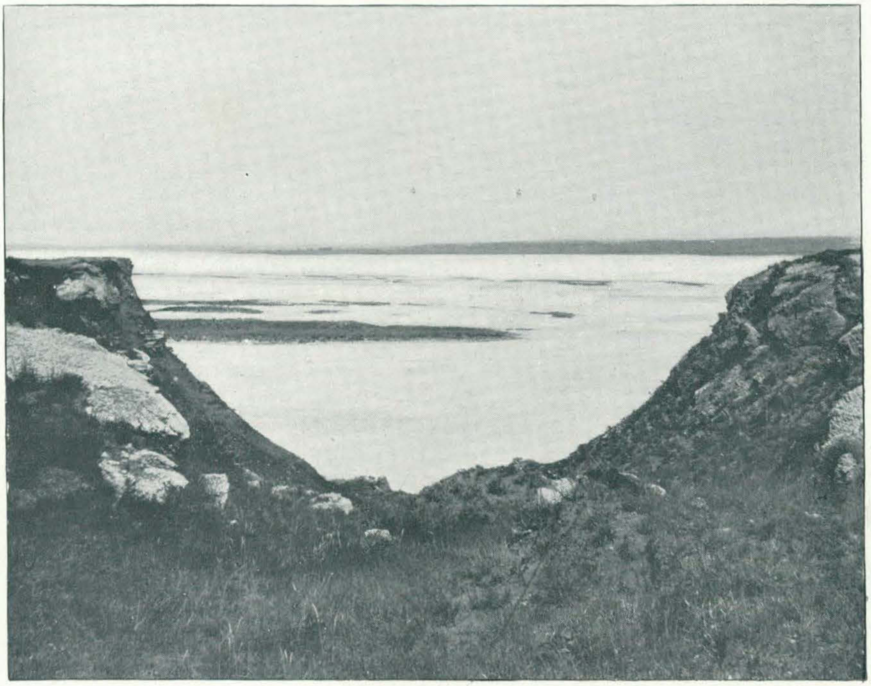
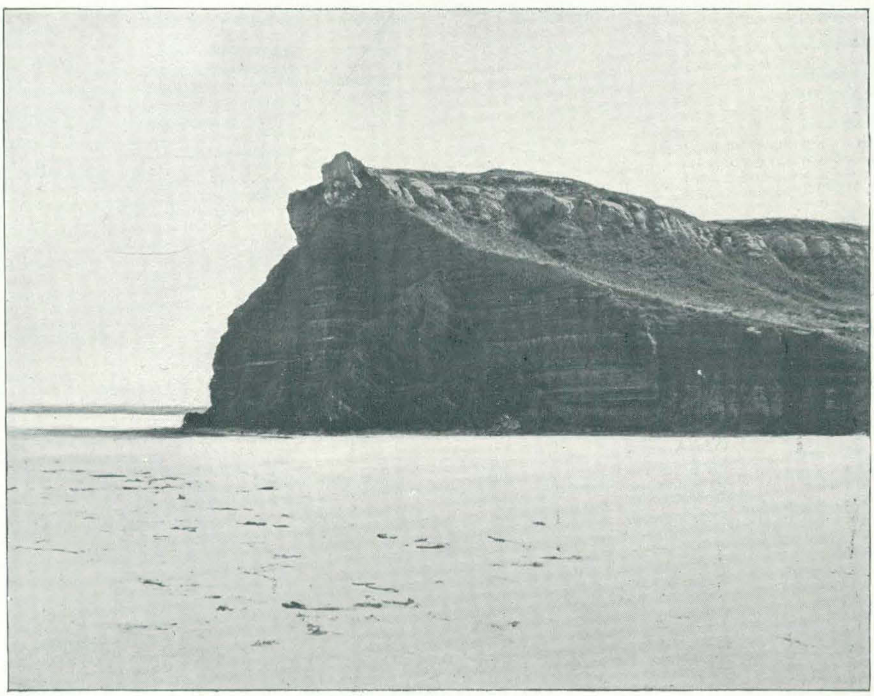
[1] See also U. S. G. S. Topographic Atlas U. S., Meade quadrangle.



A.



B.

THE SALT PLAIN, CIMARRON VALLEY, OKLAHOMA.

it noticeably, the distinction between erosion grades and the broad slopes of original basining being conspicuously marked. At the point of outlet of the Meade Basin, there are bluffs for a space on either side, and these show bedding, cut across. The actual notch, constituting the outlet, is clearly the product of erosion, but lower Crooked Creek here, like Sand Creek, which seems destined in time to work through the narrowed uplands and behead the other, has tapped the basin. Eventually the narrow upland strip will be eaten through at many points; the line of breaks will then be immediately advanced the 7 miles across the Meade Basin to the front which now constitutes its western rim, and the basin will become subdivided among the several capturing streams, adding merely another group to the anomalous valley expansions within the zone of breaks.

The Meade Basin was originally a large and irregular sunken area without outlet, like that at Yellow House in the interior of the Staked Plains; but, occurring near to the upland margin, it has suffered from the combined effects of marginal settlement and head-stream sapping. By regional tilting eastward its floor has been given inclination in that direction; the narrow table-land on the east has been unevenly settled and tilted also, and erosion encroachment has already on the south made a breach. Its distinctive character as a basin of settlement, not a "fry-pan" valley of excavation, is in large part preserved. As an unusual topographic form, of an essentially evanescent type, it is in an early stage on the way to obliteration, just as the Englewood Basin—the lowland area in the breaks of southern Clark County, traversed by the Cimarron—has reached a late stage, and is obsolescent.

Upon the uplands west of Meade the depth to the free water plane is about 50 feet. Ground water has movement; though continually renewed, it nevertheless continually drains away; its surface therefore has slope. Under any broad alluvial table-land, and back from the marginal lines of escape, both the direction and the grade of this slope will commonly approximate that of the ground surface. West of the Meade Basin both the uplands and the water plane normally have eastward inclination, and the grade in each case is about 10 feet to a mile.

Extended across the Meade depression the water plane should pass high above the floor—70 feet above at the western border, 90 feet above at the center, and 40 feet above at the eastern border. Eastward tilting has been greater by 30 feet than the original eastward inclination of the surface.

If the Meade Basin were completely inclosed, the uplands extending far beyond, and if the artesian "cover," or interbedded clay sheet, were strictly impervious (which it is not), permitting of no upward leakage in springs (which in fact it does), this water plane, extended on its 10-foot grade, would be the artesian "grade plane." Wells at the points mentioned, for example, would have rates of delivery to be measured, respectively, by these heads of 70, 90, and 40 feet. That is, in pipes, continuing the well tubes upward, the rising water would come to a stand at these several altitudes.

The relative elevations of all the flowing wells in the Meade Basin were carefully determined by leveling.[1] Rates of delivery were measured at a small number of selected wells, their heights of rise to a stand being ascertained at the same time. As will be seen, the wells occur in groups. None of them have strong flow, or high rise in standpipes, the highest rise being 22 feet. By comparison with tested wells the mean deliveries and heights of rise in each group were estimated. The map shows the positions and elevations of 209 flowing wells. Those of a few others, of insignificant yield and having scattered distribution, are not shown, though they were obtained. They have useful bearing, however, upon the position of the hydraulic grade plane. Depths to standing water, also, were determined in five other

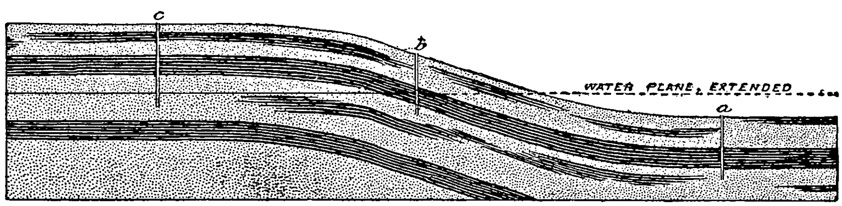
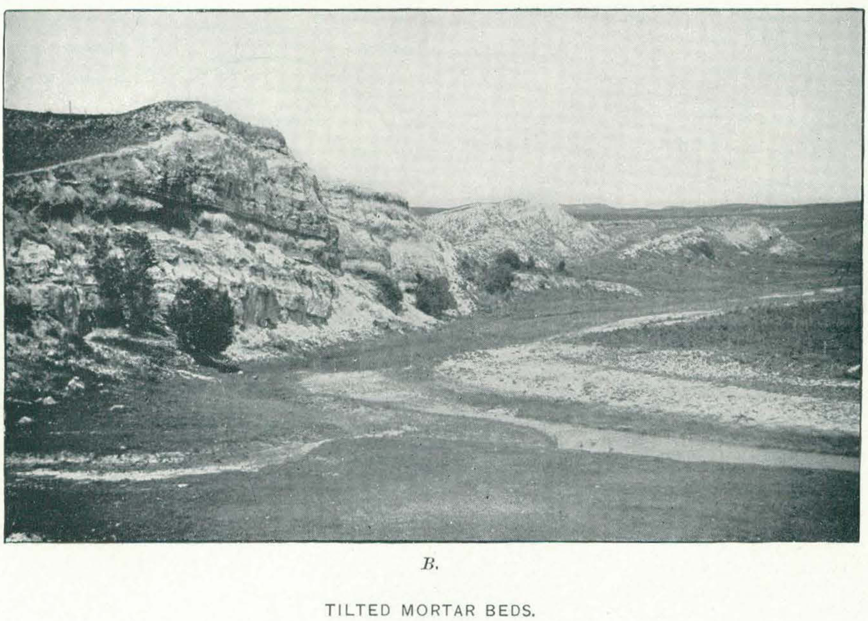


FIG. 318—Hypothetical section of rim of Meade Basin.

wells (marked P, indicating "pumping wells") occurring within the bordering zone, where there is artesian rise, though not sufficient to reach to the ground surface. Among the groups of flowing wells the experimental heights attained in standpipes have considerable range. This was found to be largely due to imperfect casing, permitting leakage into the porous ground overlying the "cover," the usual tubular lining frequently having been omitted wherever the lightly cemented ground material proved to be strong enough to maintain an opening without it. For fairer comparison with the scattering individual wells, therefore, means were taken. The resulting hydraulic grade plane, indicated on Pl. CXLIV by dotted contours, may, however, be accepted as closely approximating the true one. The figures on the contours are restored from the means and represent the assumed true position of the grade plane. Altogether this generalized theoretical surface is based upon 226 precise ground-surface elevations, having range as follows: Southwest to northeast, +76 feet; southeast to northwest,

[1] The accompanying map of the Meade Basin (Pl. CXLIV) has been prepared, in its general outlines, from the data of the Meade quadrangle, U. S. G. S. topographic atlas. The positions of wells and their elevations, however, were obtained from original meanders and checked levels by the writer's assistant, Mr. Dennis D. Doty.

A.



B.

TILTED MORTAR BEDS.

+86 feet; southwest to northwest, +128 feet; from the center of the floor to the highest flowing well at its margin, +96 feet, and from the center to the lowest flowing well, −32 feet. To these, in order to determine the hydraulic grade plane, plus or minus corrections have been applied, mainly by estimate, but within a measured range of only 22 feet, and therefore subject to small probable error.

The true position of this surface of equilibrium to which the basined ground water seeks to rise in well borings is of interest mainly as revealing hollowed deformation, rudely corresponding with that of the topographic surface. Theoretically, as we have seen, it should be an inclined plane, identical with that of the upland ground water, extended. There is, in fact, inclination in the same direction, but the inclination is steeper, the general level is lower, and the profile of the slope is hollowed. The hollowing appears to be due to leakage through artesian springs rising from the basin floor in the region of lowest depression and strongest upward pressure. As above stated, the normal water plane, extended, would pass 70 feet above the floor at its western border, 90 feet above at the center, and 40 feet above at the eastern border. Along this line, at the same points, the actual rise is, however, only 2, 18, and 4 feet, respectively. The hydraulic grade plane, in fact, barely skims the surface. It does so as a rule only where the surface is itself, in many places, basined in a minor way. Here occur the groups of flowing wells, with maximum rise of a little more than 20 feet. The faintly domed areas between the minor basins it slightly underruns, and here, on the other hand, the artesian rise falls short of the ground surface.

The direction taken in this region by the line of breaks, or erosion margin of the uplands, is southwest-northeast. The drainage heading at the breaks, made up of the many branches of Big Sandy, Bear, Bluff, and the smaller creeks, has courses at right angles to this line, southeastwardly to the Cimarron. Above Wilburn, Crooked Creek, as we have seen, has a course a little north of east, and seems at one time to have been tributary to the Arkansas. The backward turn it makes at Wilburn, and which it maintains not only to Meade, but for 12 miles beyond, to Odee, gives it a course directly away from the Arkansas for 30 miles. Along this 30 miles it parallels the line of breaks, with a narrow strip of upland intervening. It does not run in a canyon, except in the brief passage through the notch at Meade. From Meade to Odee, as from Wilburn to Meade, it follows along the foot of a limiting bluff at the eastern border of a broad, basin-like expansion, tilted toward the southeast. At Odee, however, it turns directly against the strip of upland, and, cutting through it, joins the parallel system of Cimarron tributaries. In this change from the Arkansas system of drainage to the Cimarron system, the middle 30-mile section of Crooked Creek forms, with the other two, a great letter Z.

The valley of Crooked Creek is normal and sharply cut from its termination upon the broad Cimarron bottom back to Odee. It is an ordinary valley of erosion also from Wilburn to its source. But from Odee to Wilburn, along the middle arm of the Z, the low-lying area which it traverses is obviously not a stream valley at all, and only in its minor configuration a product of erosion. Below Meade a second oval-form basin of settlement is extended southwestward, fading out a few miles below Odee. The shallow notch at Meade is a product of erosion, by backward cutting, connecting the two depressions, and the opening at Odee is another, establishing through drainage. The original Crooked Creek below Odee was a short stream, like Sand Creek, heading in the breaks against the narrow strip of upland. By sapping it has worked its way through.

The Odee basin is deeply incised by arroyos tributary to Crooked Creek, coming in from the west. Along their side slopes, at various points, these show eastward dip of bedding planes and mortar beds of the Tertiary, and well borings almost invariably develop the phenomenon of artesian rise. In several instances, also, these long drainage lines, though dry in their upper courses, have perennial flow lower down from artesian springs. The northernmost of the series, Spring Creek, appearing at the southwest corner of the map (Pl. CXLIV), carries through to Crooked Creek, which it sustains as a perennial stream for several miles. A number of the spring sources of Crooked Creek issue with considerable force from beneath impervious layers, either clay masses or mortar beds. A comparatively light spring of this character, on the north slope of the Canadian Valley, in northern Texas, has been walled in. It rises about 4 feet, at which height it ceases to flow. This level, however, is constantly maintained, though the spring is continually resorted to for drinking purposes by large numbers of cattle.

A spring so placed at the folded margin of a plateau having interbedded impervious sheets will mark the lower limit, very nearly, of the hydraulic grade plane if the ground water happen to be confined by the folded sheets. The ground water normally has dip from an upland to a valley, and if descent of the ground surface be too rapid, and if there are no impervious layers interposed, it may pass out at the surface before the foot is reached, resulting in visible drainage off in the form of springs. But if the slope is not the product of erosion, but is the rim of a settled area, with underlying clay sheets inclined also, the ground-water surface will be forced into a position steeper than it would normally assume. Wells sunk to it then will show artesian rise (as at *b* in fig. 318), and springs in arroyo indentations near the foot will be of the upward-boiling variety—that is, they will be artesian.

Of the two basins, the lower one is the older and the more advanced in transformation by stream erosion. Toward its gateway of escape Crooked Creek has cut through the Tertiary, exposing the Red Beds floor, and the margin of artesian escape has, in consequence, been carried some distance upstream, not only on the main creek but along several of its tributaries. The Odee basin has no flowing wells, but above the margin referred to wells generally have artesian rise. Possibly there may have been head sufficient for flowing wells originally, as in the case of the Meade Basin at present. There the Red Beds floor, as indicated by the test boring near the Salt Well, is still covered by about 300 feet of Tertiary. Stream incision of the Tertiary has weakened the artesian head; eventually it will, by this process, be completely destroyed.

It thus appears that the phenomenon of rise of water in well borings is not confined to the so-called Meade Artesian Basin. A much larger area, including it, is involved. There is a narrow zone on the west in which wells exhibit rise, in rapidly diminishing amount, backward to the undisturbed ground-water level. This zone broadens southward, extending some miles beyond Odee; but it also has broad extension eastward, including the upland strip, which has been settled bodily from its proper level, as well as much of the eroded Tertiary of the breaks, descending to a thinned margin upon the uncovered Red Beds. Just above this margin, in the valley of Sand Creek, 5 miles southeast of Meade, is a group of feeble-flowing wells, at an elevation 60 feet below that of the southernmost flowing well in the Meade basin. Here, too, mortar beds, as well as original bedding planes, not only bear witness, in diverse tiltings (Pl. CXLI, *B*), to caving in detail, but by their general southeastward inclination testify also to general marginal settlement.

This settlement has occurred, determining the line of breaks, where the Cretaceous, which to the northwest is thick, thins out southeastward, leaving the Tertiary resting directly upon the Red Beds with their included soluble deposits of salt and gypsum. The depressed area back of the line of breaks, of which the Odee and Meade basins are the lowest portions, merely appear to mark the site and general outlines of an erosion embayment in the Cretaceous margin.

In a discussion, in 1897, of the origin of the Meade Basin, in one of the Water-Supply Papers of the United States Geological Survey, Professor Haworth ascribes it to faulting.[1] Under the subtitle, "Crooked Creek Valley and fault," pages 22 and 23, he says:

> These peculiar physiographic conditions in the vicinity of Crooked Creek, in connection with geological data gathered from wells, led the writer to conclude that local deformation had produced them. * * * The general upland plain, from 8 to 12 miles to the west of Crooked Creek, both physiographically and geologically,

[1] Underground waters of southwestern Kansas, by Erasmus Haworth: Water-Supply and Irrigation Papers U. S. Geol. Survey, No. 6, 1897.

corresponds with the plain on the east of the creek, which approaches to within less than a quarter of a mile of the creek valley. The general appearance from Meade southward is that of a fault, with the western wall dropped and Crooked Creek occupying a position over the fault line. Northward the whole artesian valley seems to have been dropped downward, leaving an abrupt wall on the west and a more gentle wall on the east. Standing anywhere in the valley one can see the wall all around. On the west it is considerably over 100 feet in height, while to the east it is somewhat less, but still very perceptible. We have here a valley occupying about 60 square miles, which is so different from anything else known in this part of the country that it is exceedingly difficult to explain its origin by attributing it to erosion. The peculiar position of the creek is likewise hard to explain by ordinary erosion. The sharp angle at Wilburn, and the southwestern direction for nearly 20 miles across a plain sloping to the southeast, are certainly very remarkable, and probably have a cause different from that which ordinarily determines the location and direction of streams. But, if in post-Tertiary times a triangular area, equaling in size and position the present artesian area, could have dropped 100 feet or more with a single fault line extending southward to beyond the limits of Kansas, thereby changing the direction of Crooked Creek into the present channel below Wilburn, the general physiographic conditions could easily be accounted for.

Again (p. 27), referring to certain anomalous irregularities in the Red Beds floor, he says:

The character of the upper surface of the Red Beds is interesting on account of the great irregularities which it presents. * * * Aside from this rapid inclination southward there are other local irregularities. In the Cimarron Valley, where the whole surface is covered by a layer of the soil and silt from 10 to 15 feet deep on an average, occasional places have been found in well drilling where great depressions exist. At one farm house, on the land of Colonel Perry, a well was sunk to the unusual depth of 175 feet without reaching the Red Beds, while less than a half mile away they are exposed almost at the surface. Such irregularities are probably due to surface erosion in pre-Tertiary time.

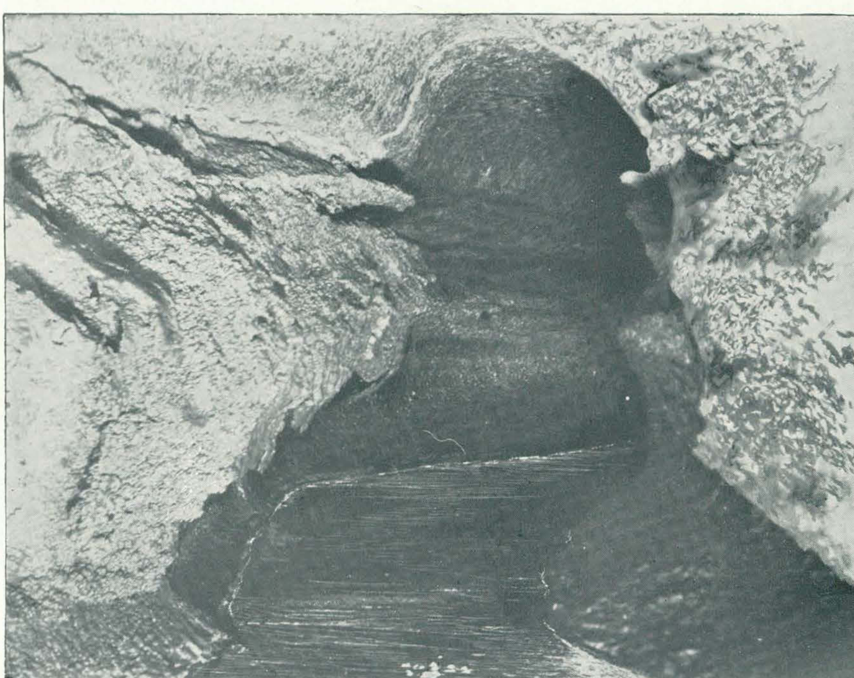
Professor Haworth is here speaking of the large depressed area within the breaks (the Englewood Basin), which the present writer referred to above as apparently similar in origin to the Meade Basin, only obsolescent. Elsewhere, in describing the Cimarron Valley, he says of this basin (p. 21):

The valley of the Cimarron rarely exceeds 2 miles in width throughout its course across the Meade quadrangle, but it has scarcely passed beyond these limits when it suddenly widens to an unusual extent. Beginning a few miles above Englewood it has a valley more than 5 miles wide. North of Englewood is a valley, or an area which seems to be a valley of erosion, 10 or 12 miles wide. * * * Such a wide valley appearing so suddenly along the course of a stream is very interesting, as its origin is hard to determine.

Disregarding an irregular grouping of sand hills which form a partially separating ridge only, the two flat areas may properly be regarded as one. The Cimarron wanders along its southern border. A short distance above, this stream is in a canyon, eroding its bed; and below, it runs in a canyon, eroding again; but within the basin it meanders, temporarily at baselevel.

Professor Haworth gives no consideration to the possibility of

A. SINK-HOLE CONNECTION WITH UNDERGROUND DRAINAGE SYSTEM.



B. UNDERGROUND CHANNEL.

origin by faulting here. The west wall of the Meade depression and the east wall of the Odee depression, falling approximately in line, lend some degree of plausibility to his suggestion in the case of those two basins. The difficult assumption has to be made, however, that the two tilted blocks are in the one case tilted away from the fault, and in the other toward it. Furthermore, in the case of the Meade Basin the assumption of faulting would seem to be called for in explanation of west and east walls alike.

Professor Haworth gives but slight consideration to the possibility of origin of such basin-form valleys in widespread caving and settlement of the Red Beds, resulting from removal in solution of their included deposits of gypsum and salt. He notes (pp. 28, 29) the wide occurrence of such included deposits:

> It [gypsum] seems to be well stratified in the vicinity of Medicine Lodge, forming heavy layers from 5 to 10 feet in thickness. These strata have a lateral extent of many miles, and have been important agents in the production of the peculiar and varied physiography for which portions of Barber and Comanche counties are noted. * * *
>
> Salt is also scattered irregularly through the Red Beds. It is leached out by the water and is deposited along the salt marshes, so common in the Cimarron River Valley to the south of the State line [where the Red Beds have been extensively uncovered by erosion]. Probably the salt is irregularly disseminated throughout the material; possibly heavy deposits of rock salt may yet be found beneath the surface, although no positive indication of such has yet been observed. * * * The origin of the Red Beds is pretty well indicated by their character. The large amount of iron oxide, of gypsum, and of salt which they contain * * * imply that they are the result of the accumulation of sediment in a concentrated ocean water. * * * The large deposits of rock salt in what has heretofore been called the Upper Permian—the salt beds supplying the mines at Hutchinson, Lyons, and other places in the south-central part of Kansas—have probably been formed by the desiccation of an inland ocean.

On the other hand, as will be seen from the foregoing quotations, he is inclined to ascribe the Englewood Basin to erosion, adding, however, that its origin is hard to determine. Almost everywhere in the surrounding hills, though sometimes under cappings of Tertiary, the Red Beds are in evidence, indicating that if this is a basin of erosion, the Tertiary in all likelihood has been wholly removed and a considerable depth of excavation accomplished in the bed rock as well. The bed rock (Red Beds) should constitute the floor, except for a light mantling of recent stream alluvium. But on the contrary, Professor Haworth finds, coincident in position with this topographic anomaly, an unusual depth of loose material and a "great depression" of the bed-rock floor. This basining of the buried Red Beds surface he attributes in turn to pre-Tertiary erosion.

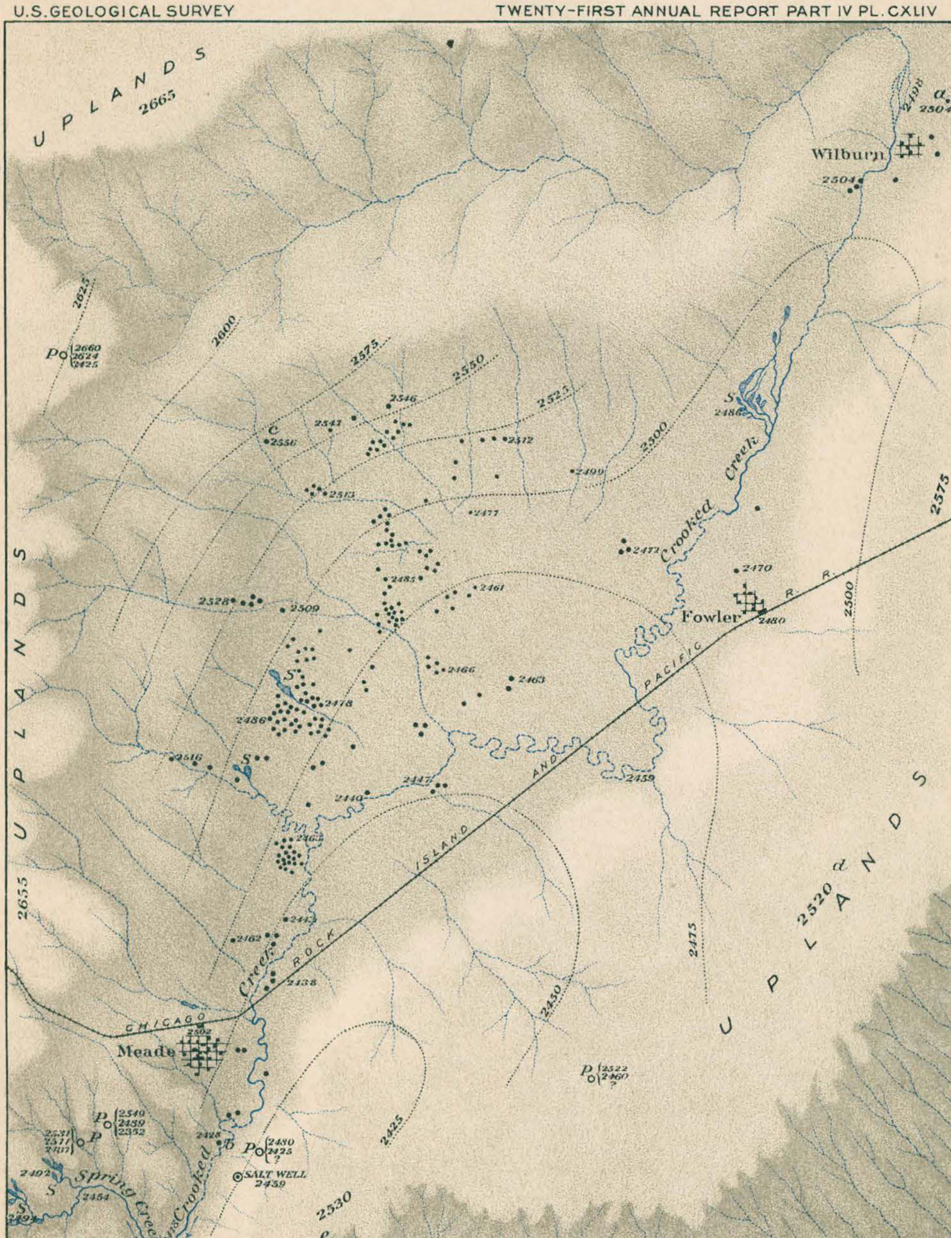
On the assumption of settlement by caving within the floor, coincidence of the two depressions is to be expected; furthermore, multiplication of such occurrences does not add to the difficulty of their explanation. A "fry-pan" valley of erosion is an exceptional topographic form. It reflects an exceptional structure in the material acted upon. Such a structure may have been locally present in the Red Beds, accounting for the depression in the underlying rocks, though these show no fry-pan valleys where exposed to the southeast, but in the Tertiary it is certainly not present to such extent as to account for the exact superposition here of the surface basin.

The surface basins in this region—extending through great range in size and in degree of definition—are in fact numerous. The headwaters of Bluff Creek originate in one upon the uplands, just back of the line of breaks, from which escape is made in a sharp canyon. The town of Ashland, 16 miles northeast of Englewood, lies in another, at the foot of the breaks. Seemingly no line of drainage of any considerable length, anywhere within many miles, has had normal development, undisturbed by ground settlement. While the great majority of the appearances suggestive of settlement are not absolutely convincing, yet unmistakable evidences here and there are presented, as for example, on a small scale, St. Jacob's Well, the Salt Well, and certain "basins" referred to as having surrounding sod cracks, and on a moderately large scale, the Big Basin. The fact once established, in even a single instance, of Tertiary settlement resulting from caving in the Red Beds, with their widely distributed soluble deposits, widely distributed basining of the Tertiary surface, wherever the Red Beds lie close beneath, becomes intelligible.

On this hypothesis, the Meade Basin, with all its minor detail of configuration, its present tilted position, the general lowering of levels and diverse tiltings in the near neighborhood, as well as the manifestations of head in the ground water over the whole area thus affected, becomes intelligible also.

As in the case of the Englewood Basin, there is indication in the Meade area of corresponding depression of the Red Beds surface. Wells there have attained a depth of nearly 300 feet, wholly in sand, gravel, and clay, and without reaching bed rock. This depth corresponds to an elevation above sea level of about 2,150 feet. At the Salt Well, on the southern border of the basin, the Red Beds were encountered at a depth of 292 feet, or at an elevation above sea of 2,167 feet. Ten miles below Meade the red formation is exposed on the creek at 2,325 feet. The creek bed at its point of exit from the Meade Basin is 95 feet higher; but the buried Red Beds there, at an elevation of 2,167 feet above sea, have a lower position by 158 feet. That is, in the 10 miles southward, while the eroded surface of the Tertiary declines 95 feet, the Red Beds, from a depth of 253 feet, rise 158 feet to meet it.

Neither the west side of the Meade Basin nor the east side of the Odee Basin, in the course of the supposed "single fault line extending



W. D. Johnson, del. *Well positions and levels by D.D.Doty.*

THE MEADE ARTESIAN BASIN

Scale of miles

0 1 2 3 4 5

Flowing wells (•) Pumping wells (*P* o) Artesian springs (*S*)

Figures indicate elevations above sea level. Larger figures, on uplands, approximate. Bracketed figures at pumping wells indicate, first, ground level; second, level in well to which artesian water rises; third, level at which artesian water was encountered. Figures on dotted contours indicate assumed elevations of hydraulic grade plane.

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southward to beyond the limits of Kansas," presents a cliff-like escarpment. The margin of the deeply incised and older Odee Basin is much the more abrupt of the two. On the assumption of dulling and recession of an original escarpment by erosion, the fresher Meade Basin should exhibit a difference the other way. Actual faulting is in evidence at several points about the borders of the Yellow House Basin, in the interior of the Staked Plains. This depressed area is closed, and the faulted sections of its rim are arc-form. Their exposures, as well as the records of borings in the basin floor, indicate that rather strongly cemented mortar beds here are both numerous and of unusual thickness. Even assuming origin in general settlement, due to caving within the floor, a sharply localized marginal effect might reasonably be looked for in this stiffened alluvial material. The fault, as a topographic feature, does not appear at Meade, and here arroyo exposures and well records indicate a relatively feeble development of the mortar beds. Faulting, whether profound or superficial, might be expected to operate against the production of artesian pressure—certainly not directly to favor it; and in the Yellow House Basin, though its floor is much below the general water-plane level of the surrounding uplands, there is only very feeble flow at the surface, and then only at one end, away from the faulted escarpments. On the other hand, springs occur, as might be expected, at the escarpment foot. The ranch houses appearing in the illustration (p. 728) are located along a line of such springs. The fact that there are flowing wells in large number in the Meade Basin may, indeed, be taken as evidence that there has been no serious rupturing of the impervious sheets.[1]

Probably not one-third of the total area of the valley floor, or not more than 10,000 acres, has flowing wells. Prospecting for water has been thorough, and the areas of possible flow, as shown on the map, are outlined with a fair degree of accuracy by the actual distribution of wells. As already stated, the hydraulic grade plane barely skims the basin floor, slightly underrunning its undulations between minor basins. The possible irrigable area is somewhat larger than the total of these areas of flow, since the wells have rise above the surface and grades are light. In few wells, however, is this rise more than 15 feet. On the other hand, the small basin bottoms, in which rainwater lingers and dries away periodically, do not respond profitably to cultivation. The maximum area possible of reclamation, from this point of view,

[1] In the summer of 1896, several months previous to the beginning of the somewhat detailed study of the artesian phenomena and physiography of the Meade region, which was to be preliminary to the general examination of the High Plains, the writer spent two days at Meade with Professor Haworth, who at that time was engaged in his investigation of the underground waters of southwestern Kansas. The Meade Basin, Spring Creek, and Crooked Creek, down to the outcropping of the Red Beds, were visited in his company, and the writer had, in advance of any definite impressions of his own, the benefit of Professor Haworth's, views, substantially as presented in the report quoted from above. Professor Haworth not only stated his hypothesis of faulting, but gave it as his conviction that the artesian manifestations were the result of local depression of the ground water of the Tertiary, due, apparently, however, to the dropping of a faulted block.

therefore, may safely be placed at 10,000 acres. The area actually irrigated in 1897 was but a fraction of this amount.

Of the 209 flowing wells shown on the map, only about 180 have flow sufficient in amount to be of appreciable value. The delivery in individual cases ranges up to about 50 gallons a minute. A fair average yield among the 180 serviceable wells would be 10 gallons a minute, giving a total yield of 4 second-feet. Making the liberal estimate that half of the yield throughout the entire year could be stored and delivered as needed, only about 1,500 acres each year could be supplied with 12 inches of water.

By multiplying wells at points where delivery is strongest, the total yield might in some measure be increased. It is questionable, however, whether it could be largely increased. Grouping has already been carried so far that further additions to groups would result in perceptible reduction of the average delivery per well. Tests were made to determine this question so far as possible. One of these tests was as follows: In a small isolated group of three strong wells, lying equidistant from one another, about 100 yards apart, and each having a depth of about 160 feet, one was brought to a stand in a pipe continuing the well tube upward. The height reached above the ground surface was 11 feet 4 inches. The two other wells were then plugged. The water level in the standpipe rose slowly. In ten minutes it had ascended 5 inches; in 30 minutes, 9 inches, and in something less than an hour it again became stationary at 15½ inches. After another hour the two plugged wells were allowed to resume their flow. The level in the standpipe then sank, at about the same rate it had risen, to its original level. The experiment was repeated later with only one well plugged, and the rise was nearly 9 inches. Thus, in the case of this single isolated well, the addition of another close by resulted in the reduction of its original efficiency by 6 per cent. From general inspection and the universal testimony of well makers, it became clear that the total yield in the basin at least can not be so greatly increased as to serve the 10,000 acres given above as the maximum area of available lands. It would seem, indeed, that it can not be increased by so much as 50 per cent. That is, the probable limit of yield is within 6 second-feet. The actual yield is about 4 second-feet. The combined flow of the several artesian springs at the head of Spring Creek, already referred to, is a little in excess of 4 second-feet.

The explanation of this low maximum delivery is involved, apparently, in that of the hollowing of the hydraulic grade plane shown by the dotted contours. The ground water beneath the uplands on the west is the source of supply, and under ideal conditions it would seem yield should be conditional only upon the ability of this supply to sustain it. But a hollowing of the grade plane coincident with the topographic depression indicates that ideal conditions do not obtain. The

A.

B.

ARTESIAN WELLS OF MEADE BASIN.

grade plane should have fairly uniform inclination, modified only by the varying resistance of the ground material, and this variation will be too rapid for broadly extended effects.

Local hollowing must result from local leakage. The impervious cover is at best only relatively impervious. Clay beds beneath the upper level of saturation of the ordinary ground water are saturated equally with the beds of coarse material. A boring extended to the free water plane will encounter it at virtually the same level whether in clay or in gravel. Delivery from clay is comparatively very slow. A boring penetrating to a considerable depth below the water plane wholly in clay may readily be pumped dry. It will then slowly fill again to the original level. But if it be extended farther, to some underlying bed of gravel, and kept dry during extension, strong inflow will be encountered from the gravel bed. This inflow will have upward pressure equal to the weight of a column of water reaching to the water plane, and its rise will be of the nature of artesian rise. In the absence of the well opening there is no upward pressure against the clay, because the latter is itself saturated up to the water plane. If, now, the clay bed could all at once be exhausted of its contained water, it would constitute an artesian cover. However, because it is not absolutely impermeable, it would be a leaking cover. Therefore, it would in time be refilled and the original water plane would be reestablished.

In the case of the Meade Basin the cover is of this character, depression of the whole mass having left the original level of equilibrium above the ground surface. It is slowly permeable. It is therefore a leaking cover. The ground water, however, is not extended above it to a reestablished water plane, because there is drainage off of this leakage. The clay sheet—or connected grouping of clay masses—is in general more or less deeply buried. It leaks into overlying sands and gravels of considerable thickness; and because the basin is tilted, presumably there is drainage off through these overlying porous beds at the lowest point in the rim of the basined clay sheet.

If the clay-sheet basin at its rim rose sufficiently high on all sides, the water of upward leakage would accumulate to the level of the upland water plane extended, as shown in fig. 318 (p. 718). The clay sheet would not then be subjected to upward pressure and would not constitute an artesian cover. The actual hydraulic grade plane is hollowed above the sunken area, and falls below the theoretical water-plane level as shown, because, in the first place, the basined clay sheet beneath is not strictly impermeable, and furthermore, because the water which leaks upward does not accumulate there, but finds passage off southward, through the sunken and eroded areas in that direction, at a steeper grade than the general eastward inclination of the ground water.

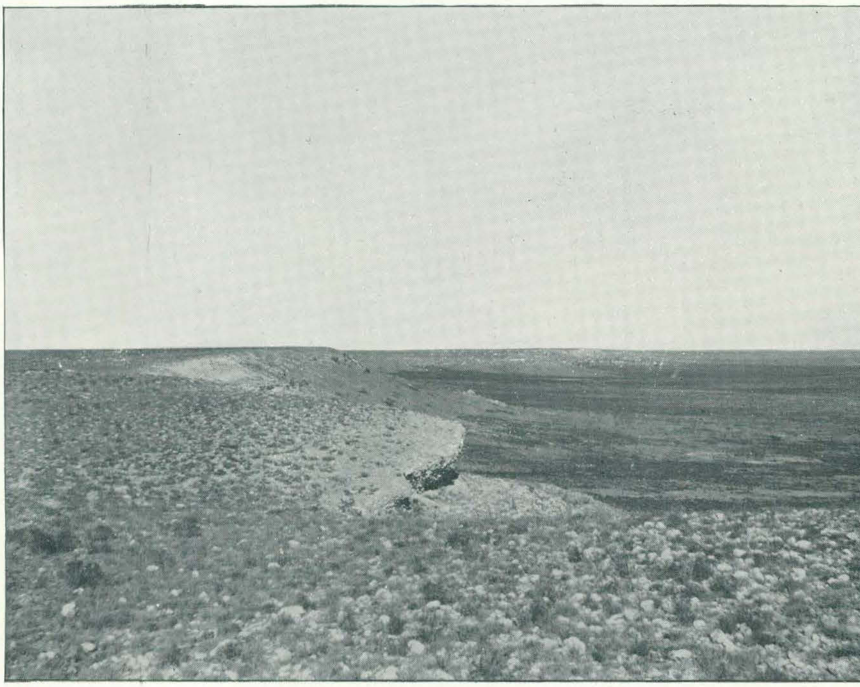
The condition may be likened to that of a pipe lying in an open trench, carrying water under light head, but sustaining loss at imperfect joints, the escaping water forming a stream submerging the pipe. A vertical tube set in the pipe will then show rise to a stand at some height above the water level in the trench. This rise will be less than if there had been no loss from leakage, but on the other hand it will reach higher than any level the water in the trench can assume (unless ponded), however slow its movement.

As we have seen, the flow of wells in the Meade Basin is much more feeble than might theoretically be expected, and this it appears is so because the deep-lying clay beds serve but imperfectly as an artesian cover, permitting upward leakage of water into overlying porous beds, where to a considerable depth it accumulates, though at the same time it drains away. In consequence, above the cover in this porous mass there is a local ground water, having inclination and movement southward. Though surface inflow to the basin may at times contribute to it appreciably, its derivation in the main, unlike the ground water of the uplands, is from below.

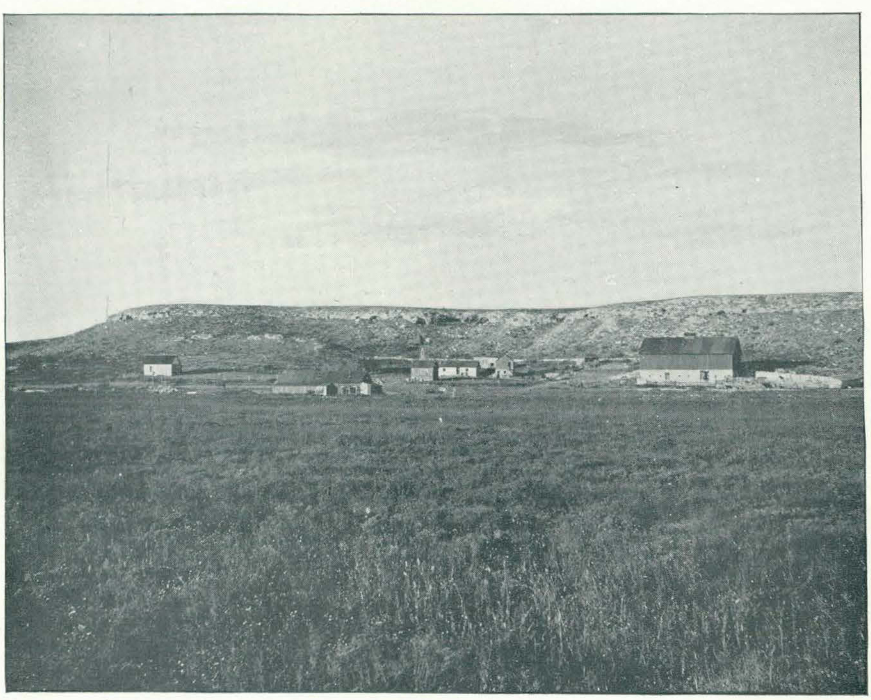
As with the water in the ditch, the depth of accumulation, because of drainage off, is not sufficient to balance the upward pressure of the confined water beneath the clay floor, or artesian cover, and when a way is opened for it the latter rises through the overlying accumulation, as the water in the pipe rises through the vertical tube, to some level above the stream in the ditch.

Since it is not to be assumed that the buried cover is a uniform sheet of clay, everywhere permeable in equal degree, this local ground water should have a correspondingly uneven water plane. The so-called surface water is in fact encountered at depths so uneven as to indicate marked undulation. And this undulation shows no relation to that of the basin floor. At several points upon the floor there are small marshy tracts indicating intersection of the two surfaces, yet none of these coincide in position with the minor basins; they occur rather upon slopes. At other points, marked S on the map, there are actual springs. As might be expected, these occur where borings disclose the strongest pressures. They may properly be termed "artesian springs," since their source of supply is not to one side and above, but deep seated and vertically beneath. They rise through the basin ground water and in some cases issue upon the virtually level basin floor. Adjoining wells penetrate to depths exceeding 100 feet—sometimes even to 250 feet—before encountering artesian pressures.

Generally speaking, in the marginal region of the High Plains, wherever the Red Beds constitute the floor, or where their covering of Cretaceous has been greatly thinned, there will be characteristically a zone of gently descending uneven slopes, separating the undisturbed upland from the erosion escarpment or line of breaks. Incidentally, within this zone, there may occur basins of sharply localized settle-



A.



B.

ESCARPMENT OF YELLOW HOUSE BASIN.

ment. But the zone, as a whole, will be one of settlement, its profiles retaining in the main the original surface. Wherever extensive interbedded clay sheets occur, depressing the water plane below the inclination it would normally assume, artesian pressures will be developed, and the pumping lift in wells may be found to be materially reduced from that upon the uplands. This reduction of lift may, in some cases, approximate to the depth of surface lowering.

The margin of the Cretaceous swings off southwestward from the Meade region in Kansas. The Beaver River in western Oklahoma has cut down deeply into the Red Beds, but the Cretaceous is exposed here and there along its valley slopes on either hand, showing deep Tertiary above and the Red Beds beneath. Upon the "North Plains," between the Beaver and the Canadian, in northern Texas, the Cretaceous at one point even rises to the upland surface, plantation there having brought it into conformity with the general upland level. Along the Canadian it reappears, sometimes thick, sometimes thin, and again altogether absent. The Tertiary, in short, has marked variation in depth, though its upper surface is virtually a plain. The floor upon which it rests, deeply and variously eroded, is in the main, perhaps, of Cretaceous rocks, but along the deeper pre-Tertiary valleys these rocks have doubtless been widely removed. Apparently this is the condition beneath the great plateau of the Staked Plains, as indicated along the canyon walls of the Paladuro and other deeply incised spring streams, which head back some distance within the eastern plateau front. The large basins occurring in linear arrangement, as well as the wide trough-like depressions, sections of which are occupied and accentuated by lines of drainage, have already been referred to. Furthermore, in contrast with the flatness of the plateau in general, much broader areas exhibit diverse and faint but far-reaching grades, which are hardly to be accounted for except on the assumption of uneven regional settlement. Thus artesian manifestations from the ground water may reasonably be looked

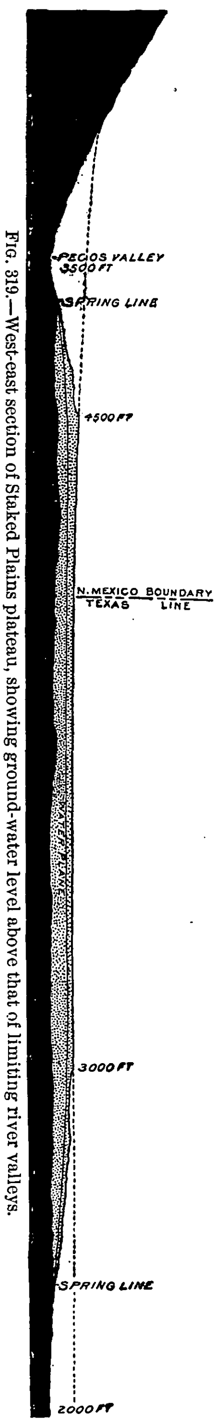


Fig. 319.—West-east section of Staked Plains plateau, showing ground-water level above that of limiting river valleys.

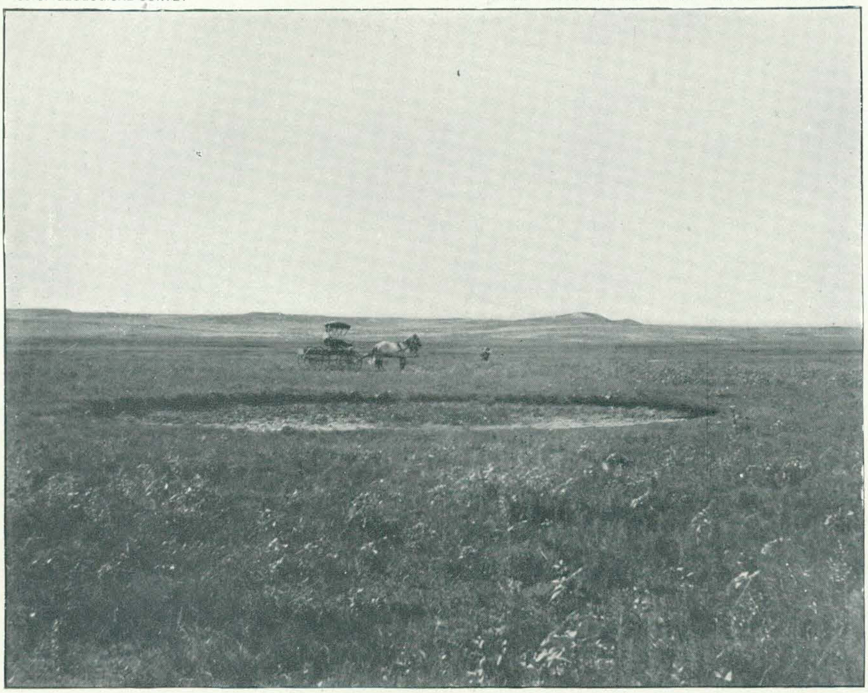
for in the interior of the plateau areas, as well as along the marginal region, as at Meade.

It was the writer's expectation at the outset of this investigation that it would be found to be possible to duplicate the results at Meade in many of the large interior basins. It appears, however, that conditions at Meade were exceptionally favorable. The depth to water in that region is comparatively slight. It is but 50 feet on the uplands to the west of the Meade Basin. Upon the uplands generally it is much greater than this. The depth varies slowly, but it ranges down to 150 feet and more. Probably the mean is little short of 100 feet.

In order that there may be flow at the surface, therefore, and not rise in wells part way merely, the basin floors must have these considerable depths below the general level; at the same time there must be unbroken extension of impervious beds beneath. As a rule the basins are not deep enough. As a rule, also, the requisite underlying clay sheet, of greater extent than the basin, is not present. Commonly the water plane is encountered, at some slight depth, at a level continuous with that beneath the surrounding uplands. There is marked advantage in this, owing to the great reduction of the pumping lift, and the gain here is but slightly offset by diminution of power to windmills, since the depth of a basin is slight relatively to horizontal extent; but in no other instance has the writer found that the water-plane level extends high above the basin floor. The Yellow House Basin and a few others already mentioned have flow at the surface over fractional areas of their bottoms, though in no case in sufficient volume for important irrigation. That it may not be materially increased appears from the fact that in each instance the water plane beneath the uplands near by is barely above its level.

In one particular the Yellow House depression presents an interesting exception to the general rule. As at Meade, the floor is not level, but sensibly hollowed. The artesian patch lies at one side of the center on a faint grade. There is, in consequence, a central area a mile or more in diameter which has a lower position by several feet than the upland water plane.

It would seem, therefore, that the ground water here should be exposed, forming a broad and shallow lake, as, in the case of the small basin near Englewood it forms a relatively deep pond (Pl. CXXXII). There is instead a marsh of somewhat less dimensions, with open water in pools. In winter the pools enlarge; in summer they become smaller or may even wholly disappear. There is a considerable upland area which the backward cutting of storm drainage has made tributary to the basin, and after heavy rains a flood-water lake is created; but this soon dries away. Apparently it is by evaporation, also, that a ground-water lake is kept down. The factors here are the rate of evaporation on the one hand, and on the other



A.

B.

ARTESIAN SPRINGS.

the rate at which the ground material is permeable to the upward rise of water under the light head which evaporation creates. In wells at the marsh border water stands flush with the surface and borings give sections of uniformly fine material, so far as they have gone. Hence, at all points within the marshy area water rises as readily as it is contributed to these wells. No borings have penetrated to the floor. It is, therefore, not unlikely that open-textured material exists beneath. Some distance back from the marsh, far enough to secure an intervening belt of irrigable land on the faint slope, it would seem that it might be worth while to put down a test boring. The belt could have but little breadth at best, for it is limited between the two planes of the hypothetical lake-level and the actual evaporation level of the marsh, and with retreat upgrade the possible artesian rise above the ground surface would correspondingly diminish. It happens, however, that the marsh is strongly saline—a result in this case, apparently, of long accumulation of the evaporated residue from surface waters—and ponding after rains annually spreads a salt deposit to a broadly expanded shore line.

As we have seen in the case of the Meade Basin, such artesian covers as the complex structure of the Tertiary may afford are only relatively impervious, and operate as such only when there is opportunity for the inevitable upward leakage to drain away. At Meade there is drainage through overlying porous beds, because the basin is at the edge of the uplands, where the water plane dips strongly, intersecting its floor. An interior basin, though provided with a continuous clay sheet and lying below the nearly level water plane, must reproduce the latter as a lake surface—except for the slight amount that evaporation will lower it. It will not matter that the rate of upward passage through the clay sheet is gradual. The clay sheet can be effective as an artesian cover only where there is drainage off through overlying porous beds at some rate more rapid.

It is therefore apparent that the utmost that can be looked for in the way of artesian possibilities within the large depressions of the High Plains is the occurrence occasionally—not always—of a small tract on the slope of a hollowed basin floor which will afford flow sufficient merely for the irrigation of a garden patch, determining the location of a ranch headquarters or a watering place for stock. More promising, however, than the inclosed basins are the long, flat slopes, products of settlement also, which occasionally intervene between the erosion front and the uplands proper, or which sometimes for considerable distances border the valleys of the larger transecting streams, such as the Canadian.

These tilted marginal tracts of the old plain often have steeper inclination than the dipping water plane beneath, and where the requisite clay sheet is present and there are erosion channels lowering the ground surface locally there is opportunity for flowing wells. Here occur the numerous small perennial streams, having origin in springs which may properly be termed artesian, which from the beginning of the stock-growing industry have been utilized for ranch sites. Their number may be notably increased above the natural "spring line" by artificial outlet for the imprisoned waters.

THE GROUND WATER.

All the materials of the earth's crust—the hard rocks in great variety and their loose covering of disintegration products alike—are permeable to water; and virtually the whole is saturated with water. There is even an excess over saturation, as indicated by the oceans.

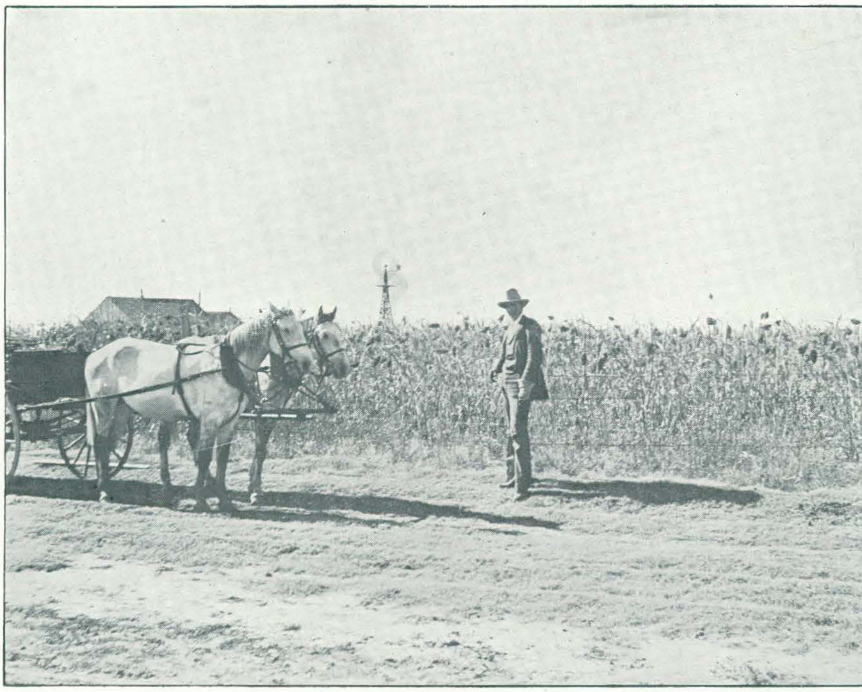
Except for crustal unevenness, which leaves it ponded in confluent basins, this excess would form a continuous ocean envelope. Wherever it does extend, however, the ocean surface conforms very nearly to the ideal spheroidal figure of the earth; and that figure would in effect be completed, by continuation of the ocean level as a level of saturation, or universal water plane, beneath all continental and island masses, if it were not for the endless round of evaporation and precipitation by which water is continually lifted from ocean surfaces to be showered upon land surfaces. This water of precipitation in large part runs off again to the sea; a part also is evaporated, either directly or out of the soil; yet some portion penetrates downward beyond recall. Thereby the saturation surface everywhere is built up virtually to the land surface.

But ground water is not permanently stored. Its level tends continually to sink. There is drainage off along faint grades to the sea, and at rates varying as greatly as the permeability of the various rock materials and their loose covering varies. The mean rate of this movement, however, is exceedingly slow. It is much slower than the mean rate of replenishment from precipitation. Underground loss can exceed the precipitation supply only on grades that for surface run-off would be steep; and all land masses, excepting small mountainous islands, have such broad extent relatively to elevation above sea that, topographic irregularities of the surface aside, their grades are faint.

Thus, with the rate of filling notably greater than the rate of loss, greater even under the average of desert conditions, the saturation surface would coincide with the land surface if it were not for topographic irregularity, which affords steep grades locally. In consequence, the water plane beneath a mountain mass may lie at a considerable depth, though even then it will be domed above its general level, or on a slope it may pass out at the surface, marked by a spring line; or across a hollow it may have representation, approximately, in the surface of a lake. That is, locally it may lie at a considerable depth below ground, with compensation by escape elsewhere.

A. SAND-HILL TRACT.

B. A SAND HILL.



A. "DRY FARMING."

B. A "TANK."

Streams in their flood flow represent the run-off from precipitation direct; but essentially it is from the ground water seeking to adjust diverse grades to a mean grade of equilibrium that streams in their normal perennial flow are sustained. Perennial streams, strictly so called, lie below the water plane; intermittent streams, above. Even in humid lands the branchings of a system of drainage at relatively high grades are intermittent—have flood flow only. In this

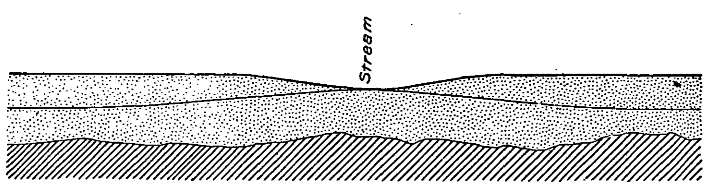


FIG. 320.—Mountain stream of perennial flow contributing to Plains ground water.

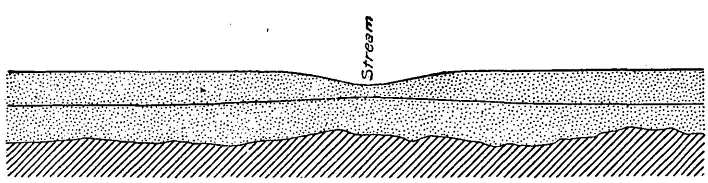


FIG. 321.—Mountain stream of intermittent flow contributing to Plains ground water.

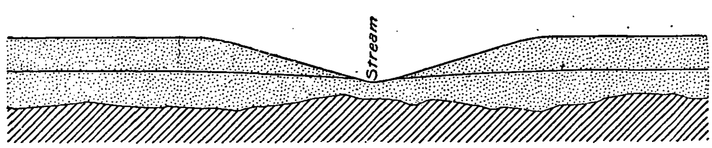


FIG. 322.—Mountain stream of perennial flow draining Plains ground water.

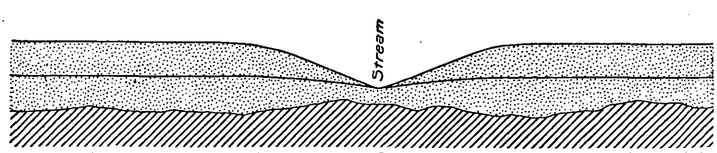


FIG. 323.—Mountain stream of intermittent flow made perennial by contribution from Plains ground water.

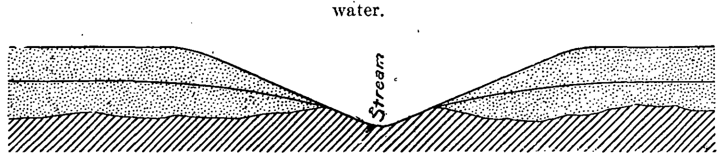


FIG. 324.—Mountain stream, either perennial or intermittent, sunk into Plains bed rock, spring-fed along base of Tertiary.

zone above the plane of ground-water equilibrium the whole surface may be regarded as covered with them. Below is the zone of ground-water escape. But as the permeability of ground materials is very widely variable, escape will take the form of springs, heading streams, or contributing to their flow from beneath; and as clear running water cuts channels, the slowly permeable interstream areas will be drained down approximately to stream level, as a marsh is drained by ditching. Thus there is an upper zone in which normally dry stream beds everywhere lie above the ground water, though in flood they in a measure contribute to it, and another in which the ground water extends its surface sensibly above the streams, maintaining them in perennial flow after the surface contribution has passed. Toward the close of a protracted period of drought the spring sources of perennial flow become largely revealed. The perennial streams, then, in their upper reaches at least, are the measure and indicate the importance of the ground-water contribution to run-off.

But while the regions of higher elevation everywhere are the zones of ntermittent flow, in arid lands the saturation surface underlies usually at a considerable depth the areas of low elevation as well. There are normally no perennial streams. Spring flow may for short distances occur in canyons at the sharp change of slope at the foot of a desert range. Or, under exceptional conditions, such as obtain at

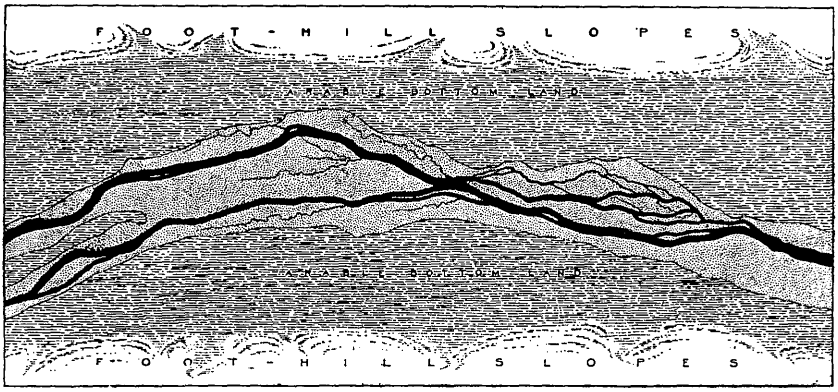
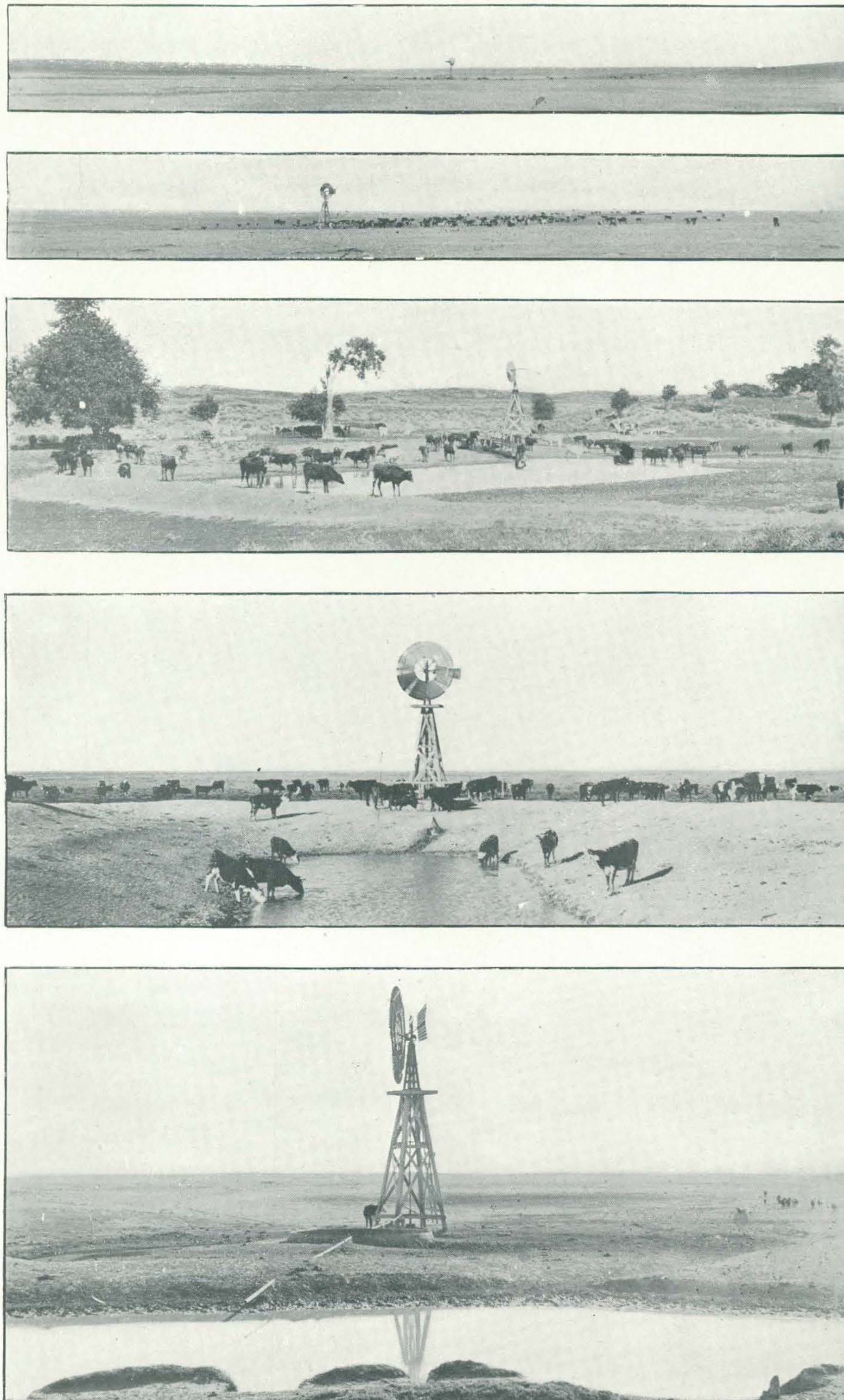


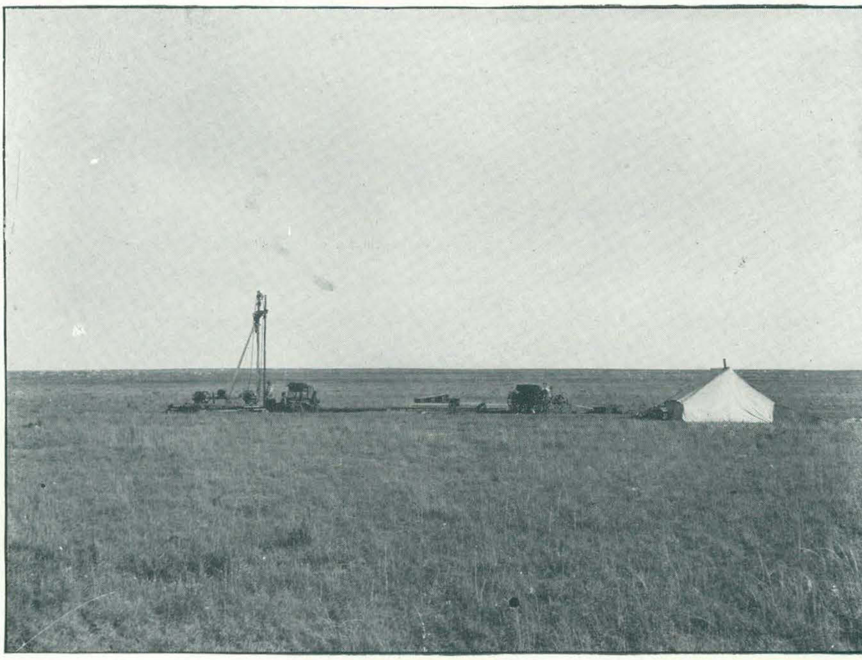
FIG. 325.—Map of valley floor subject to floods, showing sand-wash belt and subdividing stream.

present upon the Plains, the intermittent drainage from a range may be reversed from the aggrading to the degrading habit, and, sunk in valleys to the desert ground water, be sustained thereby between the infrequent rains. But normally in arid lands the water plane everywhere underruns the ground surface, and after floods drainage lines quickly resume their characteristic aspect of dry stream beds—not because the flood water has passed on to the sea as in humid lands, but because it has been extended upon unsaturated ground and become absorbed.

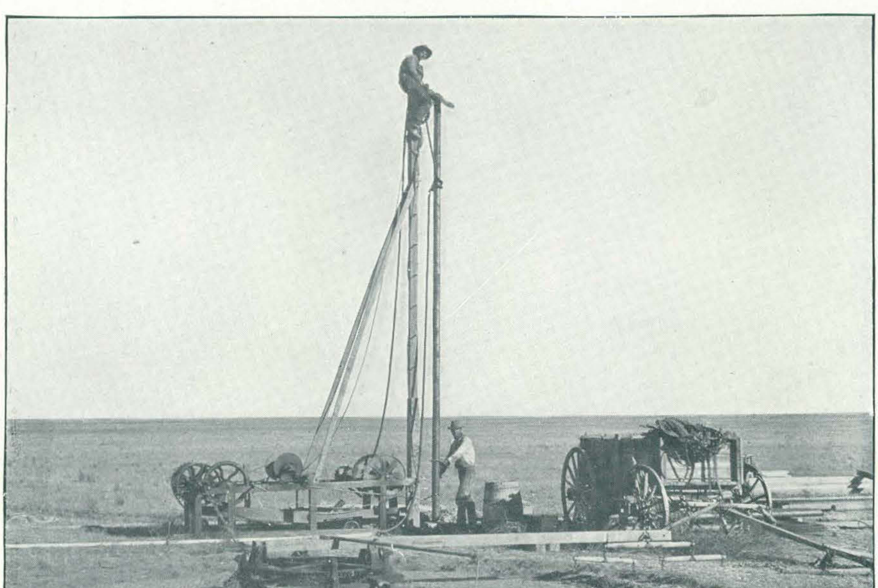
The fact that under normal conditions the water plane in desert lowland regions of seaward inclination nowhere intersects the surface, but, on the contrary, is almost universally low lying, is not to be attributed to the relatively light precipitation. The explanation is to be looked for in the deep burial of bed rock under open-textured material, which affords opportunity for relatively rapid drainage. At



DEEP-WELL STOCK-WATERING PLANTS ON UPLANDS.



A.



B.

DEEP-WELL MAKING ON UPLANDS.

the same time in deserts, as regions of aggradation, the tendency is away from topographic diversity toward uniformity of grade. Thus the ground-water surface has the impressive character of a vastly extended plane.

In humid lands, as a rule, the depth through loose ground to bed rock is slight. Occasionally even the rock is exposed at the surface or lies so thinly covered that it may readily be reached for building foundations. This is not true of base-level plains along coasts and rivers, but these are subordinate features; humid lands are primarily regions of degradation, and the covering of bed rock is, as a rule, shallow and discontinuous. In deserts, on the other hand, the tracts undergoing degradation are essentially islands of bare rock merely, rising amid far-reaching accumulations of their own waste products. On the desert plains, built and spread out by these accumulations, the depth of burial of the bed-rock floor is comparatively great. It is

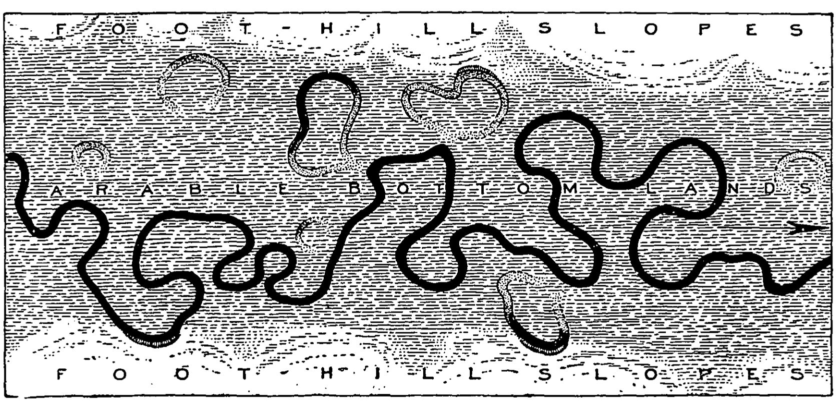


FIG. 326.—Map of valley floor not subject to floods, showing intricately meandering stream.

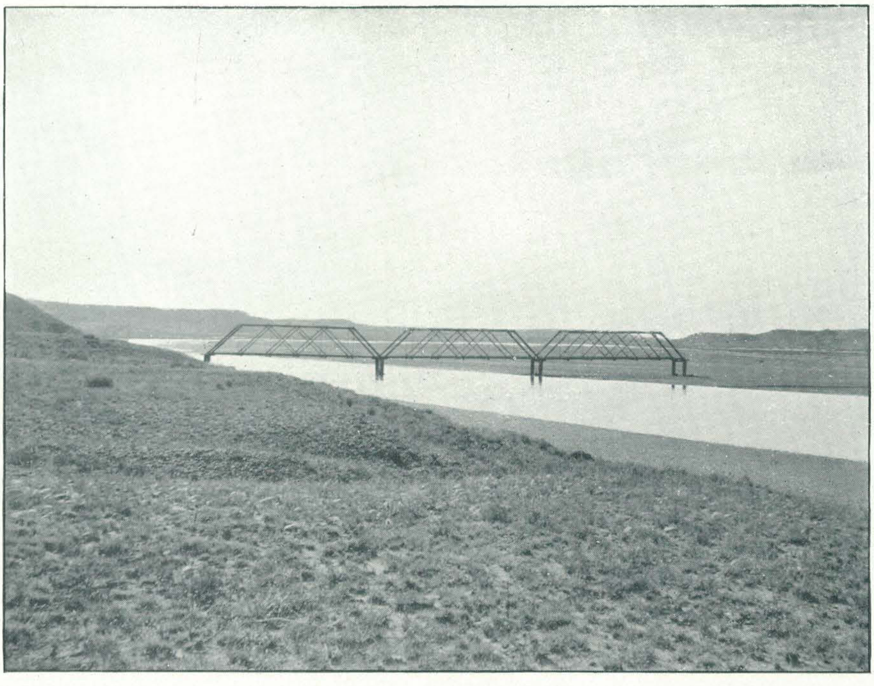
variable; for, while the ground surface does not have the diversified relief characteristic of humid lands, the buried bed-rock surface will usually be uneven; nevertheless, in deserts this covering of loose material is relatively continuous and deep. At the same time, it is true, the depth to the water plane is notably greater than in humid lands. As a rule, however, the depth to water is but a small part of the total depth in water to the floor.

Commonly it is in loose material only that ground water delivers to wells freely. The fact of its occurrence in sound, unfissured rock (below the universal water plane) is not appreciable to the well user. The "voids" which are present even in fine-grained rock may be completely filled—that is, the rock may be saturated—and yet the rate of escape into a well opening under the head created by the depth of well excavation below the water plane will be inappreciably slow. A block of building stone, for example, removed to the open air from below the water plane, or "water table" as it is styled in quarries, may take days or months to dry out. On the other hand, and at the other extreme, open-textured sandstone may have about equal permeability to that of clay beds in unconsolidated material. But while, generally speaking, the actual saturation content per unit of mass of consolidated and unconsolidated material does not greatly differ, there is such very marked difference in their rates of delivery that in matters of water supply, as a rule, it is only loose ground that may be said to be "water-bearing" at all. Since all materials of the earth's crust have this nearly equal capacity for water, the more accurate expression would be "water yielding;" yet as the rates of permeability, or, what is the same thing, the rates of delivery under pressure, diminish at a rapidly increasing ratio with diminution of the openings between grains, a well in bed rock if the rock be unfissured is virtually nonyielding. Ground water seemingly ends where loose ground comes to a bottom on solid rock. Within such limits it is the water of the common well.

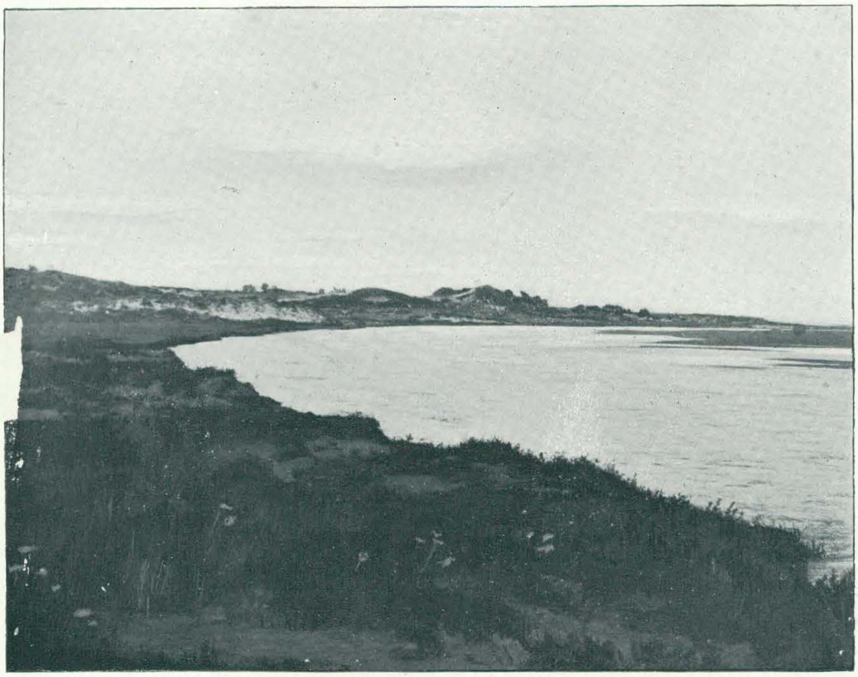
It is generally recognized only in a vague way that loose ground can not be in a condition of saturation, or at least does not permanently remain so, unless the underlying rocks also are saturated. Especially there is no general recognition of a single water plane, continuous through all materials, though undulated in response to widely varying rates of drainage movement, and below which all materials are saturated to indefinite depths. A sharp distinction is made, where essentially there is none, between the water in loose ground and so-called "underground waters." This distinction originates in humid regions of extensive degradation, where the loose covering of bed rock is characteristically thin and discontinuous and where in consequence the contained water has but shallow depth to its floor. The water of the common well in such regions is looked upon as a surface accumulation merely, since often it lies virtually pocketed in basins of the bed rock and may be materially reduced in volume by heavy pumping. The water plane in humid lands, it is true, is usually to be encountered close to the surface, so that a well rarely fails of some yield, but it is only under exceptional conditions there that a water supply in large volume is to be had from the ground water.

Though saturation continues indefinitely downward, it is only under exceptional conditions also that the presence of water in bed rock becomes apparent. It is found standing free, in fissures, or draining off, as streams, through solution passageways, to which fissures may become enlarged where they occur in easily soluble rocks, such as limestone. In the one case, minutely fissured rock may have a delivery, under the light head which the ordinary well excavation affords, fairly approximating that of unconsolidated material; and underground drainage, through solution passageways, may have the

A. CANADIAN RIVER IN NORMAL FLOW.



B. CANADIAN VALLEY AFTER HEAVY FLOOD.



A.

B.

BEAVER RIVER IN FLOOD.

volume of considerable streams. Again, a broadly continuous and undisturbed bed of open-textured rock, such as coarse sandstone, covered in turn by some close-textured rock, may give striking evidence of the presence of water by the instant filling, or even the overflow, of a well opening reaching down to it. Such vigorous yield is termed "artesian;" and this deep-seated water will come to rest at a water-plane level of its own; nevertheless, the water in the artesian bed and that in its cover are of the same body. The rates of its yielding to pressure merely, in the open-textured and in the close-textured materials, are very widely different. The water plane, as noted, is not an evenly domed surface over land areas, but is locally either hollowed or mounded, because of varying resistance to the general ground-water movement seaward; and the relatively free-moving water of the "artesian" bed seeks instantly to attain, through the well opening, the level it would have had if all beds had been of equal permeability. It does so under the impulse of a "head" pressure vastly greater than that afforded by pumping in the ordinary well in loose ground.

Delivery, or "flow," from the ordinary well results from the lowering, as a rule, by only a foot or so, of its standing-water level—that is, the general water-plane level extended across it. Flow is set up from the relatively inert water in the ground surrounding, seeking to restore the depressed level. The head, here, inducing flow, is merely the foot or more of lowering. Response to such light impulse is liberal and rapid because the frictional resistance to movement, say in gravelly ground, is immeasurably less than in even the most open textured of solid rocks. Under the same head the deep-lying "artesian" sandstone, from which water literally gushes when it is first reached by an open boring, would appear not to be water bearing at all—just as the close-grained cover through which the boring must pass, though saturated also, is relatively nonbearing as compared with the sandstone. But the sandstone yields freely, like the surface gravel, because of the great depth below the water plane at which an opening is made for it. If a tube, closed at bottom, could be sunk to an equal depth wholly in gravel and then opened, there would be the same high head and heavy upward pressure, but a much more violent uprush in proportion, as the permeability of the material would be greater.

Water encountered in fissures, and conspicuously in the case of deep-lying fissures in generally sound rock, behaves in essentially the same manner as so-called artesian water.

In minutely fractured rock the water plane may be extended much as in loose ground (see fig. 327), but this condition rarely continues to any considerable depth. In a boring penetrating to a system of fairly open fissures, deep below the water plane and in close-textured rock, there will be instant rise, showing that, relatively, this "underground" water is confined there under pressure. Strictly, the phenomenon is one merely of comparative rates of delivery. The inclosing rock has its interstices filled with water under like pressure; it delivers it to the well opening, however, at an inappreciable rate. Furthermore, the rising water from a fissure usually comes to a stand at a level more or less out of accord with the position which the water plane has locally. As with a deep-lying, far-extended, open-textured sandstone, this level marks a hydraulic grade plane—that of the fissure system. And if, like the artesian bed, there is comparatively free

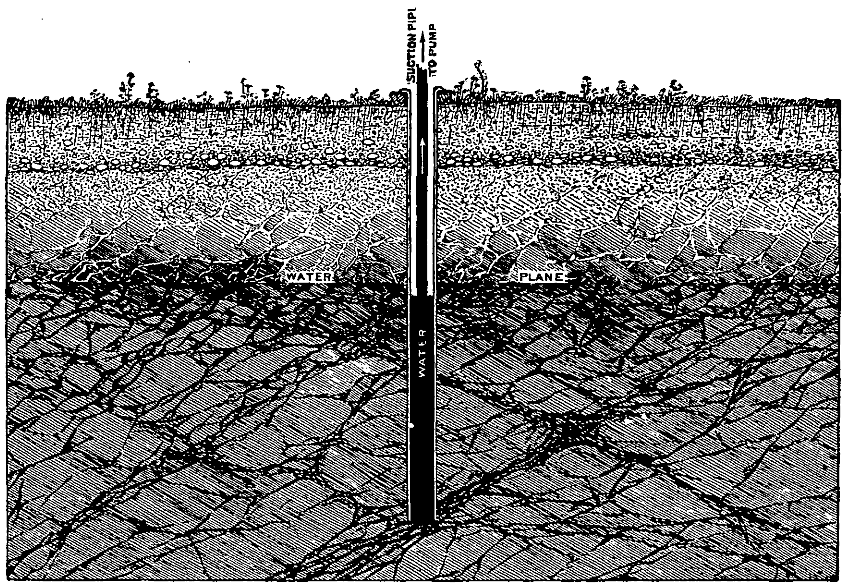


FIG. 327.—Water plane in fissured rock.

surface connection at a distance upgrade, and virtually none in any other direction, this level of equilibrium may lie not only above the normal water plane, but above the ground surface, resulting in voluntary delivery.

A group of tubular wells, one reaching to an artesian bed, another stopping in the relatively impervious rock constituting the artesian cover, and a third opening communication with a system of fissures in such impervious rock, would be likely to show differing, perhaps even widely differing, levels in the region of the water plane. These levels might lie either above or below the water plane, as revealed, for example, in an adjoining "shallow" well wholly in loose ground. Thus artificially brought into contrast, they would present a comparative measure of the differing rates of drainage movement at the several depths to which they penetrated. Those which lay above the

WILD-HAY BOTTOM IN A SPRING-STREAM VALLEY.

IRRIGATION IN CIMARRON VALLEY.

normal water plane would indicate comparatively retarded movement. In the case of an artesian bed, from which, nevertheless, flowing wells are had, the tendency to rise in a boring above the water plane is indication of slower general movement than in loose ground at the surface.

The phenomenon of surface overflow—of the flowing well—is the effect merely of the local accident of topographic configuration by which the ground surface has been given position below the level which the water plane would assume if drainage conditions, affording the same rate of movement as in the artesian bed, continued upward to it without change. While movement within the artesian bed normally is slower than in loose ground at the surface, rapid movement, in a region about the well foot, is set up toward this artificial opening, and there is continuous rise and overflow, owing to the fact that the column of water in the well tube fails to reach a balancing level. The upward

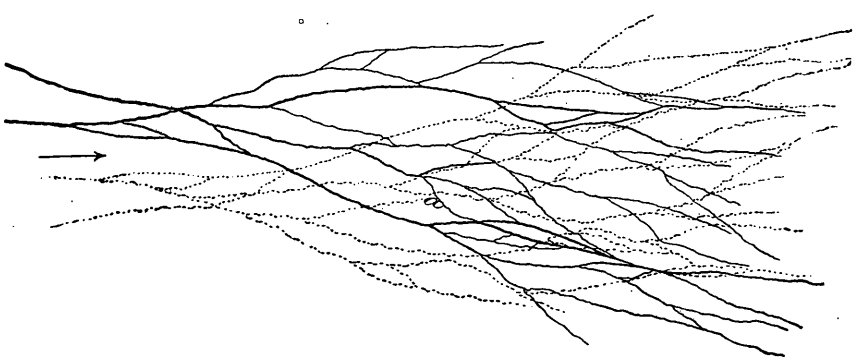


FIG. 328.—Superposed gravel courses.

impulse at the well foot is the equivalent of the weight of that length by which the column falls short of this balancing level—that is, the water in the porous rock in the region immediately surrounding the well at its foot is under hydrostatic pressure equal to that of a column of free, standing water reaching to the hydraulic grade plane. The actual column of water in the well tube exerts an opposing pressure, but less by the amount that it is cut off below the grade plane, or is shorter than the theoretical column. It is only this difference, or the weight of the extra height necessary to bring the artesian column to a stand, that is the effective head operative within the artesian bed beneath, to produce flow at the surface. As hydrostatic pressure, exerted for instance against a cap closing the well at top, it would be the same whether the connection below were with a relatively porous rock sheet or a system of open fissures. It would be the same even if there were connection with another pipe rising to a reservoir at the grade-plane level.

But with the cap removed, the rate of response to pressure in the several cases would be very different. From the fissure system it might closely approximate to that from the assumed pipe rising to a reservoir; from the artesian bed, however, the factor of frictional resistance to the movement thus set up would play so prominent a part that only under high heads could there be any considerable yield at all. Though in a standpipe above the ground surface artesian water might at first rise rapidly because the head was high, the rate of rise would rapidly diminish, and finally, through a number of feet, it would be barely appreciable. It is owing to this fact that in the marginal region of an artesian area there are often so many wells which apparently just overflow, and seem, therefore, to mark the hydraulic grade plane, though among themselves there may be considerable differences of elevation.

Conditions requisite for the development of the high head—i. e., high position of the grade plane above the local water plane, necessary to the production of strong flow from even the most open-textured rock—rarely present themselves. That they are ever present is due

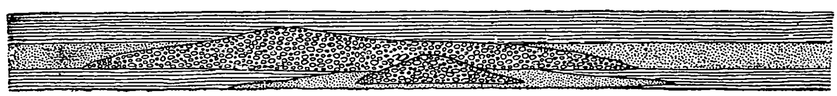
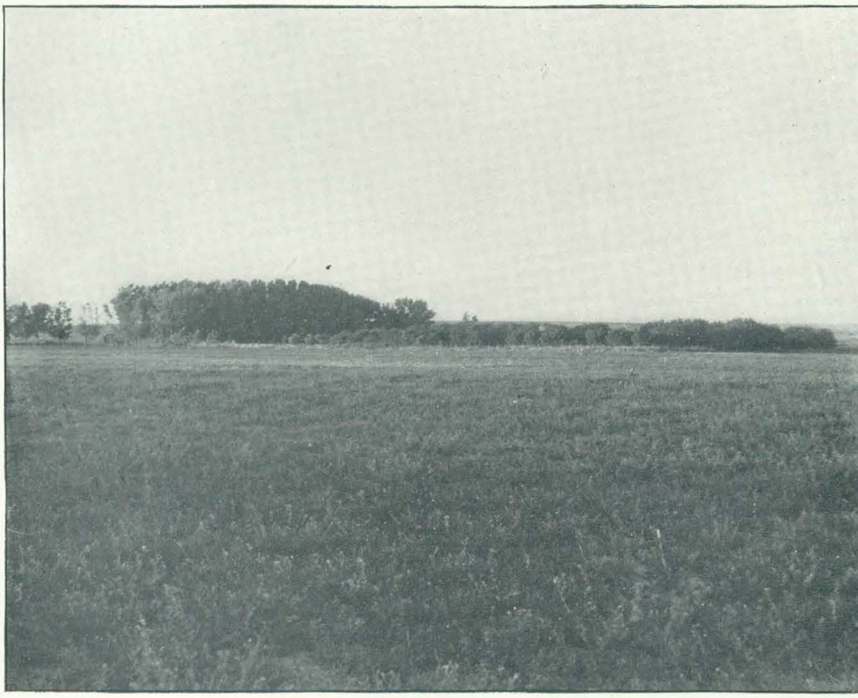


FIG. 329.—Gravel courses in vertical connection.

to the fact that bedded rocks of widely differing degrees of permeability sometimes extend from high areas beneath sloping plains to great distances.

On the other hand, since water from extensive fissures, however deep under ground, will rise in a well opening to its grade plane virtually at a jump, high heads would not be essential to the development of strong flow. But with fissures the grade plane will usually lie below, not only the ground surface, affording no opportunity, therefore, for flowing wells, but below the local water plane also. For where there is fissuring at all, it is usually widely extended, and though these fissures or fracture planes may penetrate deeply, they multiply and open toward the surface rather than downward, thus affording drainage way within bed rock which may be superior to that in the depth of loose ground overlying. A closed system of fissures—that is, one with no opening to the surface—would show a grade plane in a well boring no different from that of its inclosing rock; and one opening at a distant point upgrade only, would show prompt rise to that distant level; but ordinarily the rise of water from fissures in bed-rock falls short of the local water plane, as shown in the comparatively shallow "surface" wells. The deep well of this character, therefore, has the disadvantage of a more or less increased pumping lift. This is a marked characteristic. The disadvantage may



A. HEADQUARTERS CATTLE RANCH ON A SPRING CREEK.

B. A "WATER HOLE."

be compensated, however, by superior freedom of delivery. In other words, because circulation through the fissure system is comparatively unimpeded, a single well will draw promptly from a considerable radius. But as compared with the volume of water in loose ground of a corresponding area above, that in the fissure system is small. By many wells operated together and continuously, its level would be rapidly drawn down to an uneconomical pumping lift. They would somewhat rapidly recover, but under ordinary and continuous pumping, simultaneously, they would nevertheless be rapidly "exhausted." The fact does not become apparent, since fissure openings are encountered only by blind sinking, and rarely.

The yield from an isolated well of this character, therefore, is delusive. The occurrence of such deep-seated water presents striking features. It comes to a standing level independent of that in the loose ground surrounding, seeming to indicate a different source of supply. Its response to pumping is rapid, suggestive of an abundant supply. But especially it rises to its level through an interval of apparently barren rock, and whether from a fissure or a porous sandstone, it begins its rise with force.

It is not recognized by the well user that the apparently barren rock is in fact saturated also, and that, so far as static pressures are concerned, it transmits them undiminished, the differences of the standing-water levels for different materials being due to relief of pressure by drainage off at different rates. It is for this reason, as before stated, that popularly a sharp distinction is made between the water in loose ground covering bed rock and "underground waters." The one is nearly universal, and is regarded as the ground water proper; the other, whether encountered in fissures or in exceptionally porous beds, is seemingly adventitious and unusual, penetrating dry rock masses.

[Owing to unavoidable circumstances this paper could not be finished by its author in time for publication of the whole in this volume. Some of the later plates and figures were intended primarily to illustrate the unwritten portion of the paper; they are here included because they are of general interest in connection with the subject. It is hoped that the author will be able in the near future to write the complementary portion, in accordance with his original plan, for publication in supplemental form.—F. H. N.]

INDEX.

S.

T.

O

ADVERTISEMENT.

[Twenty-first Annual Report, Part IV.]

The statute approved March 3, 1879, establishing the United States Geological Survey, contains the following provisions:

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization; and the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

Except in those cases in which an extra number of any special memoir or report has been supplied to the Survey by resolution of Congress, or has been ordered by the Secretary of the Interior, this office has no copies for gratuitous distribution.

ANNUAL REPORTS.

I. First Annual Report of the United States Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 62 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884–'85, by J. W. Powell. 1885. 8°. xxix, 570 pp. 65 pl. and maps.

VII. Seventh Annual Report of the United States Geological Survey, 1885–'86, by J. W. Powell. 1888. 8°. xx, 656 pp. 71 pl. and maps.

VIII. Eighth Annual Report of the United States Geological Survey, 1886–'87, by J. W. Powell. 1889. 8°. 2 pt. xix, 474, xii pp., 53 pl. and maps; 1 p. l., 475–1063 pp., 54–76 pl. and maps.

IX. Ninth Annual Report of the United States Geological Survey, 1887–'88, by J. W. Powell. 1889. 8°. xiii, 717 pp. 88 pl. and maps.

X. Tenth Annual Report of the United States Geological Survey, 1888–'89, by J. W. Powell. 1890. 8°. 2 pt. xv, 774 pp., 98 pl. and maps; viii, 123 pp.

XI. Eleventh Annual Report of the United States Geological Survey, 1889–'90, by J. W. Powell. 1891. 8°. 2 pt. xv, 757 pp., 66 pl. and maps; ix, 351 pp., 30 pl.

XII. Twelfth Annual Report of the United States Geological Survey, 1890–'91, by J. W. Powell. 1891. 8°. 2 pt. xiii, 675 pp., 53 pl. and maps; xviii, 576 pp., 146 pl. and maps.

XIII. Thirteenth Annual Report of the United States Geological Survey, 1891–'92, by J. W. Powell. 1893. 8°. 3 pt. vii, 240 pp., 2 maps; x, 372 pp., 105 pl. and maps; xi, 486 pp., 77 pl. and maps.

XIV. Fourteenth Annual Report of the United States Geological Survey, 1892–'93, by J. W. Powell. 1893. 8°. 2 pt. vi, 321 pp., 1 pl.; xx, 597 pp., 74 pl.

XV. Fifteenth Annual Report of the United States Geological Survey, 1893–'94, by J. W. Powell. 1895. 8°. xiv, 755 pp. 48 pl.

XVI. Sixteenth Annual Report of the United States Geological Survey, 1894–'95, Charles D. Walcott, Director. 1895. (Part I, 1896.) 8°. 4 pt. xxii, 910 pp., 117 pl. and maps; xix, 598 pp., 43 pl. and maps; xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl.

XVII. Seventeenth Annual Report of the United States Geological Survey, 1895-'96, Charles D. Walcott, Director. 1896. 8°. 3 pt. in 4 vol. xxii, 1076 pp., 67 pl. and maps; xxv, 864 pp., 113 pl. and maps; xxiii, 542 pp., 8 pl. and maps; iii, 543-1058 pp., 9-13 pl.

XVIII. Eighteenth Annual Report of the United States Geological Survey, 1896-'97, Charles D. Walcott, Director. 1897. (Parts II and III, 1898.) 8°. 5 pt. in 6 vol. 440 pp., 4 pl. and maps; v, 653 pp., 105 pl. and maps; v, 861 pp., 118 pl. and maps; x, 756 pp., 102 pl. and maps; xii, 642 pp., 1 pl.; 643-1400 pp.

XIX. Nineteenth Annual Report of the United States Geological Survey, 1897-'98, Charles D. Walcott, Director. 1898. (Parts II, III, and V, 1899.) 8°. 6 pt. in 7 vol. 422 pp., 2 maps; v, 958 pp., 172 pl. and maps; v, 785 pp., 99 pl. and maps; viii, 814 pp., 118 pl. and maps; xvii, 400 pp., 110 pl. and maps; viii, 651 pp., 11 pl.; viii, 706 pp.

XX. Twentieth Annual Report of the United States Geological Survey, 1898-'99, Charles D. Walcott, Director. 1899. (Parts II, III, IV, V, and VII, 1900.) 8°. 7 pt. in 8 vol. 551 pp., 2 maps; v, 953 pp., 193 pl. and maps; v, 595 pp., 78 pl. and maps; vii, 660 pp., 75 pl. and maps; xix, 498 pp., 159 pl. and maps; viii, 616 pp.; xi, 804 pp., 1 pl.; v, 509 pp., 38 pl. and maps.

XXI. Twenty-first Annual Report of the United States Geological Survey. 1899-1900. Charles D. Walcott, Director. 1900. 8°. 7 pt. in 8 vol.

MONOGRAPHS.

I. Lake Bonneville, by Grove Karl Gilbert. 1890. 4°. xx, 438 pp. 51 pl. 1 map. Price $1.50.

II. Tertiary History of the Grand Cañon District, with Atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.00.

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VIII. Paleontology of the Eureka District, by Charles Doolittle Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

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155. Earthquakes in California in 1896 and 1897, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1898. 8°. 47 pp. Price 5 cents.
156. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1897, by Fred Boughton Weeks. 1898. 8°. 130 pp. Price 15 cents.
157. The Gneisses, Gabbro-Schists, and Associated Rocks of Southwestern Minnesota, by Christopher Webber Hall. 1899. 8°. 160 pp. 27 pl. Price 45 cents.

158. The Moraines of Southeastern South Dakota and their Attendant Deposits, by James Edward Todd. 1899. 8°. 171 pp. 27 pl. Price 25 cents.

159. The Geology of Eastern Berkshire County, Massachusetts, by B. K. Emerson. 1899. 8°. 139 pp. 9 pl. Price 20 cents.

160. A Dictionary of Altitudes in the United States (Third Edition), compiled by Henry Gannett. 1899. 8°. 775 pp. Price 40 cents.

161. Earthquakes in California in 1898, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1899. 8°. 31 pp. 1 pl. Price 5 cents.

162. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1898, by Fred Boughton Weeks. 1899. 8°. 163 pp. Price 15 cents.

163. Flora of the Montana Formation, by Frank Hall Knowlton. 1900. 8°. 118 pp. 19 pl. Price 15 cents.

164. Reconnaissance in the Rio Grande Coal Fields of Texas, by Thomas Wayland Vaughan, including a Report on Igneous Rocks from the San Carlos Coal Field, by E. C. E. Lord. 1900. 8°. 100 pp. 11 pl. and maps. Price 20 cents.

165. Contributions to the Geology of Maine, by Henry S. Williams and Herbert E. Gregory. 1900. 8°. 212 pp. 14 pl. Price 25 cents.

166. A Gazetteer of Utah, by Henry Gannett. 1900. 8°. 43 pp. 1 map. Price 15 cents.

167. Contributions to Chemistry and Mineralogy from the Laboratory of the United States Geological Survey; Frank W. Clarke, Chief Chemist. 1900. 8°. 166 pp. Price 15 cents.

168. Analyses of Rocks, Laboratory of the United States Geological Survey, 1880 to 1899, tabulated by F. W. Clarke, Chief Chemist. 1900. 8°. 308 pp. Price 20 cents.

169. Altitudes in Alaska, by Henry Gannett. 1900. 8°. 13 pp. Price 5 cents.

170. Survey of the Boundary Line between Idaho and Montana from the International Boundary to the Crest of the Bitterroot Mountains, by Richard Urquhart Goode. 1900. 8°. 67 pp. 14 pl. Price 15 cents.

171. Boundaries of the United States and of the Several States and Territories, with an Outline of the History of all Important Changes of Territory (Second Edition), by Henry Gannett. 1900. 8°. 142 pp. 53 pl. Price 30 cents.

172. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1899, by Fred Boughton Weeks. 1900. 8°. 141 pp. Price 15 cents.

173. Synopsis of American Fossil Bryozoa, including Bibliography and Synonymy, by John M. Nickles and Ray S. Bassler. 1900. 8°. 663 pp. Price 40 cents.

174. Survey of the Northwestern Boundary of the United States, 1857–1861, by Marcus Baker. 1900. 8°. 78 pp. 1 pl. Price 10 cents.

175. Triangulation and Spirit Leveling in Indian Territory, by C. H. Fitch. 1900. 8°. 141 pp. 1 pl. Price 10 cents.

176. Some Principles and Methods of Rock Analysis, by W. F. Hillebrand. 1900. 8°. 114 pp. Price 15 cents.

In preparation:

— Catalogue and Index of the Publications of the U. S. Geological Survey, 1880–1901, by P. C. Warman.

— Bibliography and Catalogue of the Fossil Vertebrata of North America, by Oliver Perry Hay.

WATER-SUPPLY AND IRRIGATION PAPERS.

By act of Congress approved June 11, 1896, the following provision was made:

"*Provided*, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed one hundred pages in length and five thousand copies in number; one thousand copies of which shall be for the official use of the Geological Survey, one thousand five hundred copies shall be delivered to the Senate, and two thousand five hundred copies shall be delivered to the House of Representatives, for distribution."

Under this law the following papers have been published:

1. Pumping Water for Irrigation, by Herbert M. Wilson. 1896. 8°. 57 pp. 9 pl.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis. 1897. 8°. 97 pp. 31 pl.
3. Sewage Irrigation, by George W. Rafter. 1897. 8°. 100 pp. 4 pl.
4. A Reconnoissance in Southeastern Washington, by Israel Cook Russell. 1897. 8°. 96 pp. 7 pl.
5. Irrigation Practice on the Great Plains, by Elias Branson Cowgill. 1897. 8°. 39 pp. 12 pl.
6. Underground Waters of Southwestern Kansas, by Erasmuth Haworth. 1897. 8°. 65 pp. 12 pl.
7. Seepage Waters of Northern Utah, by Samuel Fortier. 1897. 8°. 50 pp. 3 pl.
8. Windmills for Irrigation, by E. C. Murphy. 1897. 8°. 49 pp. 8 pl.
9. Irrigation near Greeley, Colorado, by David Boyd. 1897. 8°. 90 pp. 21 pl.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 8°. 51 pp. 11 pl.
11. River Heights for 1896, by Arthur P. Davis. 1897. 8°. 100 pp.
12. Underground Waters of Southeastern Nebraska, by N. H. Darton. 1898. 8°. 56 pp. 21 pl.
13. Irrigation Systems in Texas, by William Ferguson Hutson. 1898. 8°. 67 pp. 10 pl.
14. New Tests of Pumps and Water-Lifts used in Irrigation, by O. P. Hood. 1898. 8°. 91 pp. 1 pl.
15. Operations at River Stations, 1897, Part I. 1898. 8°. 100 pp.
16. Operations at River Stations, 1897, Part II. 1898. 8°. 101–200 pp.
17. Irrigation near Bakersfield, California, by C. E. Grunsky. 1898. 8°. 96 pp. 16 pl.

18. Irrigation near Fresno, California, by C. E. Grunsky. 1898. 8°. 94 pp. 14 pl.
19. Irrigation near Merced, California, by C. E. Grunsky. 1899. 8°. 59 pp. 11 pl.
20. Experiments with Windmills, by T. O. Perry. 1899. 8°. 97 pp. 12 pl.
21. Wells of Northern Indiana, by Frank Leverett. 1899. 8°. 82 pp. 2 pl.
22. Sewage Irrigation, Part II, by George W. Rafter. 1899. 8°. 100 pp. 7 pl.
23. Water-right Problems of the Bighorn Mountains, by Elwood Mead. 1899. 8°. 62 pp. 7 pl.
24. Water Resources of the State of New York, Part I, by G. W. Rafter. 1899. 8°. 99 pp. 13 pl.
25. Water Resources of the State of New York, Part II, by G. W. Rafter. 1899. 8°. 101-200 pp. 12 pl.
26. Wells of Southern Indiana (Continuation of No. 21), by Frank Leverett. 1899. 8°. 64 pp.
27. Operations at River Stations for 1898, Part I. 1899. 8°. 100 pp.
28. Operations at River Stations for 1898, Part II. 1899. 8°. 101-200 pp.
29. Wells and Windmills in Nebraska, by Erwin H. Barbour. 1899. 8°. 85 pp. 27 pl.
30. Water Resources of the Lower Peninsula of Michigan, by Alfred C. Lane. 1899. 8°. 97 pp. 7 pl.
31. Lower Michigan Mineral Waters, by Alfred C. Lane. 1899. 8°. 97 pp. 4 pl.
32. Water Resources of Puerto Rico, by Herbert M. Wilson. 1899. 8°. 48 pp. 17 pl.
33. Storage of Water on Gila River, Arizona, by Joseph B. Lippincott. 1900. 8°. 98 pp. 33 pl.
34. Geology and Water Resources of SE. South Dakota, by J. E. Todd. 1900. 8°. 34 pp. 19 pl.
35. Operations at River Stations, 1899, Part I. 1900. 8°. 100 pp.
36. Operations at River Stations, 1899, Part II. 1900. 8°. 101-198 pp.
37. Operations at River Stations, 1899, Part III. 1900. 8°. 199-298 pp.
38. Operations at River Stations, 1899, Part IV. 1900. 8°. 299-396 pp.
39. Operations at River Stations, 1899, Part V. 1900. 8°. 397-471 pp.
40. The Austin Dam, by Thomas U. Taylor. 1900. 8°. 51 pp. 16 pl.

In press:

41. The Windmill; Its Efficiency and Economic Use, Part I, by E. C. Murphy.
42. The Windmill; Its Efficiency and Economic Use, Part II, by E. C. Murphy.
43. Conveyance of Water for Irrigation, by Samuel Fortier.
44. Profiles of Rivers in the United States, by Henry Gannett.
45. Water Storage on Cache Creek, California, by A. E. Chandler.

TOPOGRAPHIC MAP OF THE UNITED STATES.

When, in 1882, the Geological Survey was directed by law to make a geologic map of the United States, there was in existence no suitable topographic map to serve as a base for the geologic map. The preparation of such a topographic map was therefore immediately begun. About one-fifth of the area of the country, excluding Alaska, has now been thus mapped. The map is published in atlas sheets, each sheet representing a small quadrangular district, as explained under the next heading. The separate sheets are sold at 5 cents each when fewer than 100 copies are purchased, but when they are ordered in lots of 100 or more copies, whether of the same sheet or of different sheets, the price is 2 cents each. The mapped areas are widely scattered, nearly every State being represented. About 1,100 sheets have been engraved and printed; they are tabulated by States in the Survey's "List of Publications," a pamphlet which may be had on application.

The map sheets represent a great variety of topographic features, and with the aid of descriptive text they can be used to illustrate topographic forms. This has led to the projection of an educational series of topographic folios, for use wherever geography is taught in high schools, academies, and colleges. Of this series the first three folios have been issued, viz:

1. Physiographic types, by Henry Gannett. 1898. Folio. Four pages of descriptive text and the following topographic sheets: Fargo (N. Dak.-Minn.), a region in youth; Charleston (W. Va.), a region in maturity; Caldwell (Kans.), a region in old age; Palmyra (Va.), a rejuvenated region; Mount Shasta, (Cal.), a young volcanic mountain; Eagle (Wis.), moraines; Sun Prairie (Wis.), drumlins; Donaldsonville (La.), river flood plains; Boothbay (Me.), a fiord coast; Atlantic City (N. J.), a barrier-beach coast. Price 25 cents.

2. Physiographic types, by Henry Gannett. 1900. Folio. Eleven pages of descriptive text and the following topographic sheets: Norfolk (Va.-N. C.), a coast swamp; Marshall (Mo.), a graded river; Lexington (Nebr.), an overloaded stream; Harrisburg (Pa.), Appalachian ridges; Poteau Mountain (Ark.-Ind. T.), Ozark ridges; Marshall (Ark.), Ozark Plateau; West Denver (Colo.), hogbacks; Mount Taylor (N. Mex.), volcanic peaks, plateaus, and necks; Cucamonga (Cal.), alluvial cones; Crater Lake special (Oreg.), a crater. Price 25 cents.

3. Physical geography of the Texas region, by Robert T. Hill. 1900. Folio. Twelve pages of text (including 11 cuts); 5 sheets of special half-tone illustrations; 5 topographic sheets, one showing types of mountains, three showing types of plains and scarps, and one showing types of rivers and canyons; and a new map of Texas and parts of adjoining territories. Price 50 cents.

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geologic Atlas of the United States is the final form of publication of the topographic and geologic maps. The atlas is issued in parts, or folios, progressively as the surveys are extended, and is designed ultimately to cover the entire country.

Under the plan adopted the entire area of the country is divided into small rectangular districts (designated *quadrangles*), bounded by certain meridians and parallels. The unit of survey is also the unit of publication, and the maps and descriptions of each rectangular district are issued as a folio of the Geologic Atlas.

Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

Two forms of issue have been adopted, a "library edition" and a "field edition." In both the sheets are bound between heavy paper covers, but the library copies are permanently bound, while the sheets and covers of the field copies are only temporarily wired together.

Under the law a copy of each folio is sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Prepayment is obligatory. The folios ready for distribution are here listed.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston	Montana	110°–111°	45°–46°	3,354	25
2	Ringgold	Georgia Tennessee	85°–85° 30′	34° 30′–35°	980	25
3	Placerville	California	120° 30′–121°	38° 30′–39°	932	25
4	Kingston *a*	Tennessee	84° 30′–85°	35° 30′–36°	969	25
5	Sacramento	California	121°–121° 30′	38° 30′–39°	932	25
6	Chattanooga	Tennessee	85°–85° 30′	35°–35° 30′	975	25
7	Pikes Peak *a*	Colorado	105°–105° 30′	38° 30′–39°	932	25
8	Sewanee	Tennessee	85° 30′–86°	35°–35° 30′	975	25
9	Anthracite-Crested Butte.	Colorado	106° 45′–107° 15′	38° 45′–39°	465	50
10	Harpers Ferry	Virginia West Va Maryland	77° 30′–78°	39°–39° 30′	925	25
11	Jackson	California	120° 30′–121°	38°–38° 30′	938	25
12	Estillville	Virginia Kentucky Tennessee	82° 30′–83°	36° 30′–37°	957	25
13	Fredericksburg	Maryland Virginia	77°–77° 30′	38°–38° 30′	938	25
14	Staunton	Virginia West Va	79°–79° 30′	38°–38° 30′	938	25
15	Lassen Peak	California	121°–122°	40°–41°	3,634	25
16	Knoxville	Tennessee N. Carolina	83° 30′–84°	35° 30′–36°	925	25
17	Marysville	California	121° 30′–122°	39°–39° 30′	925	25
18	Smartsville	California	121°–121° 30′	39°–39° 30′	925	25
19	Stevenson	Alabama Georgia Tennessee	85° 30′–86°	34° 30′–35°	980	25
20	Cleveland	Tennessee	84° 30′–85°	35°–35° 30′	975	25
21	Pikeville	Tennessee	85°–85° 30′	35° 30′–36°	969	25
22	McMinnville	Tennessee	85° 30′–86°	35° 30′–36°	969	25
23	Nomini	Maryland Virginia	76° 30′–77°	38°–38° 30′	938	25
24	Three Forks	Montana	111°–112°	45°–46°	3,354	50
25	London	Tennessee	84°–84° 30′	35° 30′–36°	969	25
26	Pocahontas	Virginia West Va	81°–81° 30′	37°–37° 30′	951	25
27	Morristown	Tennessee	83°–83° 30′	36°–36° 30′	963	25
28	Piedmont	Maryland West Va	79°–79° 30′	39°–39° 30′	925	25
29	Nevada City: Nevada City Grass Valley Banner Hill	California	 121° 00′ 25″–121° 03′ 45″ 121° 01′ 35″–121° 05′ 04″ 120° 57′ 05″–121° 00′ 25″	 39° 13′ 50″–39° 17′ 16″ 39° 10′ 22″–39° 13′ 50″ 39° 13′ 50″–39° 17′ 16″	 11.65 12.09 11.65	50
30	Yellowstone National Park: Gallatin Canyon Shoshone Lake	Wyoming	110°–111°	44°–45°	3,412	75
31	Pyramid Peak	California	120°–120° 30′	44°–45°	932	25
32	Franklin	Virginia West Va	79°–79° 30′	38° 30′–39°	932	25
33	Briceville	Tennessee	84°–84° 30′	36°–36° 30′	963	25
34	Buckhannon	West Va	80°–80° 30′	38° 30′–39°	932	25
35	Gadsden	Alabama	86°–86° 30′	34°–34° 30′	986	25
36	Pueblo	Colorado	104° 30′–105°	38°–38° 30′	938	50
37	Downieville	California	120° 30′–121°	39° 30′–40°	919	25
38	Butte Special	Montana	112° 29′ 30″–112° 36′ 42″	45° 59′ 28″–46° 02′ 54″	22.80	50
39	Truckee	California	120°–120° 30′	39°–39° 30′	925	25
40	Wartburg	Tennessee	84° 30′–85°	36°–36° 30′	963	25
41	Sonora	California	120°–120° 30′	37° 30′–38°	944	25
42	Nueces	Texas	100°–100° 30′	29° 30′–30°	1,035	25
43	Bidwell Bar	California	121°–121° 30′	39° 30′–40°	918	25
44	Tazewell	Virginia West Va	81° 30′–82°	37°–37° 30′	950	25
45	Boise	Idaho	116°–116° 30′	43° 30′–44°	864	25
46	Richmond	Kentucky	84°–84° 30′	37° 30′–38°	944	25
47	London	Kentucky	84°–84° 30′	37°–37° 30′	950	25

a Out of stock.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
48	Tenmile District Special.	Colorado	106° 8′–106° 16′	39° 22′ 30″–39° 30′ 30″	55	25
49	Roseburg	Oregon	123°–123° 30′	43°–43° 30′	871	25
50	Holyoke	Mass. Conn	72° 30′–73°	42°–42° 30′	885	50
51	Big Trees	California	120°–120° 30′	38°–38° 30′	938	25
52	Absaroka: Crandall Ishawooa	Wyoming.	109° 30′–110°	44°–44° 30′	1,706	25
53	Standingstone	Tennessee	85°–85° 30′	36°–36° 30′	963	25
54	Tacoma	Washington.	122°–122° 30′	47°–47° 30′	812	25
55	Fort Benton	Montana	110°–111°	47°–48°	3,273	25
56	Little Belt Mts	Montana	110°–111°	46°–47°	3,295	25
57	Telluride	Colorado	107° 45′–108°	37° 45′–38°	236	25
58	Elmoro	Colorado	104°–104° 30′	37°–37° 30′	950	25
59	Bristol	Virginia Tennessee	82°–82° 30′	36° 30′–37°	957	25
61	Monterey	Virginia West Va	79° 30′–80°	38°–38° 30′	938	25
62	Menominee Special.	Michigan.	(a NW.-SE. area, about	22 m. long, 6½ wide)	150	25
63	Mother Lode	California	(a NW.-SE. rectangle,	70 m. long, 6½ wide)	455	50
64	Uvalde	Texas	99° 30′–100°	29°–29° 30′	1,040	25
65	Tintic Special	Utah	111° 55′–112° 10′	39° 45′–40°	229	25
66	Colfax	California	120° 30′–121	39°–39° 30′	925	25
67	Danville	Illinois Indiana	87° 30′–87° 45′	40°–40° 15′	228	25
68	Walsenburg	Colorado	104° 30′–105°	37° 30′–38°	944	25
69	Huntington	West Va Ohio	82°–82° 30′	38°–38° 30′	938	25

STATISTICAL PAPERS.

Mineral Resources of the United States, 1882, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

Mineral Resources of the United States, 1889 and 1890, by David T. Day. 1892. 8°. viii, 671 pp. Price 50 cents.

Mineral Resources of the United States, 1891, by David T. Day. 1893. 8°. vii, 630 pp. Price 50 cents.

Mineral Resources of the United States, 1892, by David T. Day. 1893. 8°. vii, 850 pp. Price 50 cents.

Mineral Resources of the United States, 1893, by David T. Day. 1894. 8°. viii, 810 pp. Price 50 cents.

On March 2, 1895, the following provision was included in an act of Congress:

"*Provided*, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the Director of the Geological Survey."

In compliance with this legislation the following reports have been published:

Mineral Resources of the United States, 1894, David T. Day, Chief of Division. 1895. 8°. xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl. Being Parts III and IV of the Sixteenth Annual Report.

Mineral Resources of the United States, 1895, David T. Day, Chief of Division. 1896. 8°. xxiii, 542 pp., 8 pl. and maps; iii, 543-1058 pp., 9-13 pl. Being Part III (in 2 vols.) of the Seventeenth Annual Report.

Mineral Resources of the United States, 1896, David T. Day, Chief of Division. 1897. 8°. xii, 642 pp., 1 pl.; 643-1400 pp. Being Part V (in 2 vols.) of the Eighteenth Annual Report.

Mineral Resources of the United States, 1897, David T. Day, Chief of Division. 1898. 8°. viii, 651 pp., 11 pl.; viii, 706 pp. Being Part VI (in 2 vols.) of the Nineteenth Annual Report.

Mineral Resources of the United States, 1898, by David T. Day, Chief of Division. 1899. 8°. viii, 616 pp.; ix, 804 pp., 1 pl. Being Part VI (in 2 vols.) of the Twentieth Annual Report.

The money received from the sale of the Survey publications is deposited in the Treasury, and the Secretary of the Treasury declines to receive bank checks, drafts, or postage stamps. All remittances, therefore, must be by MONEY ORDER, made payable to the Director of the United States Geological Survey, or in CURRENCY—the exact amount. Correspondence relating to the publications of the Survey should be addressed to—

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *February*, 1901.